CEMARE Report 67
UK Fleet Futures Modelling (2004-2013)

- Literature Review

D Tingley
UK Fleet Futures Modelling (2004-2013)

- Literature Review

August 2005

Prepared by:
Diana Tingley
Research Fellow
Centre for the Economics & Management of Aquatic Resources (CEMARE)
Boathouse no 6, College Road, HM Naval Base, Portsmouth, PO1 3LJ, UK.
tel: +44 (0) 23 9284 4283  email: diana.tingley@port.ac.uk

For:
Policy Team
Sea Fisheries Division
Department for Agriculture and Rural Development Northern Ireland (DARDNI)
Annexe 5, Castle Grounds, Stormont Estate, Belfast, BT4 3PW
Contents

1 INTRODUCTION ............................................................................................................ 1

2 REVIEW OF MODELLING APPROACHES ..................................................................... 1
  2.1 WHAT IS A MODEL? ..................................................................................................... 1
  2.2 SHORT-TERM IMPACT ASSESSMENT ........................................................................ 2
  2.3 DYNAMIC SIMULATION ............................................................................................ 3
  2.4 OPTIMISATION ........................................................................................................... 4

3 REVIEW OF APPLIED MODELS ................................................................................. 5
  3.1 IMPACT ASSESSMENT MODELS ................................................................................ 6
  3.2 BIO-ECONOMIC SIMULATION MODELS ................................................................... 7
  3.3 OPTIMISATION MODELS ............................................................................................ 8
  3.4 LONGEVITY AND USE OF MODELS ......................................................................... 9

4 REVIEW OF FUTURES ANALYSIS: METHOD AND APPLICATIONS .................. 10

ANNEX 1: OVERVIEW OF SELECTED MODELS .......................................................... 12

REFERENCES ..................................................................................................................... 22

Index of Figures

FIGURE 1: SHORT-TERM IMPACT ASSESSMENT SIMULATION MODEL ............................................ 3
FIGURE 2: DYNAMIC SIMULATION BIO-ECONOMIC MODEL .......................................................... 4
1 Introduction

This literature review is intended to provide a brief review of the variety of modelling approaches that can be used to analyse fisheries systems and specifically future fishing fleet sizes. Analysis of future fleet sizes and development options is not a new activity: work on this subject was being undertaken in the UK in the early 1980’s. The review begins by discussing modelling as an analytical tool and outlining basic modelling structures. A review of some European and non-European fisheries system models follows. Futures analysis is also discussed as a complementary tool for considering future fleet structures. Appendix 1 provides a more detailed and technical overview of six of the most relevant and recent (mainly European) models.

This document is aimed at a technical and/or advanced non-technical audience. It has been compiled to provide context for the ‘UK fleet futures modelling exercise’ undertaken by CEMARE (Northern Ireland) and Seafish (Great Britain) in 2005 for the UK Fisheries Departments in response to the recommendations contained in the Strategy Unit’s ‘Net Benefits’ report (Cabinet Office, 2004).

The ‘UK fleet futures modelling exercise’ built directly upon work undertaken previously in the ‘Net Benefits’ project. A complete outline of the methodology used in the Northern Ireland component of this analysis undertaken by CEMARE can be found in the report:


2 Review of modelling approaches

2.1 What is a model?

A ‘model’ attempts to create a simplified or idealised description of a particular system, situation or process. Models can be created as conceptual or mental representations. In the fisheries sector they are usually described in mathematical terms, which allows for the numeric quantification of impacts and solutions or predictions of responses to changes in key inputs to the system. Quantitative models are constructed using key data found within the system, an estimate of the relationship between these key data and ‘rules of the system’ are explicitly described. The most important types of data are known as ‘key variables’ which are influential pieces of data that can vary within the system in response to changes in other variables. For example, fishing effort is often used as a key variable in modelling as its magnitude depends on the type and level of management restrictions in place and in turn fish stock sizes are affected by the level of fishing effort. The profit level is another type of key variable; its magnitude depends on market prices (for example) whilst the current profit level can also affect the future fleet size.

The sophistication of a model is dependent on the level of resources available with which to create it (e.g. time, finances, data availability, etc.). Developing a model involves making a series of trade-off choices. For example, if a model is very complex it may become difficult to
interpret its results in a meaningful way. Alternatively, if the model is too simple it may not be able to describe the system in enough detail and so its results may lack credibility.

Models of the fisheries system can be developed for a range of purposes and the purpose usually drives the structure of the model. Models are comprised of a range of linked components (which include key variables and the relationships between them). Some components usually receive more detailed attention than others depending on the purpose of the modelling exercise. For example, if the most important objective of the model is to simulate (and hence attempt to predict) the behavioural response of fishermen to a change in management policy (e.g. to identify where fishermen would spatially diversify effort in response to the imposition of a closed area) then the model would probably have a detailed focus on the factors influencing why fishers decide to fish in certain areas. Other important and linked aspects, such as profit generation or stock effects, would still be included, but in a less detailed manner.

