DEVOTES
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Development of innovative tools for understanding marine biodiversity and assessing good environmental status

WP 4 Deliverable 4.1

Available models for biodiversity and needs for development

Deliverable 4.1

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Contents

1. Introduction

1.1. Rationale

The purpose of this report is to review the current capabilities of the modelling community to inform on indicators outlined in the Marine Strategy Framework Directive (MSFD), for biodiversity (D1), and food webs (D4) and seafloor integrity (D6), and, where possible, also non-indigenous species (D2).

Where models are available to the DEVOTES project team we also aim to utilize the models within the project to explore sensitivity of indicators of biodiversity to potential ecosystem change resulting from anthropogenic drivers and natural change. The goal is to determine which models are able to demonstrate: 1) the linkages between indicators and ecosystem structure and function; 2) the impact of pressures on state and thus indicators. Based on this knowledge, we report on gaps in model capability and suggest needs for development.

BOX 1. DEFINITION OF TERMS

Model name - (normally an acronym) refers to the label used to identify a particular model.

Model - is a representation of an ecological system (ranging from an individual population to an ecological community or even an entire biome), which is studied to gain understanding of the real system.

 # Model applicability - relates to the number of applications occurring using a particular model.

Model Type - refers to model characteristics/properties and/or to the technique used to assess specific ecosystem (e.g., remote sensing).

Model derived indicator - is an indicator resultant from a model output.

Status of development - In the context of this report, this was defined in relation to the development status of the model derived indicators:

- **Operational** when the indicator is developed, tested and validated;
- **Under development** an indicator proposal exists, but not yet validated in field/real data;
- **Conceptual** an indicator idea, supported by theoretical grounds, although no practical measure/metric is yet available.

1.2. Summary of achievements

1.2.1. Product 1. Catalogue of model-derived indicators

The catalogue compiled and presented in this report includes model derived indicators and an inventory of known models by regional sea. This Catalogue also drew upon the information collated through the previous EU project MEECE. The information collected here will steer some model development later in the project and potentially by others.

The current list of available model derived indicators together with the list of indicators currently in use across several national and international initiatives (described in the DEVOTES Deliverable 3.1, out by January 2014) constitute the full **DEVOTES Catalogue of Marine Biodiversity Indicators** suitable for addressing the MSFD biodiversity related descriptors (D1, D2, D4 & D6). In the near future, this catalogue will be available to the public in the DEVOTES Project website through the **DEVOTool** software currently under development (by MariLIM partner). The details on the current catalogue structure and fields are described in **Annex 1** of this report, while the list of model derived indicators so far compiled is presented as **Annex 2** and supported by a concise description of the underlying models (**Annex 3**).

1.2.2. Product 2. Ecosystem Model runs (MS14)

Indicators have been derived where possible from existing model simulations (including North Sea Ecosim with Ecopath-EwE and tGAM; Bay of Biscay OSMOSE and Ecopath; Ionian Sea EwE) and described in the Milsestone 14 (MS14) report. These runs have been uploaded to the partners' area of DEVOTES website and will be further used within the project (T4.1.2) to demonstrate the relationships between pressures, states and indicators.

1.3. Links to other DEVOTES project outputs and tasks

The current report links to DEVOTES Deliverable 3.1 on the Catalogue of Indicators. This second DEVOTES Catalogue provides the set of empirical indicators from which model derived indicators can be contrasted. Using the knowledge reported here in D4.1, we will apply models where possible temporally (Task 4.1.2) and spatially (T4.1.3 & T4.1.4) to link indicators, states and pressures. These models will then allow an assessment of how representative the pilot areas (WP6) are relative to the wider regional seas (T4.2.1) and enable a modelling study to determine reference levels for indicators and/or target levels or directions for indicators (T4.2.2).

