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Models for an ecosystem approach to fisheries

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The increased awareness of the importance of taking into account interactions among fishery resources and the ecosystem in fisheries management has prompted the need to improve the knowledge base on how ecosystems function including how they are impacted by marine capture fisheries. Over time this has led to the development of different approaches for the modelling of ecological interactions in marine ecosystems exploited by fisheries. This paper reviews the models available for assessing the impacts of ecological (indirect) direct interactions between species and fisheries and the implications these have for fisheries management.

As this is a broad and rapidly-evolving issue, the report provides an overview of the main types of modelling approaches rather than detail each aspect of the models. Moreover, it includes a critical analysis of the advantages, disadvantages and limitations of each modelling approach for representing ecosystem dynamics and interactions between ecosystems and human activities, including in particular, fisheries. This report is expected to serve as a useful reference for fisheries scientists and managers seeking an overall view of the relative merits of the main types of modelling approaches available for fisheries assessment in an ecosystem context.

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Abstract

This report reviews the methods available for assessing the impacts of interactions between species and fisheries and their implications for marine fisheries management. A brief description of the various modelling approaches currently in existence is provided, highlighting in particular features of these models which have general relevance to the field of the ecosystem approach to fisheries (EAF). The report concentrates on the currently available models representative of general types such as bionergetic models, predator-prey models and minimally realistic models. Short descriptions are given of model parameters, assumptions and data requirements. Some of the advantages, disadvantages and limitations of each of the approaches in addressing questions pertaining to EAF are discussed. The report concludes with some recommendations for moving forward in the development of multi-species and ecosystem models and for the prudent use of the currently available models as tools for provision of scientific information on fisheries in an ecosystem context.

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Abbreviations and acronyms

(See also the list of model acronyms in Table 1.)

ABM	Agent-Based Models
ADMB	AD Model Builder
AGGMULT	Simplified version of MULTSPEC with only the age structure retained
ASPM	Age-Structured Production Model
BENEFIT	Benguela Environment Fisheries Interaction and Training Programme
BM2	Bay Model 2
BORMICON	BOReal MIgration and CONsumption model
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CITES	Convention on International Trade in Endangered Species
CPUE	Catch per Unit Effort
DEAT	Department of Environmental Affairs and Tourism (South Africa)
EAF	Ecosystem Approach to Fisheries
EBFM	Ecosystem-based Fisheries Management
ECONMULT	Model for describing the economy of the Barents Sea fisheries under different harvesting control rules
ENSO	El Niño Southern Oscillation
EPOC	Ecosystem Productivity Ocean Climate Model
ERSEM	European Regional Seas Ecosystem Model
ESAM	Extended Single-species Assessment Model
ESD	Ecologically Sustainable Development
EwE	ECOPATH with ECOSIM
FAO	Food and Agriculture Organization of the United Nations
GADGET	Globally applicable Area-Disaggregated General Ecosystem Toolbox
GEEM	General Equilibrium Ecosystem Model
GIS	Geographical Information System
GLM	Generalised Linear Model
GOTM	General Ocean Turbulence Model
IBM	Individual-Based Models
ICES	International Council for the Exploration of the Sea
IGBEM	Integrated Generic Bay Ecosystem Model
IMR	Institute of Marine Research, Bergen, Norway
IWC	International Whaling Commission
KPFM	Krill-Predator-Fisheries Model
LME	Large Marine Ecosystem
MCM	Marine and Coastal Management, South Africa
MOOVES	Marine Object Oriented Virtual Ecosystem Simulator
MP	Management Procedure (analogous to OMP and MSE)
MPA	Marine Protected Area
MRM	Minimally Realistic Model
MSE	Management Strategy Evaluation (analogous to MP and OMP)

MSFOR	Multi-species Forecasting Model
MSM	Multi-species Statistical Model
MSVPA	Multi-species Virtual Population Analysis
MSY	Maximum Sustainable Yield
MULTSPEC	Multi-species model for the Barents Sea
NAMMCO	North Atlantic Marine Mammal Commission
NMFS	National Marine Fisheries Service
OMP	Operational Management Procedure (analogous to MP and MSE)
OSMOSE	Object-oriented Simulator of Marine ecOSystems Exploitation
P	Production
P/B	Production:Biomass ratio
PPBIM	Port Philip Bay Integrated Model
PVM	Parallel Virtual Machine
Q/B	Consumption per unit biomass (or per capita biomass)
R	A language and environment for statistical computing (R Development Core Team. 2003)
SAM	Single-species Assessment Model
SKEBUB	SKEleton BUlk Biomass ecosystem model
SEAPODYM	Spatial Ecosystem And Population Dynamics Model
SEASTAR	Stock Estimation with Adjustable Survey observation model and TAg-Return data
SIR	Sampling-Importance-Resampling algorithm
SMOM	Spatial Multi-species Operating Model
SPM	Sequential Population Analysis
SSEM	Shallow Seas Ecological Model
SSMU	Small-Scale Management Units
SystMod	System Model for the Norwegian and Barents Sea
TAC	Total Allowable Catch
VPA	Virtual Population Analysis
WSSD	World Summit on Sustainable Development

Executive summary

This report reviews the methods available for assessing the impacts of interactions between species and fisheries and their implications for marine fisheries management. The focus is on modelling methods and multi-species population dynamics effects, rather than on the full range of ecosystem aspects of fishing which encompass, for example, environmental effects and technical interactions (e.g. bycatch issues), although minor mention of these is made.