The type of model and its intended use is often influenced by the time-frame over which questions are being asked. Economists make a distinction between the short-run and long-run based on the time it takes to adjust capital and other fixed inputs. In the fishing sector, it is generally assumed that fixed and capital costs cannot vary in the short-run whilst variable costs can. For example, it is assumed that skippers cannot invest in a new vessel in the short-run or make significant gear changes but they can increase or decrease activity levels and hence variable costs in that time-frame. In the long-run it is assumed that all inputs (variable, fixed and capital) can be changed. If changes in fleet structure are to be analysed, the model will therefore need to be constructed from a long-run perspective.

Three major distinctions can be drawn between fisheries models based on their intended purpose and use:

- Firstly, a model can be developed to aid short-term (1-2 years) impact assessments of specific changes to key variables. These type of models attempt to simulate the system being analysed and can be used to answer questions such as: “What’s the impact of…?”
- Secondly, models can be developed to provide a dynamic simulation framework for considering interactions between key variables over the longer-term (5-15 years) and to answer questions such as “What happens if…?”
- Thirdly, optimisation models can be configured to answer “What’s best?” questions; that is they can determine the ‘optimal’ level of key variables depending on a range of assumptions.

### 2.2 Short-term impact assessment

Short-term impact assessment models are mainly used to determine the impact of a change in key variables from one time period to the next. For example, a model can be constructed which represents a static (non-dynamic) fisheries system; with a static system being one where key input variables are determined exogenously\(^1\) and there are few dynamic linkages between variables over time. Figure 1 provides a simple representation of this type of model\(^2\) in which the objective is to analyse the short-run impact of a change in Total Allowable

---

\(^1\) Externally to the model

\(^2\) Figure 1 provides a simple representation of the structure of the EIAA model which is described later on in this review.
Catches (TACs) on fleet profits. The model is driven by exogenously derived TAC levels, i.e. the levels imposed by fisheries managers. It is constructed so that fleet profits are a function of revenues and costs associated with fishing, where revenues are a function of prices and catches and catches are based on the level of TAC. In this model a relationship between fish prices and the level of catch is included, to represent the market price interaction.

As the model analyses the short-run impact, potential changes in fleet structure in response to changing profit levels are not considered – this would be a long-run, dynamic reaction. For example, if higher TACs were set, the short-static run impact may be higher profits for the current fleet. In the long-run however, vessel owners may decide to invest in new larger vessels in response to improved profits and/or stock levels may reduce in response to increased catches, but these types of structural change to the model are outwith the scope of the short-run impact assessment model shown in Figure 1.

Figure 1: Short-term impact assessment simulation model

2.3 Dynamic simulation

An extension to the short-term impact assessment model is one which considers a fisheries system over a longer period of time, and specifically which allows for key variables in the model to be determined endogenously\(^3\) (i.e. it allows for multiple dynamic interactions). The classic dynamic simulation model used to represent fisheries systems is known as the bio-economic model in which biological, fishing and economic components of the system are linked together to provide a dynamic representation of the changing and interlinked relationship between fishing effort, economic returns from the activity and impact on fish stocks. These models can be extended to incorporate a range of other features (e.g. behavioural responses to management measures, fleet entry/exit decisions, etc.) depending on the purpose of the modelling exercise.

Figure 2 provides a simple pictorial representation of a dynamic bio-economic simulation model. The objective of this model is simulate the dynamic affect of a change in fleet activity on fleet profits, fleet size and stock levels over a long-run time frame, e.g. 15 years. This model is constructed so that fleet activity is the most important variable and it is assumed that

---

\(^3\) By the magnitude of, and relationship with, other variables in the previous time period
fleet activity changes and is bounded due to the imposition of externally imposed management measures (e.g. days at sea restrictions). As the model is dynamic the change in key variables in each year can be tracked over time.

In Figure 2 the basic Figure 1 model has been built upon to include a number of dynamic interactions, including a dynamic stock interaction, fleet investment decision process and fishing effort component. Where TACs were exogenously determined in the previous model, they are now determined by the level of TAC which is assumed to be set as some proportion of the Spawning Stock Biomass (SSB) which is itself influenced by the level of catches in the previous year. There is an implicit assumption that catch levels in the current period directly effect SSB levels in the next period; this assumption may be appropriate for some species (i.e. shark, flat-fish) but not appropriate for others (i.e. shrimp). An investment dynamic has also been added in which boat owners make an annual decision to continue fishing next year (as opposed to exiting the fleet) based on the amount of profit generated this year. In reality, the investment decision may be influenced by more than simply whether sufficient profit is being generated. For example, it may be affected by the extent to which operating costs are being covered, availability of external credit, alternative employment possibilities in the region, etc. Finally, a fishing effort dynamic has been added where the level of fishing effort in one period affects fleet catches and fishing costs. If fleet investment has been stimulated by high profits, the levels of fishing activity may increase (assuming management measures aimed at containing it are not effective) which in turn may increase catches which could have a negative effect on the SSB leading eventually to lower profits. The model is essentially driven by the assumptions and rules imposed by the developers and can be as complex or as simple as is appropriate given its intended purpose and resource constraints.

