



## Review

## Using ecological models to assess ecosystem status in support of the European Marine Strategy Framework Directive



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## ABSTRACT

The European Union's Marine Strategy Framework Directive (MSFD) seeks to achieve, for all European seas, "Good Environmental Status" (GENS), by 2020. Ecological models are currently one of the strongest approaches used to predicting and understanding the consequences of anthropogenic and climate-driven changes in the natural environment. We assess the most commonly used capabilities of the modelling community to provide information about indicators outlined in the MSFD, particularly on biodiversity, food webs, non-indigenous species and seafloor integrity descriptors. We built a catalogue of models and their derived indicators to assess which models were able to demonstrate: (1) the linkages between indicators and ecosystem structure and function and (2) the impact of pressures on ecosystem state through indicators. Our survey identified 44 ecological models being implemented in Europe, with a high prevalence of those that focus on links between hydrodynamics and biogeochemistry, followed by end-to-end, species distribution/habitat suitability, bio-optical (remote sensing) and multispecies models. Approximately 200 indicators could be derived from these models, the majority of which were biomass and physical/hydrological/chemical indicators. Biodiversity and food webs descriptors, with ~49% and ~43% respectively, were better addressed in the reviewed modelling approaches than the non-indigenous species (0.3%) and sea floor integrity (~8%) descriptors. Out of 12 criteria and 21 MSFD indicators relevant to the abovementioned descriptors, currently only three indicators were not addressed by the 44 models reviewed. Modelling approaches showed also the potential to inform on the complex, integrative ecosystem dimensions while addressing ecosystem fundamental properties, such as interactions between structural components and ecosystems services provided, despite the fact that they are not part of the MSFD indicators set. The cataloguing of models and their derived indicators presented in this study, aim at helping the planning and integration of policies like the MSFD which require the assessment of all European Seas in relation to their ecosystem status and pressures associated and the establishment of environmental targets (through the use of indicators) to achieve GENs by 2020.

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## 1. Introduction

The use of robust and appropriate indicators that can assess whether an ecosystem and its services are well maintained and sustainably used (Layke, 2009; Walpole et al., 2009; TEEB, 2010) has been recognised as an essential step for the practical implementation of conservation and management policies (Rombouts et al., 2013). Several efforts have been undertaken at a European scale to evaluate marine ecosystem structure and their response to human activities, using key indicators to assess and sustain “Good Environmental Status” (GenS; Borja et al., 2011). These initiatives have been carried out to assist the Marine Strategy Framework Directive (MSFD, 2008/56/EC; European Commission, 2008), the main European Directive that focuses on marine waters and aims at assessing the status of an ecosystem under anthropogenic pressures and the required interventions to bring the system back to its desired good status, making human activities sustainable, since this is one of the objectives of the MSFD. To achieve GenS, 11 descriptors, 29 associated criteria and 56 indicators (from biological, physico-chemical indicators as well as pressure indicators—including hazardous substances, hydrological alterations, litter and noise, and biological disturbance such as introduction of non-indigenous species) have been identified (Cardoso et al., 2010; European Commission, 2010) (Tables 2 and 4).

Despite the fact that several attempts have been made to assess the environmental status of marine waters in an integrative manner (Borja et al., 2011; Halpern et al., 2012; Tett et al., 2013), significant gaps still exist on understanding marine ecosystem structures and functions and their response to human pressures (Katsanevakis et al., 2014; Borja et al., 2013). Currently, ecological models have been recognised as powerful tools to evaluate ecosystem structure and function and predict the impacts of human activities (Fulton and Smith, 2004; Shin et al., 2004; Christensen and Walters, 2005; Plagányi, 2007; Fulton, 2010) and climate change (Tomczak et al., 2013; Chust et al., 2014) on marine systems.

Thus, this study aims to assess the most commonly used capability of the modelling community to inform on indicators outlined in the EU MSFD (2008/56/EC), focusing particularly on biodiversity related descriptors: biological diversity (D1), non-indigenous species (D2), food webs (D4), and seafloor integrity (D6). To date, there has been no thorough evaluation of the capabilities of ecological models to provide information as explicitly outlined by the MSFD indicator structure, this task has been only partially undertaken (e.g., Reiss et al., 2014). With this work, we aim to fill in this knowledge gap by providing an inventory of models in EU regional seas that could assess MSFD indicators associated with

biodiversity, non-indigenous species, food webs and seafloor integrity. For this reason, we have built a model catalogue ranging from lower to higher trophic levels, including those that successfully couple the two compartments and associated ecosystem processes. This inventory, developed as part of the DEVOTES FP7 Project (<http://www.devotes-project.eu/>), serves to highlight the vast potential of model-derived indicators that can be associated with MSFD descriptors and aims to provide a thorough assessment of their relevance and degree of “operationality.” A detailed description of models and associated references together with the full catalogue are provided as supplementary materials (S1 and S2).

Yet, we acknowledge that this study does not aim to serve as review of all the existing models available in the literature, but instead highlight a process of exploring modelling potential to support specific European policies. Because of the nature of these issues, though, similar case studies conducted elsewhere are likely to lead to similar outcomes, conclusions, and recommendations (e.g., because of similar/same model availability and/or process understanding). Thus, this work emphasises several types of ecological modelling and derived indicators that exist at EU level stressing how such diversity of modelling approaches could be useful to support management policies and the limitations that still occur to achieve this task.

In particular, this study is divided into six sections, comprising (1) catalogue structure; (2) a general overview of model characteristics; (3) model potential to address MSFD GenS descriptors and indicators (including the ability to address biodiversity components and habitat types); (4) geographical coverage of models; (5) ability to address pressures; and (6) gaps in models type/modelling capability and needs for further development.

## 2. Catalogue structure

The catalogue has been built primarily with models/areas targeted by the DEVOTES partners (which represent 23 research institutions from EU and non EU countries), yet with an effort to integrate available models/areas from other inventories (e.g., the MEECE project <http://www.meece.eu/Library.aspx>) and scientific literature (see S1).

The catalogue has been structured with several fields following the MSFD Commission Decision 2010/477/EU (European Commission, 2010) and grouped into six main categories:

- i. Model/Indicator properties with the following sub-categories:
  - a. MSFD descriptor/indicator, descriptor/indicator outlined in the directive

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