2. Models and indicators to support biodiversity (D1), alien-species (D2), food-web (D4), and seafloor integrity (D6)

The first important step of DEVOTES WP4 was to critically evaluate all types of models built for the European Seas that had capabilities to assess, at least partially, indicators associated with MSFD descriptors mainly focusing on Biodiversity (D1) and Food webs (D4), but extending to Non-Indigenous Species (D2) and Seafloor integrity (D6) descriptors where possible. For this reason, we built the DEVOTES Model library with models describing either lower trophic level or higher trophic level organisms and processes and also the coupling between these two compartments. This inventory intended to build on the work of the MEECE FP7 project on the state of the art of marine ecosystem models (e.g., biogeochemical ROMS-NPZD and fisheries food-web models EwE) by highlighting the vast potential of model derived indicators that can be associated to MSFD descriptors and conducting a thorough assessment of their status and quality.

2.1. MEECE model library – a quick review

The MEECE library was a deliverable from the FP7 project called “Marine Ecosystem Evolution in a Changing Environment” (MEECE) launched in 2008 and concluded in 2013, aimed at investigating the responses of marine ecosystems to both climate change and anthropogenic activities (MEECE, 2013). The Model Library (http://www.meece.eu/Library.aspx) was built to help identify the suite of modelling tools (targeting major trophic components of the marine ecosystem, from phytoplankton to higher trophic level organisms) that could assess the ecosystem status relative to environmental and anthropogenic pressures. In the library, the models (Table 1) are described with their technical support guides and related metadata that empower scientists to assess the modelled responses of selected marine ecosystems to multiple drivers (ocean circulation, ocean climate, ocean acidification, eutrophication, pollution, fishing and alien invasive species). One model has been implemented for a global system while the others have been built for six European regions (Barents and Nordic Sea; NE Atlantic; Baltic Sea; Black Sea; Adriatic Sea and North Aegean Sea) and one non-European region (Benguela upwelling). During MEECE, models outputs were also associated to 7 of the 11 descriptors (D1, D2, D3, D4, D5, D7, D8) for Good Environmental Status (GEnS) of the EU’s MSFD. Standardised example model outputs and descriptions under a number of different future scenarios for the different regions can also be seen in the interactive MEECE Atlas (http://www.meeceatlas.eu/Menu/).

2.1.1. Linkages between DEVOTES and MEECE libraries and new developments

One of the goal of the DEVOTES Models library was to improve and develop further the work of the MEECE FP7 project on the state of the art of marine ecosystem models (Table 1), not only by increasing its list of models but also by focusing on model derived indicators with a thorough assessment on their quality and ability to inform on MSFD descriptors/criteria. To summarize, DEVOTES library has succeeded in:

a. Increasing the list of models (up to 44) at the European scale. All MEECE models were included with the exception of NEMO-PISCES-APECOSM and the Individual based model (IBM);
b. Extending the geographic scope where those models have been implemented;
c. Linking the model derived indicators to all 11 MSFD descriptors with an emphasis on D1, D2, D4, D6;
d. Linking the model derived indicators specifically to biodiversity components (e.g., phytoplankton, fish, marine mammals) and habitat type (e.g., coastal, shelf, ocean);
e. Associating pressures and model-derived indicators.

As a result, the DEVOTES library is more complex and details a set of finer scale model-derived indicators that is more suitable to evaluate model capability with respect to biodiversity assessment.

2.2. Model derived indicators that may support the MSFD

The DEVOTES Catalogue of model derived indicators is analysed here from a broad perspective to explore models' general characteristics (Section 2.2.1) and their potential to address MSFD GEnS Descriptors (2.2.2). An evaluation of the model's capability for modelling the assessment criteria and indicators for the biodiversity related descriptors: D1, D2, D4 and D6 outlined in the EU Com Dec (2010) is also given, which draws upon the detailed knowledge of the model implementations in the regional seas (**Annexes 3** and **4**). The geographical coverage of the models (2.2.3), the biodiversity components and habitats they are relevant to (2.2.4) and the pressures (**Annex 5**) they are capable of responding to (2.2.5) are also subject of this initial overview. Models require data to validate their capabilities and the catalogue highlights those importance sources of data from existing monitoring programs for modelling approaches: where these same data are used to determine indicators empirically, the models are likely to be of particular relevance and we show here for which conventions this is the case (2.2.6). For further details and scrutiny of the catalogue content or properties refer to **Annexes 1** and **2** of this report.