**Figure 2: Dynamic simulation bio-economic model**

### 2.4 Optimisation

The third type of model attempts to ‘optimise’ the magnitude of one or a range of key variables according to a set of predefined criteria. An optimisation model attempts to find the best ‘solution’ or set of solutions within a system. The model presented in Figure 2 could
transformed into an optimisation model if its objective was altered to: Optimise fleet size according to a range of constraints, including a minimum profit level for the average vessel and an effective upper limit on fleet activity and catch rates. Optimisation models can be used as components in both static and dynamic frameworks. In a static framework the optimum fleet size would be determined for that particular time period, whereas in a dynamic framework the optimum fleet size (and hence effort level) would be determined so that other key variables were kept at relatively constant levels over time. As models become more complex, optimisation models require an increased number of constraining criteria to be able to find a solution. The combined effect of increased model complexity and constraining criteria is that an increasing amount of computing power is required to generate and find solutions and this can be a practical limiting factor to their use.

Models are generally created using a variety of tools from the modelling ‘tool-box’. These tools allow data to be input to, and/or generated within, the model and in fisheries models, usually take a quantitative numerical form. The relationships between key variables can be expressed in a range of ways (e.g. as ratios or indices). The interaction between variables can be defined, and impact of a change in these variables simulated, using a variety of different analytical methods (e.g. regression analysis, co-integration price analysis, functional analysis, (i.e. Stochastic Production Functions, cost functions)). As discussed previously, models can contain optimisation components. Stock sizes can be estimated using biological modelling tools (e.g. surplus production and age-structured analysis) and uncertainty and probabilities in biological and economic data and their relationships can be simulated using techniques specifically designed for this purpose (e.g. stochastic/Monte-Carlo simulation, Bayesian analysis). The preferences between different groups of people can be incorporated (e.g. through the Analytical Hierarchy Process) and the impact of the fishing sector on the wider economy assessed (e.g. through Input-Output analysis). The range of tools used, and time spent specifying the structure of each tool for a specific fishery and/or fleet being analysed, depends on objectives of the project, extent of available resources (e.g. time, finances, data availability, etc.) and desired level of complexity.

The operating platform (i.e. type of software) for models is also dependent on the level of resources available but can also be influenced by the purpose and intended use of the model as well as the level of its complexity. For example, relatively simple models can be created in MS Excel which has the advantage of being widely used and familiar to many people. This enhances transferability and use of the model and ease of creation. Alternatively, more complex models can be written using specialist computer programming software (i.e. MS Visual Basic, GAMS⁴, Vensim, etc.) which are more quantitatively powerful and allow for more advanced methodologies to be used in the model. User-friendly graphical interfaces can be added to allow users to explore the impact of changing some key parameters in the model and to present the outputs in an easily understandable manner.

3 Review of applied models

Analysis of fishing fleet sizes is not a new development with respect to the UK fisheries sector. Work was carried out in the early 1980’s which considered issues such as the extent of overcapacity in the UK whitefish fleet resulting from the loss of access to traditional distant-water resources (Garrod & Shepherd, 1981). Other work at the time developed analytical methods to determine the extent of fleet size adjustment required to achieve sustainable full-

---

⁴ General Algebraic Modeling Systems (GAMS)
time employment opportunities (Shepherd, 1981) and taking into account socio-economic considerations relating to the speed at which adjustment occurs (Shepherd & Garrod, 1981).

Frost & Løkkegaard (2001) provide a list of management models developed during the 1990’s and early 21st Century that have been populated with real data, which consider the impact on fish stocks and fleet viability (i.e. capital stocks) as a result of the interaction between fleet size, fishing effort and catch rates, as a result of management decisions. They list many models which have been developed to predict impacts and also note that other types of analytical tool have also been developed in fisheries to explore the issues, e.g. Data Envelopment Analysis, stochastic production frontier analysis and capital and price formation. Data Envelopment Analysis has most recently been developed to provide estimates of the extent of excess capacity that exists in fishing fleets (Pascoe & Gréboval, 2003). However this type of analysis provides a snap-shot estimate of short-run excess capacity and is dependent on the operating efficiencies and capacities of peers in the fleet against which all operators are gauged at the time of the analysis. Longer-run estimates of overcapacity compared to long-run objectives require a different form of usually model-based analysis.

### 3.1 Impact assessment models

Short-run impact assessment analysis is usually undertaken to address very specific questions relating to the impact of a change in key variables in the near future (i.e. next fishing season or year). A good example of such a model which has been created for use in the European context is the EIAA model (Economic Interpretation of ACFM Advice). It was originally developed to assess the economic consequences of the change in Common Fisheries Policy TACs proposed annually by the European Union’s Advisory Committee for Fisheries Management (CEC, 2005). The model is driven by annual changes in the TAC and provides a short-run impact assessment of how key fleet segments will be financially affected by proposed changes in TACs. The model was developed through a Concerted Action funded by the European Union and was carried out in tandem with a vessel cost and earnings data collection program for selected fleets. The model is essentially output driven and assumes a constant fleet structure. It is therefore non-dynamic although a basic fish price flexibility is used for all species to represent a market price reaction to expected changes in landings (as a result of the change in TAC) for that species. Large changes in TAC will affect the confidence of results from the model: if large changes in TAC are experienced, it is likely that a structural and behavioural response will occur within even a short timeframe. More detailed information about this model (and others) is contained in [Annex 1: Overview of selected models] which also includes a basic schematic showing the structure of the model.