The first section takes a broad overview of some of the most commonly applied multi-species/ecosystem approaches to fisheries management. The next section summarizes the results and conclusions reached by previous studies and workshops on the subject, including the ICES/SCOR Symposium on Ecosystem Effects of Fishing, the Workshop on the Use of Ecosystem Models to Investigate Multi-species Management Strategies for Capture Fisheries, the International Whaling Commission (IWC) Modelling Workshop on Cetacean-Fishery Competition, the North Atlantic Marine Mammal Commission (NAMMCO) workshops and the Workshop on Ecosystem Approaches to Fisheries in the southern Benguela.

A brief description of the various modelling approaches currently in existence is provided, highlighting particular features of these models which have general relevance to the field of the ecosystem approach to fisheries (EAF). Models discussed include: whole ecosystem/dynamic system models, minimum realistic models, individual-based models and bioenergetic models.

These models are compared in a series of tables and figures, using the following criteria:

1. the level of complexity and realism, e.g. the number of modelled species, the representation of size/age structure of the species, and the types of processes represented (physical and biological);
2. the types of functional responses of predators to changes in abundance of prey species and their consequences and limitations;
3. how uncertainties in model structure, parameters and data are treated;
4. how environmental effects and interactions with non-target species (e.g. marine mammals; sea turtles; sea birds) are incorporated;
5. the spatial representation of species interactions and habitat related processes;
6. model suitability for dealing with migratory species, i.e. species that cross ecosystem boundaries;
7. where possible, model adequacy to allow the analysis of the different types of management controls in use, such as effort control, minimum size, total allowable catch, protected areas and closed seasons;
8. model adequacy to allow the assessment of the effects of short, medium and long-term ecosystem changes;
9. model suitability to conduct assessment and policy exploration, considering the model's potential use to conduct historical reconstruction of resources to describe the current status of the ecosystem and to evaluate the potential effects of various kinds of decisions (short and long term);
10. model transparency of operation and ease of use; and
11. data requirements and model suitability for data poor areas.

A description is also given of model parameters, some important assumptions, data requirements, technical information such as the computing platform, a list of examples where the approach has been used, notes on the model history as well as any additional useful features of an approach. Some advantages, disadvantages and limitations of each of the 20 approaches are listed, together with notes on the ease of presentation of model outputs and the user-level of programming and mathematical skills required.

The most widely used approach is undoubtedly ECOPATH with ECOSIM (EwE), which is likely to remain a forerunner given the user friendly interface and on-going improvements to the software. However, faced with incomplete knowledge of ecosystem functioning, there has been increasing recognition that definitive conclusions cannot be drawn from a single model structure. There has thus been a parallel increase in efforts to modularize models so that different components can be easily substituted. Spatial considerations are similarly playing an increasingly important role in the development of ecosystem modelling approaches. Nonetheless, even some of the earliest approaches such as Multi-species Virtual Population Analysis (MSVPA) are still being used and improved. A summary is presented of some recent advances being planned for the different modelling approaches.

A set of commonly asked questions pertaining to EAF is identified and the potential of the various modelling approaches to address these questions is assessed. This preliminary analysis suggests that a range of different model constructions are needed; no one model is necessarily superior to all others in all respects. EwE is capable of addressing the widest range of topical EAF research questions. The model considered to show the greatest potential to contribute to practical fisheries management advice (such as changes to total allowable catch (TAC)) is Globally applicable Area Disaggregated General Ecosystem Toolbox (GADGET). Although still under development, this is currently the model with the most rigorous statistical framework for testing multi-species based management advice. It is also the modelling approach most capable of detailed sensitivity investigations to alternative growth, consumption and recruitment formulations. Additionally, it operates within a spatial framework and overcomes many of the associated computing constraints by running on multiple computers in parallel. Nonetheless, it too has limitations in that it is capable of representing only a relatively small component of the ecosystem and is not suitable for all systems. Models such as EwE and ATLANTIS are more appropriate for addressing broader questions.

The incorporation of ecosystem considerations into current Operational Management Procedures (OMPs) and other management strategies for marine resources is also discussed. ATLANTIS is ranked the best operating model within a simulation testing framework. Unfortunately it seems unlikely that sufficient data will be available to implement an ecosystem operating model framework in most marine systems. Further development is encouraged of approaches that take explicit account of uncertainty and management issues, for example, through the use of a simulation framework incorporating feedback control rules used in actual management.

Approaches such as the Extended Single-Species Assessment Models (ESAM) are often a good first step. Similarly, examples are given of equations that provide a useful starting template for multi-species modelling approaches, being built up slowly and in synchrony with data availability. Some of the less well-known (in a global context) modelling approaches are shown to include some additional useful features, for example, SEAPODYM's (Spatial Environmental POpulation DYnamics Model) habitat index and OSMOSE's (Object-oriented Simulator of Marine ecOSystem Exploitation) explorations with simple individual predation rules.

This report is a first step towards initiating more detailed discussions of these models, their uses and their limitations. This process is considered critical in moving forward the development of methods for assessing indirect ecosystem impacts of fisheries. Arguments are presented that whereas a good range of models has been developed for the task of EAF, greater focus is needed on strengthening these approaches and conducting the necessary data collection and experimentation to underpin confidence in these approaches. Would-be model developers are encouraged to assess whether they would be adding anything to the current suite of models, given that approaches such as EwE and GADGET have benefited from an extensive network of collaborators over a number of years.

Considerable scope exists for significant future developments in multi-species and ecosystem models, particularly with respect to their use as tools in EAF. Some of the major areas of current research include:

- investigations pertaining to the effects of model complexity – in particular, the effect of specific formulations (often feeding functional responses) on model outputs;
- the treatment of uncertainty;
- representation of socio-economic factors and human behavioural drivers;
- multiple sector dynamics and management (with OMPs being an increasingly popular method); and
- the effective (and feasible) representation of biodiversity.