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Capabilities of Baltic Sea models to assess environmental status for marine biodiversity

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ABSTRACT

To date there has been no evaluation of the capabilities of the Baltic Sea ecosystem models to provide information as outlined by the Marine Strategy Framework Directive. This work aims to fill in this knowledge gap by exploring the modelling potential of nine Baltic Sea ecosystem models to support this specific European policy and, in particular, models' capabilities to inform on marine biodiversity. Several links are found between the Model-Derived Indicators and some of the relevant biodiversity-related descriptors (i.e. biological diversity and food webs), and pressures (i.e. interference with hydrological processes, nutrient and organic matter enrichment and marine acidification). However several gaps remain, in particular in the limited representation of habitats other than the pelagic that the models are able to address for descriptor sea-floor integrity and inability to assess descriptor non-indigenous species. The general outcome is that the Baltic Sea models considered do not adequately cover all the requested needs of the MSFD, but can potentially do so to a certain extent, while for some descriptors/criteria/indicators/pressures new indicators and/or modelling techniques need to be developed in order to satisfactorily address the requirement of the MSFD and assess the environmental status of the Baltic Sea.

1. Introduction

The Directive 2008/56/EC, known as the Marine Strategy Framework Directive (MSFD), establishes a framework for community action in the field of marine environmental policy [1]. It was formally adopted by the European Union in July 2008. The MSFD outlines a legislative framework for an ecosystem-based approach to the management of human activities that supports the sustainable use of marine goods and services. The overarching goal of the Directive is to achieve Good Environmental Status (GEnS)[1] by 2020 across the European marine environment. The Directive defines GEnS as 'the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are intrinsically clean, healthy and productive, and the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for use and activities by current and future generations'. With the aim to support its implementation, the MSFD sets out in Annex I 11 qualitative *descriptors*[2] (D1-D11, Table 1), either state or pressure *descriptors*. Later, a Commission decision defines also 29 related *criteria* and 56 related *indicators* [4] that are used in the assessment of the status of the seas. An example of *criteria* and *indicators* defined for biological diversity (D1) is shown in Table 2.

With the aim to facilitate the implemention of the MSFD, Borja et al. [5] proposed an operational definition of GEnS, i.e. 'GEnS is achieved when physicochemical and hydrographical conditions are maintained at a level that main structuring components of the ecosystem are present, allowing the functionality of the system to provide resistance and resilience against deleterious effects of human pressures/activities/impacts, maintaining and delivering

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[1] Following the recommendation of Mee et al. [2] the acronym GEnS for Good Environmental Status is used here to discern from Good Ecological Status (GEcS) defined by the Water Framework Directive [3].

[2] *Descriptors/criteria/indicators/pressures* are here identified in italics when strictly referring to those defined by the Marine Strategy Framework Directive.

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Table 1
The 11 *descriptors* identified by the Marine Strategy Framework Directive and related number of *criteria* and *indicators*.

#	Type	*Descriptor*	# of *criteria*	# of *indicators*
D1	state	Biological diversity	7	14
D2	pressure	Non-indigenous species	2	3
D3	state	Exploited fish and shellfish	3	8
D4	state	Food webs	3	3
D5	pressure	Human-induced eutrophication	3	8
D6	state	Sea-floor integrity	2	6
D7	pressure	Hydrographical conditions	2	3
D8	pressure	Contaminants	2	3
D9	pressure	Contaminants in fish and seafood	1	2
D10	pressure	Litter	2	4
D11	pressure	Energy and noise	2	2

Table 2
D1 Biological diversity *descriptor* and related *criteria* and *indicators*.

Criteria	*Indicator*
1.1 Species Distribution	1.1.1 Distributional range
	1.1.2 Distributional pattern
	1.1.3 Area covered by the species
1.2 Population size	1.2.1 Population abundance and/or biomass
1.3 Population condition	1.3.1 Population demographic characteristics
	1.3.2 Population genetic structure
1.4 Habitat distribution	1.4.1 Distributional range
	1.4.2 Distributional pattern
1.5 Habitat extent	1.5.1 Habitat area
	1.5.2 Habitat extent
1.6 Habitat condition	1.6.1 Condition of the typical species and communities
	1.6.2 Relative abundance and/or biomass
	1.6.3 Physical, hydrological and chemical conditions
1.7 Ecosystem structure	1.7.1 Composition and relative proportion of ecosystem components