Another type of short-run fisheries system impact assessment model has recently been developed for the USA West Coast groundfish fishery. In response to the large amount of overfishing and associated reduction in catches and revenues since 1987, the Pacific Fishery Management Council (PFMC) adopted a strategic plan “Transition to Sustainability” in 2000 with the highest priority of the plan being to reduce fishing capacity by at least 50% in each sector (Scholz, A. (Ed), 2003). A short-run static impact analysis was undertaken to determine the immediate effect (before adjustment) of four capacity reduction scenarios on fleet composition, shore-based infrastructure, spatial dynamics and economic trends from the perspective of local fishing communities. The starting point of the analysis was an exogenous estimate of ‘optimal’ fleet size derived from ‘optimum’ historical vessel catch rates. The impact analysis involved compiling data from available sources to chart the linkages between different components of the marine ecosystem, fisheries and community sectors. A network of
data was created on a spatial basis which included information relating to bathymetric and other ocean characteristics, habitat types, fish distribution, effort distribution and ports and communities. The economic and social impacts of each fleet reduction scenario were tracked using an Input-Output model (known as ‘FEAM’) devised for analysing regional economic impacts specifically from capture fishing and processing activities on US West Coast.

3.2 Bio-economic simulation models

A number of dynamic, bio-economic models have been created for fisheries systems within the European Union and further afield. Le Roch (no date) compiled a brief review of some of the most well known models up to 1996 including:

- **BEAM 4**: Series of bio-economic models developed at the FAO which can be applied to a variety of fisheries to predict yield, value and economic performance as a function of fishery management measures, including fishing effort control, closed seasons, closed areas and minimum mesh size regulations.

- **Gulf of Mexico bio-economic shrimp model**: Funded by US National Marine Fisheries Service (NMFS), a bio-economic model was developed for the Gulf of Mexico shrimp fishery to investigate the impact of an embargo on shrimp imported unto the US. Model incorporated imports/exports, fleet size, prices and cost components and dealt with the annual biology using an abundance index due to there being no stock recruitment-relationship in the fishery.

- **ECONMULT**: Bio-economic model of Barents Sea fisheries developed in 1992 by the University of Tromso, Norway incorporating multi-species, multi-fleets and integrating biology, harvesting and economics. Designed, developed and implemented as a management tool for the Barents Sea.

Other more recent simulation bio-economic models that have been developed for fisheries in European waters include MEFISTO, TEMAS, MOSES and Invest in Fish South West. A more detailed description of each is presented in Annex 1: Overview of selected models.

The MEFISTO model was designed at the University of Barcelona and Institut de Ciències del Mar (Barcelona) to reproduce the bio-economic conditions in which Mediterranean fisheries occur. The main purpose was to simulate the impact of alternative management strategies focused on effort limitation, upon which Mediterranean fisheries management is mostly based. The MEFISTO model has more recently been used as the main building block in developing a new bio-economic simulation model of Mediterranean fisheries (BEMMFISH) which has also been designed to analyse the effect of alternative management measures controlling fishing effort (Guillen, 2004). The main components of the BEMMFISH model are (1) harvesting, (2) fishing mortality, (3) price formation, (4) cost of harvesting, (5) investment, (6) modelling the dynamics of entry to the fishery or exit from the fisher, (7) modelling the dynamics of fishing effort and (8) modelling the dynamics of catchability.

TEMAS was designed by two Danish organisations (Institute for Fisheries Management (IFM) and Danish Institute for Fisheries Research (DIFER)). The bio-economic model was developed for use in North Sea and Baltic multi-fleet/gear/species/area fisheries targeted by

---

5 An Input-Output model treats economic activity within a region as a set of interconnected sectors. It can be used to determine the income and/or employment effect of economic activity in one sector and impact of changes to the activity.
the Danish fleet to evaluate the expected impacts of various technical management measures using three Danish fisheries as case studies. Standard biological thinking – based on ICES methodologies – was incorporated and a fleet behaviour component was developed to predict how fleet effort would allocate between different fisheries according to historically observed fisher response patterns to various changes to management measures, costs, prices, resource availability, etc..

Examples of bio-economic simulation models that have been developed which specifically consider fleet investment and structural re-allocation issues are found in MOSES (Models for Optimal Sustainable Effort in the Seas) and the Invest in Fish South West model. MOSES is a bio-economic model that has been designed by a collaboration of Italian (IREPA), Icelandic (University of Iceland) and UK organisations (MRAG, Imperial College) to simulate 10 separate multi-species/fleet/gear fisheries around the Italian coastline (Arnason et al, 1998). The model places special emphasis on the management of resources and social impacts of fisheries and is aimed at supporting public administration management policy. It provides information regarding the optimal allocation of fishing effort by gear and area and achieves this by incorporating an innovative fishing effort allocation component which considers fishing costs, market prices, cost of effort diversification out of particular fishery to another region, restrictions on effort transfer between regions, element of inertia within the system due to financial constraints and unemployment levels in each region.