2.2.1. General overview of DEVOTES catalogue models' characteristics

The DEVOTES models library (defined as the "catalogue") revealed that currently 44 models have been deployed with outputs relevant to MSFD descriptors, an estimate that surpasses those in the initial MEECE model library (Table 1). Particular attention has been focused on the areas targeted by the DEVOTES project and some areas, for example the northern Celtic Seas, are not fully represented. However, the library intends to be a 'living document' that will be updated and extended over time. Of the models described, more than half were coupled ecosystem models with 65% being hydrodynamic-biogeochemical models and 35% lower trophic level models coupled with higher trophic level models. The remaining were niche/habitat suitability models (38%), remote sensing and food web models (29% each), and one biogeochemical model (5%). From an overall perspective, the most common type of models currently in the catalogue are hydrodynamic-biogeochemicals models (34%) followed by habitat suitability models and coupled low and high trophic level models (18% each), remote sensing and food web models (14%) followed by a biogeochemical model (2% each) (Table 1). Regarding data type, coupled and remote sensing models were primarily spatial-dynamic (5 out of 30 models were temporally dynamic only). The remaining models (niche and food web models) were mainly represented by their static component (only 4 and 1 model out of 14 models had dynamic and spatial components respectively) (Table 1). Half of the model derived indicators available in the DEVOTES catalogue are considered to be operational while the other half are largely still under development, with only a few conceptual approaches presented (Table 3) (for definitions on the "status of development" of the models check the guidelines in **Annex 1**). In addition, not all the models were able to address uncertainty; the majority (61%) lacked an approach to determine confidence intervals/range of uncertainty or required further validation work for indicators. From the models that attempted to address uncertainty (39%), data comparison and data validation was the most common method reported (Table 1).

Table 1. Summary table of MEECE and DEVOTES models libraries. For the DEVOTES models showing also models' name and type (Coupled: hydrodynamic-biogeochemical and hydrodynamic-biogeochemical-higher trophic levels system; Biog: biogeochemical; Niche: niche and habitat suitability), data type (SP: spatial; DY: dynamic; ST: static), number of model derived indicators and uncertainty (VOD: validated with observed data; VOD*: some of the indicators still need to be validated with observed data; NA: not available; STAT: statistical analysis; BOOT: bootstrap; PE: pedigree).

	DEVOTES Model name	In MEECE library?	Model type	Data type	Model derived indicators	Uncertainty
1	BALTSEM		Coupled	SP-DY	7	VOD
2	BFM-POM	yes	Coupled	SP-DY	5	NA
3	Black Sea coupled hydrod. and biog. model		Coupled	SP-DY	13	VOD* - STAT
4	Ecopath with Ecosim	yes	Food web	ST-DY-SP	136	PE - VOD*
5	ECOSMO	yes	Coupled	SP-DY	6	NA
6	ECOSMO-SMS	yes	Coupled	SP-DY	2	NA
7	ENFA (Ecological Niche Factor Analysis)		Niche	ST	1	NA
8	ERGOM+MOM		Coupled	SP-DY	7	VOD
9	ERGOM+MOM+fish model		Coupled	DY	2	VOD
10	ERSEM		Biog	SP-DY	2	VOD
11	ERSEM-POM	yes	Coupled	SP-DY	11	NA
12	ERSEM-POM-OSMOSE	yes	Coupled	SP-DY	10	NA
13	Bay of Biscay GAM		Niche	ST	1	NA
14	GETM-ERGOM		Coupled	SP-DY	8	VOD*
15	GETM-ERSEM		Coupled	SP-DY	16	VOD*
16	Bay of Biscay GLM		Niche	ST	1	NA
17	GOTM-ERSEM-EWE		Coupled	DY	6	NA
18	EU Hubbell's neutral model		Niche	ST	1	NA
19	IOPs model		Remote sensing	SP-DY	3	VOD
20	LeMANS		Food web	DY	2	VOD
21	MaxEnt (Maximum Entropy)		Niche	ST	2	NA
22	MOHID – LIFE		Coupled	SP-DY	4	VOD*
23	NEMO-BFM		Coupled	SP-DY	10	VOD
24	North Sea optical properties		Remote sensing	DY	1	STAT
25	North Sea tGAM		Food web	DY	4	BOOT
26	NORWECOM.E2E	yes	Coupled	SP-DY	6	NA
27	NTM		Niche	ST	1	NA
28	PDMM		Food web	DY	1	VOD
29	POLCOMS-ERSEM	yes	Coupled	SP-DY	6	NA
30	POM-BIMS-ECO	yes	Coupled	DY	4	NA
31	POM-BIMS-ECO-EWE	yes	Coupled	DY	3	NA
32	Process-driven habitat template		Niche	ST	1	NA
33	PSD (PSC) model		Remote sensing	SP-DY	3	VOD
34	Qualitative trophic model		Food web	ST	1	NA
35	RCO-SCOBI		Coupled	SP-DY	7	VOD
36	Regional Chl model		Remote sensing	SP-DY	4	VOD*
37	Regional model of downwelling radiance		Remote sensing	SP-DY	1	VOD
38	Regional spectral PP model		Remote sensing	SP-DY	1	VOD*
39	ROMS-BioEBUS	yes	Coupled	SP-DY	6	NA
40	ROMS-BioEBUS-OSMOSE	yes	Coupled	SP-DY	5	NA
41	ROMS-N2P2Z2D2	yes	Coupled	SP-DY	12	NA
42	ROMS-N2P2Z2D2-OSMOSE	yes	Coupled	SP-DY	12	NA
43	SMS	yes	Food web	DY	2	VOD
44	SPBEM		Coupled	SP-DY	7	VOD
--	*Not in DEVOTES*	IBM	--	--	--	--
--	*Not in DEVOTES*	NEMO-PISCES-APECOSM	--	--	--	--

