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Building ecological-economic models and scenarios of marine resource systems: Workshop report

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ABSTRACT

As part of the ecosystem approach to managing fisheries and other uses of marine ecosystems, there has been a growing call for the development of integrated assessment tools to support the provision of both tactical and strategic management advice. Of particular importance in this domain is the development of models that capture the dynamic interactions between social and economic systems, and marine ecosystems. In February 2013, a workshop jointly organised by the ICES working group on Integrative, Physical–biological and Ecosystem Modelling and researchers attending the "Mathematics of Bio-economics" initiative, a contribution to the international event "Mathematics of Planet Earth 2013", brought together experts to discuss recent advances and key methodological challenges posed by this field of research. The manuscript provides a brief report of the key points discussed during the workshop, including identification of the research which may help progress both the development of these modelling approaches and their application to actual management decision problems.

1. Introduction

As part of the ecosystem approach to managing fisheries and other uses of marine ecosystems, there has been a growing call for the development of integrated assessment tools to support the provision of both tactical and strategic management advice [1]. Of particular importance in this domain is the development of models that capture the dynamic interactions between social and economic systems, and marine ecosystems, allowing identification of scenarios for the future, and evaluation of potential responses to alternative management strategies [2–4].

In February 2013, a workshop jointly organised by the ICES working group on Integrative, Physical–biological and Ecosystem Modelling[1] and researchers attending the "Mathematics of Bio-economics" initiative[2] , a contribution to the international event "Mathematics of Planet Earth 2013"[3] , brought together experts to discuss recent advances and key methodological challenges posed by this field of research. The workshop combined presentations of recent work towards meeting a diversity of these challenges, and open discussion of the key domains currently thought to be crucial to progress both the development of these modelling approaches and their application to actual management decision problems.

A first challenge addressed in the workshop relates to the growing demand for tools that, in evaluating the trade-offs associated with managing marine resource systems, fully account for the multiple (economic, ecological and social) dimensions of such trade-offs and the distributional impacts of scenarios across stakeholder groups. Presentations by Luc Doyen, on the viability approach to ecological-economic scenarios [5–7], and by Martin Quaas, on the identification of winners and losers in the transition towards sustainable fisheries [8–10], illustrated recent efforts at developing such evaluations, while also taking into account the complex set of interactions and the multiple sources of uncertainty which characterise marine ecological-economic systems.

A second challenge relates to process understanding of marine ecosystem uses (including but not limited to commercial fisheries), how this can be modelled, and coupled to biophysical models in order to gain better understanding of the potential consequences of alternative economic, environmental or management scenarios. Presentations by James Innes on modelling fishing behaviour in the Australian Eastern Tuna and Billfish Fishery [11–13], and by Christian Mullon on modelling international tuna catching and trading as a global network [14] illustrated two extremes of the spectrum over which such research has been developing, in an effort to reduce a key source of uncertainty in fisheries management [2,15].

A third challenge relates to the growing complexity of models that couple representations of ecological, economic and social processes, each of which may be affected by uncertainty, making the systematic exploration of sensitivity of model projections to these different sources of uncertainty increasingly difficult. A presentation by Stephanie Mahévas [16,17] on sensitivity analysis for complex models illustrated the research efforts underway to address this issue, and develop formal methods which enable the systematic evaluation of model projections to the assumptions relating to their parameters.[4] The presentation of summary conclusions from a recent meeting focused on "modelling from first principles", by Benjamin Planque, illustrated the need felt by some members of this research community to use simple, well-established models, to delimit domains within which projections from the more complex models should remain, and should provide

[1] www.ices.dk/community/groups/Pages/WGIPEM.aspx.
[2] http://www.ihp.fr/fr/ceb/mabies.
[3] http://mpe2013.org.
[4] www.reseau-mexico.fr/welcome; www.isis-fish.org/.

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additional understanding or predictive capacity. Models considered here are based on few and simple ('first') principles with particular emphasis on mathematical theory of viability [18,19], stochastic constrained models [20] and Liebig's law of limiting factors [21].

Finally, a fourth important challenge relates to the key issues that need to be considered when models are expected to be used in decision-support processes involving multiple stakeholders. The presentations of key steps in developing operational bio-economic models for fisheries management support[5] by Claire Macher [22–25], and of the lessons learned from the SPICOSA[6] European research project in adopting a systems modelling approach to co-construct models of coastal zone management issues with stakeholders [29], both emphasised the role which models may have in assisting the management process, as well as the many practical issues which need to be addressed for this role to be effective. The presentation by Tony Smith also illustrated the importance of "social licence to operate", and the dangers of taking for granted that evidence-based decision making can withstand public perceptions relayed through social networks [2].