The Invest in Fish South West model is currently being developed by CEMARE and CEFAS as part of the Invest in Fish South West project which aims to sustain fish stocks within the Celtic Sea, English Channel and Western Approaches. The project aims to determine which management options would best benefit the region socially, economically and environmentally and in so doing balance the needs of the marine environment, fishing industry and fishing communities of all countries which fish this region - England, France, Ireland and Spain. The initiative is based on a bottom-up approach driven by stakeholders, with the aim that its final strategy will include management options that are embraced by, and not imposed upon, those it ultimately affects (Invest in Fish, no date).

The Invest in Fish South West model is being developed as a dynamic bio-economic model of fisheries in England’s southwest (English Channel and Celtic Sea) to determine the costs and benefits of sustainable fisheries management (Pascoe, 2005). The modelling (bio-economic and regional economy) aims to robustly assess the economic, fiscal, social and ecological costs and benefits of recovery options in the medium- to long-term and to identify associated short-term costs. Key components are linked sub-models of commercial fishing sector, recreational sector, regional economy (employment and fiscal effects) and environmental impacts. The predicted impact of management options on the regional economy is being assessed through the use of a purpose built regional input-output model. The effect on fleet effort allocation is to be assessed by predicting short-run changes based on spatial fisher choices and in the longer-run through fleet entry-exit choices, technical efficiency improvements and capacity rationalisation effects. Policy options being considered for inclusion in the model are: days at sea limits, decommissioning schemes, gear limits/bans, vessel input restrictions, TAC changes, levies and price intervention.

### 3.3 Optimisation models

Optimisation models can be developed in their own right or as components within larger, dynamic models. For example, MOSES, the dynamic bio-economic model described
previously, can also be run as an optimisation model. The objective function of the model was set to maximise profits subject to a range of criteria and optimisation techniques\(^6\) were used to determine the optimal allocation of effort between fleet segments and regions.

An optimisation model was developed for the Baltic Sea to determine how many ‘average’ vessels can fish profitably for a given stock size. The optimisation model was developed using linear programming techniques (Arnason et al, 1998) to calculate the number of vessels in the fleet for which total earnings covered total costs. It also could be configured to provide an estimate of the number of vessels needed to maximise economic surplus form the Baltic Sea fisheries. The model was static and included imposed cost and price conditions and optimisation restrictions included quota size and number of fishing days per year.

The Danish Research Institute of Food Economics (FOI) and University of Southern Denmark (SDU) also developed a static optimisation model encompassing the entire Danish fleet known as ‘An Economic Management Model for Fisheries in Denmark (EMMFID)’ Frost and Kjærgaard (2003). The EMMFID model disaggregates the fleet into segments, homeports, fishing areas, species and seasons (by month). The model attempts to maximise profit for the entire industry subject to a range of constraints (e.g. total catch must be less than available TACs, minimum vessel profits/profit margins, maximum/minimum vessel days at sea, pre-specified fishing grounds and target species). EMMFID solves for the optimal number of vessels and days at sea which are determined endogenously within the model. Fish stock inputs are exogenously determined and no market price interaction is assumed. The model can also be run to optimise employment and fleet size, in addition to maximising fleet profits/profit margins. As EMMFID is run as a static optimisation model (using linear programming software known as GAMS) it provides no information as to how a particular optimum fleet size/effort combination is reached and the solution is bounded by the value judgements used to set the model objectives and constraints. As it encompasses the entire fleet at a highly disaggregated level, it is very data intensive and requires updating over time, however Frost and Kjærgaard (2003) note that this is not a problem as the Danish fleet and economic data collection system is comprehensive.

An optimisation model was developed by Greig et al (2000) in the late 1990’s for analysis of the socio-economic impact of regional management options for the Irish Sea nephrops and whitefish fisheries. The model was set to maximise the present value of profits (to infinity) and a variation was developed in an alternative version which aimed to maximise profits and crew share. The control variable was kilowatt days at sea and the control period was five years. The model simulated the results over this period and a further fifteen year equilibrium adjustment period. The model included fishing activity from five countries and six species were dimensioned by age cohort. The total impact on the national economies was estimated over the twenty-year period using upstream and downstream multipliers for output, income and employment.

### 3.4 Longevity and use of models

Both Le Floch (no date) and Frost & Løkkegaard (2001) note that whilst the work modelling fisheries systems and fleet/capacity interactions undertaken to date has been comprehensive it is not often used as a permanent tool in fisheries management. Models developed in research programmes often remain untouched once they have been constructed and the project’s

---

\(^6\) linear and non-linear
financial resources are spent. This may the case if the model was designed for a specific purpose which was achieved during the course of the project or if there are problems associated with updating data (i.e. due to lack of ongoing data collection programmes or and/or resources required to maintain the models). Some models have remained intact and evolved over time (e.g. BEAM) and many new models are constructed using the building blocks of previous models (i.e. Invest in Fish, BEMMFISH). Those models that are based in institutions tend to have more longevity than others (i.e. BEAM which is based in the FAO and a generic bio-economic MS Excel spreadsheet model developed by Dan Lane for the OECD (Frost and Kjærsgaard, 2003)).