the ecosystem services that provide societal benefits in a sustainable way'. Despite the fact that several attempts have been made to assess the environmental status of marine waters in an integrative manner e.g. [6], significant gaps still remain for understanding marine ecosystem structures and functions and their response to human pressures e.g. [5]. There are several challenges related to the assessment of GEnS within the MSFD. The assessment of an ecosystem's health requires the setting of adequate reference conditions and/or environmental targets to which data should be compared [7]. The use of robust and appropriate indicators that can assess whether an ecosystem and its services are well maintained and sustainably used is one of the essential steps for the practical implementation of conservation and management policies such as the MSFD [8]. On the other hand, an accurate evaluation requires integrating knowledge across different ecosystem components and linking physical, chemical and biological aspects [9]. To this end, ecological models are a powerful tool for predicting and understanding the consequences of anthropogenic and climate-driven changes in the natural environment e.g. [10].

Within this framework, Piroddi et al. [11] assess the most commonly used capabilities of models in five regional European seas (North Sea, Baltic Sea, Mediterranean Sea, Black Sea and Bay of Biscay) to provide information about indicators outlined in the MSFD, particularly on biodiversity-related *descriptors*. They built a catalogue of European models and their derived indicators to assess which models are able to demonstrate the linkages between indicators and ecosystem structure and function, and the impact of pressures on ecosystem state through indicators. A brief summary of the models' catalogue is given in Section 2.1. Thus, Piroddi et al. [11] provide an extensive overview at pan-European scale. As the Baltic Sea is facing several health issues including an enlargement of the eutrophication problem [12] despite the adopted nutrient reduction measures [13], it was found relevant to investigate the Baltic Sea case in more details. To date there has been no evaluation of the capabilities of the ecosystem models of the Baltic Sea to provide information as outlined by the MSFD. This work aims to fill in this knowledge gap by providing a review of the capabilities of nine Baltic Sea ecosystem models to assess the environmental status of marine waters with particular focus on marine biodiversity. Yet, it is acknowledged that this study does not aim to serve as review of all the existing ecosystem models of the Baltic Sea, but instead highlights a process of exploring modelling potential to support this specific European policy. As in Piroddi et al. [11], models were analysed for potentially addressing the MSFD biodiversity-related *descriptors*: biological diversity (D1), non-indigenous species (D2), food webs (D4) and sea-floor integrity (D6). A short description of the characteristics of the Baltic Sea, the main features of the models and the criteria used for deriving indicators and assessing models' capabilities are given in Sections 2.2, 2.3 and, 2.4, respectively. The Baltic Sea Model-Derived Indicators (MDI) and their capabilities to inform on biodiversity-related *descriptors* and *pressures* are presented in Section 3.1, while Section 3.2 gives a more detailed analysis of the capabilities of each of the Baltic Sea models to address, potentially address or not address at all the biodiversity-related *indicators*. Finally, Section 4 highlights the current gaps between the MSFD and the models and suggests the use of different methods and tools as well as the development of new indicators and models to better link ecosystem models to the political framework of the MSFD.

2. Material and methods

2.1. The catalogue of european ecological models in brief

This section summarises the methodology used and the results gained from the analysis of the modelling capabilities of five European regional seas (North Sea, Baltic Sea, Mediterranean Sea, Black Sea and Bay of Biscay) to assess environmental status for marine biodiversity and presented in Piroddi et al. [11].

With the aim of developing new indicators and modelling tools to assess environmental status for marine biodiversity, it is necessary to initially evaluate the capabilities of the state-of-the-art models to do so. The work flow requires a series of sequential steps (Fig. 1). After the identification of the relevant *descriptors* in relation to marine biodiversity (biological diversity (D1) , non-indigenous species (D2) , food webs (D4) and sea-floor integrity (D6) with some relevance for commercial fish (D3) and human-induced eutrophication (D5)), the catalogue of European models that can specifically address these *descriptors* is produced (see the Supplementary material for a detail description of the structure of the catalogue). Every model output is then linked to relevant *descriptors* and related *criteria* and *indicators*, and MDI are then identified. Every MDI is then used for the assessment of its capability to relate to both *descriptors* (Table 1) and *pressures* (Table 3).

At European scale 44 ecological models were analysed for their capabilities to inform on the biodiversity-related *descriptors* [11, see Table 1]. The models are either operational i.e. tested and validated (24), or under development i.e. not yet validated (18), or conceptual (2). The type of models were grouped into 7 categories:

- biogeochemical: represents the dynamics and cycling of biogeochemical compounds of the lower trophic levels of the food web (1 model)
- meta-community: describe specific mechanistic processes to predict empirical community patterns, i.e. species composition and abundance (1)