Altogether, the approaches presented at the workshop provided a good illustration of the diversity of modelling challenges which one must face when attempting to include "human dimensions" in models of marine resources management. The following report summarises the key methodological and practical points identified by the group as requiring particular attention.

2. Model complexity: the value of formalization and parsimony

The group noted the increasing complexity which characterises models that aim to couple dynamic representations of biological and economic processes, and the diversity of approaches to managing this complexity which characterises efforts in this space. There is clearly a trade-off associated with increasing the complexity of the processes simultaneously represented in models of socio-economic systems and ecosystems. Expanding this complexity in both dimensions comes at a cost in terms of (i) the ability to understand the causes of the behaviour of the model, (ii) the ability to systematically assess the influence, on model projections, of the different sources of uncertainty in these processes and their interactions, and (iii) the ability for the models to be used in tactical decision support.

As illustrated in Fig. 1, many models aimed at understanding the ecological dynamics of marine resource systems have been developed with only limited economic content. In a similar fashion, efforts to model the dynamics of socio-economic systems often only include limited ecological content. Most of the integrated modelling efforts to date have thus been centred on relatively simplified representations of both ecology (i.e. a species, often a single species, focus) and economy (i.e. the fishing mortality "F" imposed by a fishing fleet, often a single fleet, focus). The models developed at this level have also been those used for tactical decision-support in fisheries management. The challenges identified in the workshop imply moving towards the North-East part of this figure, into a domain where the trade-offs in deciding on the level of economic and ecological complexity of models will be guided by the questions which these models are asked to provide answers to, the purposes of using a modelling approach to address these questions, and the context in which the models are to be developed and used.

The group discussed several principles which could be developed into a set of guidelines to modelling in this domain, based on the experience of participants. In particular, the group agreed that reinforcing the mathematical focus of modelling efforts could be very effective in ensuring clarity in the modelling assumptions, particularly in a multi-disciplinary context, as well as parsimony in model development. The importance of "starting simple" was also stressed, as well as the need to justify the importance of adopting more complex representations, given the modelling objectives. The "first principles" approach, discussed during the workshop, would seem particularly relevant in this respect. In addition, the development of sensitivity analysis methods for complex models appears to be a key domain in which to invest research efforts, as this may allow to better identify and rank the major sources of uncertainty which warrant further empirical research.

3. Diversity of modelling approaches: the need for systematic documentation of model characteristics

The group also discussed the large diversity of approaches which are being followed, and which was well illustrated by the presentations at the workshop. This diversity is apparent in terms of (i) the nature and scale of the economic and social processes (e.g. from models of micro-economic behaviour, to model of macro-economic systems, through the representation of strategic decision-making using game theory) as well as ecological processes (from single population dynamics to multi-population dynamics and trophic networks); (ii) the modelling approaches (optimal or viable control system dynamics, simulation, agent-based modelling, …); (iii) the diversity of tools/platforms/languages; and (iv) the diversity of contexts in, and purposes for which the models are used.

The group considered that this diversity is a positive characteristic of the research area, as it seems unlikely that a single "one size fits all" approach could suitably address the many issues and multiple scales which need to be considered. In addition, given the current limitations of knowledge, the group also acknowledged that a degree of diversity, redundancy and modularity could be considered to be a strength. For instance, a multiple-models approach may allow identifying the range of uncertainty relating to alternative scenarios. While such diversity may be difficult to justify in terms of research funding support, it could be expected to enable better adaptation to evolving needs, under the ecosystem approach to marine living resources management, as societal demand and our understanding of marine ecological-economic systems progresses.

However, the group also considered the need to seek commonalities between the different approaches, which would assist in the longer-term strengthening of integration between economic and ecological models, particularly for decision support. To assist in this, there may be a need to carry out more systematic reviews of existing models. Related to this, and to the importance of formalizing model assumptions, the group agreed that efforts to document existing models in a systematic fashion, including an evaluation of their strengths and weaknesses, would contribute to increasing the knowledge base. An approach similar to the "Overview, Design Concepts and Details (ODD)" protocol recommended by [26] for documenting complex models may be particularly useful in this regard. For case studies for which several (documented) models have been developed, a common operational framework to run models could also be a promising tool to support decision-making. This approach would consist in (i) fixing common input-scenarios (including uncertainty) and outputs variables; and (ii) running the available models to assess and compare the consequences of a selection of management measures, given the assumed uncertainty.

[5] www.umr-amure.fr/pg_partenarial_bioeco.php.
[6] www.spicosa.org.