Frost and Kjærsgaard (2003) discuss the reasons why there has been limited use of fisheries management recommendations based on economic analyses within the Common Fisheries Policy to date. They identify three main reasons: (1) fisheries economic data collection programmes have not been widespread to date (however, the EC has recently reformed its data collection programme in support of the CFP to include some economic data (CEC, 2004) which will improve the situation somewhat), (2) applied economic research does not have the same institutional background as biological research represented by the International Council for the Exploration of the Sea (ICES) and the Northwest Atlantic Fisheries Organisation (NAFO), and (3) much fisheries economic analysis has been devoted towards solving market failure problems.

4 Review of futures analysis: method and applications

In any modelling activity there is a trade off between complexity and uncertainty. It is impossible to fully incorporate and account for every component affecting, and interacting within, a fisheries system. Biological uncertainties are introduced through poor stock-recruitment relationships, mis-reporting, discarding, changes in migration due to temperature/climate, etc. (Pascoe, 2005). Economic uncertainty can exist through measurement, estimation and modelling error whilst implementation uncertainty stemming from unexpected fisher reactions may compound the problem.

Instead of attempting to accurately simulate the future using bio-economic models, given the high levels of complexity and uncertainty, a technique known as futures analysis has been developed to stimulate independent forward thinking about how the world, or fisheries system, may develop in 10 or 20 years time for example. Futures analysis can involve a variety of aspects including consultation with experts in various disciplines, studying trends and models, scanning the environment about new developments or developing scenarios to explore alternative futures and their implications (Bell, no date). The UK’s Department for Environment, Food and Rural Affairs (Defra) recently ran a ‘Science Forward Look 2004-2013’ exercise to identify the key issues and drivers that will shape their future marine and coastal science needs in order to realise their policy goals (Defra, 2004). A Horizon Scanning Programme has also been operational aimed at enhancing Defra’s ability to anticipate and prepare for new risks and opportunities which should aid the development of future policies and strategies (Defra, 2002).

Predictions of the future are more coherent when they are embedded in scenarios – “sets of coherent, plausible stories designed to address complex questions about an uncertain future.” (pp. 1360, Pauly et al, 2003). Alternative futures scenarios for the marine ecosystem have been developed by Defra as part of the Horizon Scanning exercise (AFMEC-04, 2004). Pauly et al (2003) qualitatively considered possible global fisheries futures, particularly from a
marine eco-systems perspective, based upon four scenarios developed as part of the United Nations Environment Programme (UNEP, 2002).

The Strategy Unit project Net Benefits (Cabinet Office, 2004) utilised Futures Analysis to develop three possible future development scenarios (known as Optimistic, Pessimistic and Best Guess) to inform and bound analysis of future fleet sizes based on a range of assumptions about fisheries management decisions, compliance rates, fish price and fuel cost trends and the effect of sea temperature warming on eco-system interactions.
# Annex 1: Overview of selected models

<table>
<thead>
<tr>
<th>Model Name:</th>
<th>EIAA: Economic Interpretation of ACFM Advice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brief description:</td>
<td>The EIAA model was developed to assess the economic consequences of the Total Allowable Catches (TACs) proposed by the EU’s Advisory Committee for Fisheries Management (ACFM).</td>
</tr>
<tr>
<td>Objectives:</td>
<td>Model is driven by annual TAC and provides impact assessment of how fleet will be financially affected by changes in quota species in three time periods: current year, next year and long-run case, i.e. after stocks have been recovered.</td>
</tr>
<tr>
<td>Developed by:</td>
<td>Developed as part of the ‘institutionally’ based Economic Assessment of European Fisheries (EAEF) Concerted Action funded by the EC. Model development was carried out in tandem with vessel cost and earnings data collection program, latterly in 20 countries (17 EU Member States and Iceland, Norway and The Faroes Islands).</td>
</tr>
<tr>
<td>Key specifications &amp; methodologies:</td>
<td>Framework:</td>
</tr>
<tr>
<td></td>
<td>• Model is output driven as opposed to input driven.</td>
</tr>
<tr>
<td></td>
<td>• Constant fleet structure assumed for key fleet segments.</td>
</tr>
<tr>
<td></td>
<td>• Mainly non-dynamic, static impact analysis describing linkages between key variables within the fisheries system.</td>
</tr>
<tr>
<td>Catch:</td>
<td>• Segment catch = f(national allocation of TAC, fixed distribution between segments, expected up-take ratio)(^7)</td>
</tr>
<tr>
<td>Fish prices:</td>
<td>• Prices = f(base year prices, price flexibility)</td>
</tr>
<tr>
<td>Costs:</td>
<td>• Economic impact = f(variable costs based on change in fleet activity, fixed costs)</td>
</tr>
</tbody>
</table>

---

\(^7\) A form of short-hand notation is used to define the relationship between key variables in each model. “Segment catch = f(national allocation of TAC, fixed distribution between segments, expected up-take ratio)” can be interpreted as: The catch of a segment is a function of the following variables: national allocation of TAC, fixed distribution between segments and expected up-take ratio.
**Model Name:** Groundfish Fleet Restructuring Information and Analysis Project, USA West Coast

**Brief description:** Immediate short-run spatial and regional economic impact analysis of possible groundfish fleet restructuring scenarios.