A total of 201 indicators (consult **Annex 2** for a detailed list) were inserted in the catalogue, of which 64% were "operational", 33% "under development" and 3% "conceptual" (see BOX 1. Definition of terms). From a model perspective, EwE stood out for the great number of model-derived biodiversity indicators produced (Table 1), even though the majority were biomasses by species or groups of species for each trophic level of the food web. Model-derived indicators were grouped into eight major categories (Table 2): the "Biodiversity indices" category included indicators such as Kempton diversity index and Trophic level of the community, while under "Species life-history" traits were included, for example, length, weight or life span. This categorization helped to evaluate the types of indicators produced by models but also to assess model capabilities in relation to the set of indicators provided by WP3. Not surprisingly, biomass indicators constituted the largest group with a percentage around 57% followed by physical, hydrological and chemical indicators (12%) and biodiversity indices (11%) (Table 2).

Table 2. The Model derived indicators grouped into 8 major categories with their overall percentages in the DEVOTES Model Library.

	Types of indicators	%
1	Biomass	57
2	Biodiversity indices	11
3	Primary or secondary production	9
4	Species/habitat diversity, proportions in community	2
5	Species distribution	6
6	Species life-history	1
7	Flows, energies and efficiencies	2
8	Physical, hydrological and chemical	12

Regarding target and/or reference values associated with these indicators, the catalogue highlights that only a few models in a few areas had assigned a target and/or reference value to their indicators despite the fact that the majority were "operational" (i.e. developed, tested and validated). Further work in DEVOTES (T4.2.2) will identify and develop methods to define targets for a selection of ecosystem models.

NOTE: Models' short description - A short description of the models included in the DEVOTES Catalogue of Model-derived Indicators is given in Annex 3.

2.2.2. Models' potential to address MSFD GEnS descriptors/ and assessment criteria and indicators for D1/D2/D4/D6 (EU COM Dec 2010/477/EU)

The 44 models available in the DEVOTES Catalogue are capable of addressing indicators in 8 of the 11 descriptors of the MSFD (Table 3). Their modelling potential is stronger for two of the biodiversity related GEnS descriptors, Biological Diversity (D1) and Food webs (D4), although not targeted by this study, descriptors such as Human Induced Eutrophication (D5), Hydrographical Conditions (D7) and Commercial Fish and Shellfish (D3), can also be assessed by a substantial number of these models. Within the biodiversity related GEnS descriptors, which was the focus of this survey on modelling approaches, the Non-indigenous Species (D2) and Seafloor Integrity (D6) are the most poorly tackled by the models currently in the catalogue (Table 3). However, Pinnegar *et al.* (in review) shows how EwE models can be used to assess how an ecosystem may respond to the introduction of an invasive species (D2). The assessment criteria and indicators under these descriptors are on the other hand better covered by empirical approaches compiled under the WP3 Catalogue of Indicators. In general, a single model is capable of addressing more than one descriptor, sometimes up to six MSFD descriptors as is the case of EwE (Table 3). As a result the same model may be indicated in multiple stages of development, either across descriptors or within the same descriptor. This is because the reported status of development relates not to the model itself but to the different indicators that can be derived from the model.

