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Summary

In order to fulfill society's intensifying and diversifying needs whilst ensuring ecologically sustainable development, more effective marine spatial planning and broader-scope management of marine resources is necessary. Integrated ecological–economic models (IEEM) of marine systems are needed to evaluate potential management actions and understand, and anticipate ecological, economic, and social dynamics at a range of scales from local to national and regional. To make these models most effective, it is important to determine how model characteristics and methods of communicating results influence the nature of the advice that can be provided and the impact on decisions taken by managers. This paper presents a global review and comparative evaluation of IEEM applied to marine fisheries and marine ecosystem resources to identify the characteristics that determine their usefulness and effectiveness.

Introduction

There is a growing need for tools to evaluate policies and assess trade-offs in management of marine resources and provision of ecosystem services such as fishing, aquaculture, renewable energy, shipping, conservation, and recreation. To meet this need there has been increasing development of integrated ecological–economic models (IEEM) that include various disciplines such as fish ecology, fisheries economics and sociology. Fundamentally, an IEEM is a mathematical representation of ecological, economic and social systems based on linking components and parameters of each dimension. One of the potential benefits of IEEMs is that one can develop a better and more comprehensive understanding of the feedback effects between human activity, human structures and the ecosystem dynamics which may help managers avoid unintended consequences of management actions. However, increased complexity within each dimension and greater integration of the dimensions may also increase the difficulty of conditioning the models and understanding and communicating the results. We conduct a global review of IEEMs to provide potential users an overview of when and how IEEMs can be and have been used, and to identify the characteristics that determine their usefulness and effectiveness in fisheries advice. The review evaluates model design choices such as spatial and temporal scale, scope, level of complexity and realism, the ability to model uncertainty and stochastic process impact, and the type and robustness of advice that can be provided as well as the data and expertise needed to develop and parameterize IEEMs.

Materials and Methods

In order to perform the comparative evaluation of IEEMs we collected information from model developers on model characteristics and uses including: a) model scope, type, characteristics, development, and complexity; b) model dimensions and scales; c) model input, data, parameters, and functions; d) the model linking, coupling and level of integration of biological-economic-social components; e) mo-

del output indicators and model performance criteria (and robustness and risk assessment); f) model uses (generic or case specific; strategic or tactical); g) what makes the models informative and useful to policy makers and stakeholders (user-friendliness, flexibility, complexity); h) what improves or impedes model acceptance and how can we best communicate model results; and i) the challenges and processes involved in model development and implementation. We established 3 model meta-analysis tools: a Model Evaluation Matrix, a Model Categorization and Descriptors Summary, and a Model Use and Trade-Off Summary. All model developers filling in the meta-analysis tools were involved in the review which covers 26 different models.

Results and Discussion

Most models reviewed provide short term (tactical) advice and medium term management strategy evaluation (MSE), while only some models (around 1/3) provides both short term and medium term advice, as well as medium term MSE. Nearly all models can provide long term strategic advice. Most models were classified as multi-species and mixed fisheries models having modules that also considered socio-economics in relation to fisheries. Only a few IEEM´s included biological interactions or trophic dynamics and interactions. The majority of models only operate with one geographical area and unit, i.e. they are not spatially explicit. Some models operate with several areas such as stock or ecosystem sub-areas or management and advisory sub-regions. With respect to the processes considered in the IEEM's most models incorporate dynamic processes, while only four were static models, and 5 included equilibrium processes. More than half of the models included both simulation and optimization models with respect to estimation of output parameters, while only 2 were exclusively optimization models. The rest were pure simulation models. For a bit less than half of the models analyses can only be performed by the developer. With the exception of two models which may be operated with general expertise, for the remaining models, analysis could be performed by someone other than the developer but that specialized training or expertise would be required. Only 3 IEEM's were characterized as user friendly. The majority of models have been developed using open access software but a few have specific software requirements. Most IEEM's were characterized as flexible, and only about 1/5th of the models as specialized. Most models have high data needs also adding to complexity and need for higher level expertise.

About 25% of the IEEM's have a high level of implementation (i.e. several cases of implementation and direct use in fisheries management advice). Similar proportions have a medium level of implementation in advice, low implementation or no implementation at all (i.e. only scientific development). For many of the implemented models the advice level they have targeted has been broader regional, ICES or EU, while only a few models have targeted only national advice. The latter models have typically been implemented in uni-jurisdictional systems like in North America and/or Australia. Concerning academic status and use, most of the IEEM's are published in scientific peer reviewed journals, however, only a few have frequent citations.

To guide design and implement IEEM´s efficiently it seems necessary to formulate specific management requests both with respect to ecological sustainability and economic efficiency. It is also necessary to consider how and when strategic advice moves into tactical advice, i.e. in what precise advisory context the IEEM's are supposed to develop and be used? It seems necessary to establish adequate governance structures under which relevant stakeholders and model developer experts can work together in implementing the IEEM's. It is important to involve model developers and advanced users with cross disciplinary expertise covering both biological and socio-economic disciplines to develop, adapt and apply the models for advice, as well as assure financing.

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