**Objectives:** Project goals:

- Compile comprehensive set of data and information to explore fleet reduction options and other management measures.

- Produce set of analytical, publicly available tools including (1) fleet reduction scenarios considering fleet composition, shore-based infrastructure, harvest history, spatial dynamics and economic trends from perspective of local communities; (2) matrix/simulation to analyse potential social and economic effects of scenarios; (3) case studies illustrating different port profiles, empirical information on fishing and processing businesses, market dynamics and the potential effects of fleet buyout proposals and other management measures.

- Prepare set of publicly available policy options for Pacific Fishery Management Council.

**Developed by:** Pacific Marine Conservation Council (PMCC) and Ecotrust.

**Developed when:** 2001-2003

**Development resources:** Funded by David and Lucile Packard Foundation, the Pacific States Marine Fisheries Commission (PSMFC), the Homeland Foundation and Oregon Sea Grant.

**Key specifications & methodologies:**

- Short-run, static impact analysis comparing each fleet size reduction with the current base. No adaptive dynamic responses

**Operational base:** MS Excel workbook, to ensure high ease and speed of use.

were included and interactions with other fisheries were excluded.

- Analysis was driven by exogenous calculation of ‘optimal’ fleet size (with no excess-capacity) based on historical estimates of ‘capacity’ catches.

- Multiple relationships between the marine ecosystem, fishers and communities were charted by compiling secondary data sources and describing (not predicting) the linkages between data.

- Geographic information layers included bathymetric and other ocean characteristics, habitat types, fish distribution, effort distribution and ports and communities.

- The economic and social impacts of each scenario were tracked using an Input-Output model (‘FEAM’) devised for analysing regional economic impacts specifically from capture fishing and processing activities on US West Coast.

- Analysis estimated the immediate short-run impact of fleet size reduction (before redistribution of allowable catch occurs between remaining fleet) on landings and revenues spatially between fishing communities around coast with associated regional income and employment impacts. Suitable cost and earnings data was not available and so not included in analysis.

- Four hypothetical fleet reduction scenarios were analysed.

Pictorial representation: Note: This picture is not a schematic of the model used in the project – it represents the multiple relationships within the fisheries system that were charted under the project.

Operational base: Relational database (SQL Server 2000) was used to store information and describe linkages (including spatial) between each type of information. The outputs of database queries were mapped using Geographic
MEFISTO: Mediterranean Fisheries Simulation Tool: A bio-economic model for Mediterranean fisheries

Brief description: Bio-economic dynamic simulation model for Mediterranean Fisheries

Objectives: To reproduce the bio-economic conditions in which Mediterranean fisheries occur and to simulate impact of alternative management strategies. Current management strategies involve effort limitation (i.e. no increase in nominal vessels numbers, fishing time, installed power and GRT) and TACs are not used except for tuna.

Developed by: University of Barcelona and Institut de Ciències del Mar (CSIC), Barcelona, Spain

Developed when: 1998-2000

Development resources: Funded by the Spanish Agency for the Science and Technology.

Key specifications:
- Fishery type:
  - Multi-species, multi-fleet, multi-gear

- Biology:
  - Target stock growth = f(length/weight relationship; age class; natural mortality; fecundity)
  - Other stock income = f(target stock income)

- Prices:
  - Price for each main species = f(fish size, regional factor, fleet segment, month, day, exogenous factors (introduced manually))

- Fisher decision process:
  - Profits/losses = f(costs, revenues)
  - Impact of losses = f(extent of loss, credit availability)

Pictorial representation:
TEMAS: Technical measures - Development of evaluation model and application in Danish fisheries

Bio-economic model incorporating stochastic simulation, developed for use in North Sea and Baltic multi-fleet/gear/species/area fisheries targeted by the Danish fleet.

TEMAS was developed to evaluate the expected impacts of various technical management measures using three Danish fisheries as case studies.

Institute for Fisheries Management (IFM) and Danish Institute for Fisheries Research (DIFER), Denmark

2000-2003

Funded by the Danish Ministry of Food, Agriculture and Fisheries, Danish Directorate for Development. Builds upon original BEAM 5 model developed with FAO-funding to generically model the impact of vessel decommissioning schemes (i.e. impact on stocks and economic performance of remaining vessels).

Framework:
- Fleet-based with dimensions of fleets, fisheries and stocks.

Biology:
- “Standard biologic thinking” – i.e. cohort models with growth, recruitment, migration, natural and fishing mortalities, gear selection etc. Essentially equivalent to an ICES stock forecast (using single and multi-species age-structured techniques).

Economics:
- Biological model is supplemented by a simple bio-economic model (accounting for costs and earnings).

Fleet behaviour module (component developed under TECTAC):
- Fleet effort is allocated between different ‘fisheries’ based on empirical analysis (using Random Utility Modelling) of data relating to fishers economics and ‘traditional’ reactions to a range of issues (i.e. management measures, cost and prices, range and equipment of vessels, resource availability).

TECTAC - Technical developments and tactical adaptations of important EU fleets. Research project funded by the European Commission (2002-2005). The overall objective of TECTAC is to supply fisheries managers with a modelling tool that will allow them to evaluate the impact of regulations on the dynamics of fleets and fishing mortality. The aim is to investigate the dynamics of the elements that cause changes in fleet dynamics, i.e. technological advances in gears and vessel equipment, and the overall tactical adaptation of fishing vessels.
Stochastic simulation:

- Stochastic simulation of many model components can be undertaken.

Comparison:

- A simultaneous comparison of two alternatives scenarios (two modules) is provided: namely, the operating model (i.e. “true world”); and the management procedure (i.e. using sampling, ICES Working Group + ACFM advice, management options, e.g. Harvest Control Rules).

Operational base: Purpose designed software package using Visual Basic in MS Excel.

Model Name: MOSES: Models for Optimal Sustainable Effort in the Seas
developed for 10 separate multi-species/fleet/gear fisheries around the Italian coastline.

Objectives: The model places special emphasis on the management of resources and social impacts of fisheries and is aimed at supporting public administration management policy. The model provides information regarding the optimal allocation of fishing effort by gear and area.

Developed by: IREPA, Salerno, Italy; University of Iceland, Reykjavik, Iceland; and MRAG, Imperial College, London, UK

Developed when: 1995-1998

Development resources: Funded under the European Commission’s FAIR programme (FAIR-CT 95-0561).

Key specifications & methodologies:

Optimisation:

- Objective function = profit maximisation subject to certain constraints.
- Linear and non-linear optimisation techniques used to determine optimal value for control variables.

Biology:

- Stocks are modelled as endogenous variables using classical surplus production or age-structured models.
- But also utilises Bayesian statistical estimation techniques for stock analysis.

Catch-Effort Model:

- Catch-Effort = f(fishing effort, gear, area, species, year, stock size)

Optimal Fishing Effort Model:

- Optimal Fishing Effort = f(fishing costs, market prices, cost of effort diversification out of particular fishery to another region, restrictions on effort transfer between regions, element of inertia within system due to financial constraints, unemployment level in region).

Scenario analysis:

- Scenarios = f(profit maximisation objective, biological constraints, level of inertia in system)
Model Name: **Invest in Fish South West**

Brief description: A dynamic bio-economic model of fisheries in England’s southwest (English Channel and Celtic Sea) to determine the costs and benefits of sustainable fisheries management.

Objectives: The overall project aim is to provide all necessary steps to enable local community and interest groups to collectively identify, develop and agree upon sustainable fisheries recovery plan options. The modelling (bio-economic and regional economy) aims to robustly assess the economic, fiscal, social and ecological costs and benefits of recovery options in the medium- to long-term and to identify associated short-term costs.

Developed by: Centre for the Economics & Management of Aquatic Resources (CEMARE), University of Portsmouth, UK and Centre for Environment, Fisheries and Aquatic Systems (CEFAS), UK.

Developed when: 2004-2006

Development resources: Funded by UK Department for Environment, Food & Rural Affairs (Defra).

Key specifications & methodologies: Key components:

- Includes linked sub-models of commercial fishing sector, recreational sector, regional economy (employment and fiscal effects) and environmental impacts.
- Different management measures are imposed on the interlinked dynamic systems model to determine their impact.

Commercial fisheries sector:
• Multi-species/gears/fleet/spatial segmentation.
• Commercial catch = f(fishing effort, species ‘catchability’ of segment)
• Fishing effort = f(species abundance, segment profitability, )
• Prices = f(landings, price flexibilities)
• Variable costs = f(revenue, effort)
• Capital costs = f(fleet size, fleet structure)

Recreational sector:
• Recreational catches = f(stock abundance, recreational effort, capture and release programme)
• Recreational effort = f(current level of activity, change in participation rate)

Regional economy:
• Input-output model will be included to measure direct, indirect and induced impact on regional economy.

Environmental impact:
• Key impacts to be included are on (1) cetaceans and (2) fishing ‘habitat’.

Dynamic elements:
• Stock: Age-structured and surplus production models to be used depending on data availability and reliability.
• Fleet: effort allocation (Short-term (i.e. spatial choices) and long-term (i.e. entry-exit choices)), technical efficiency improvements and capacity rationalisation.
• Price: price flexibilities
• Cost: variable, fixed and capital costs to be included to allow for financial and economic analysis.

Policy options:
• Days at sea limits, decommissioning schemes, gear limits/bans, vessel input restrictions, TAC changes, levies, price intervention.
Operational base: GAMS programming software initially, then to be converted into simulation-based software with graphical gaming user-friendly interface.

More information: http://www.investinfish.org/
References