Table 3. Models available *per* GEnS descriptor and their development status in respect to each descriptor (op: operational, ud: under development, co: conceptual), with particular emphasis on the number of operational indicators *per* model under each descriptor and the overall number of COM Dec. Criteria / Indicator that each model can inform on for biodiversity related Descriptors (D1, D2, D4, D6).

MSFD descriptors / **Models**	**D1** Biological diversity	**D2** Non-indigenous species	**D3** Commercial fish	**D4** Food webs	**D5** Human induced eutrophication	**D6** Seafloor integrity	**D7** Hydrological alteration	**D8** Contaminants	**D9** Contaminants in food	**D10** Marine litter	**D11** Energy/Noise	**Com Dec Indicators (under D1,D2,D4,D6) addressed**
Number of models	*44*	*3*	*17*	*43*	*26*	*5*	*17*	*0*	*1*	*0*	*0*	
BALTSEM	7 op			5 op	3 op		2 op					16
BFM-POM	5 op			3 op	2 op		2 op					14
Black Sea coupled hydrodynamics and biogeochemical	5 op /ud	ud		ud	ud		3 op					9
Ecopath with Ecosim	82 op /ud /co	ud	53 op /ud /co	82 op /ud /co	13 op /ud /co	17 op /ud /co						13(+1*)
ECOSMO	6 op			3 op	2 op		3 op					14
ECOSMO-SMS	ud		ud	ud								8
ENFA (Ecological Niche Factor Analysis)	1 op		1 op	1 op								14
ERGOM+MOM	7 op			5 op	3 op		2 op					16
ERGOM+MOM+fish model	2 op		2 op	2 op								7
ERSEM	ud			ud	ud							12
ERSEM-POM	11 op			6 op	3 op		5 op					14
ERSEM-POM-OSMOSE	ud		ud	ud								9
Bay of Biscay GAM	1 op		1 op	1 op								16
GETM-ERGOM	ud			ud	ud		ud					14
GETM-ERSEM	ud			ud	ud	ud	ud					19
Bay of Biscay GLM	1 op		1 op	1 op								16
GOTM-ERSEM-EWE	ud		ud	ud					ud			8
EU Hubbell's neutral model	co			co	co	co						16
IOPs model	ud			ud	ud							8
LeMANS	2 op		2 op	2 op								7
MaxEnt (Maximum Entropy)	2 op	1 op	1 op	2 op								17
MOHID – LIFE	4 op			3 op	3 op		1 op					10
NEMO-BFM	ud			ud	ud		ud					17
North Sea optical properties	ud			ud	ud							8
North Sea tGAM	ud		ud	ud	ud							10
NORWECOM.E2E	6 op			3 op	2 op		3 op					14
NTM	ud			ud		ud						9
PDMM	1 op		1 op	1 op								7
POLCOMS-ERSEM	6 op			3 op	2 op		3 op					14
POM-BIMS-ECO	4 op			3 op	2 op		1 op					14
POM-BIMS-ECO-EWE	ud		ud	ud								9
Process-driven habitat template	ud			ud		ud						11
PSD (PSC) model	ud			ud	ud							5
Qualitative models	co		co	co								8(+1*)
RCO-SCOBI	7 op			5 op	3 op		2 op					16
Regional Chl model	ud			ud	ud							6
Regional model of downwelling radiance	ud											3
Regional spectral PP model	ud			ud	ud							3
ROMS-BioEBUS	6 op			3 op	2 op		3 op					14
ROMS-BioEBUS-OSMOSE	ud		ud	ud								9
ROMS-N2P2Z2D2	12 op			8 op	5 op		4 op					13
ROMS-N2P2Z2D2-OSMOSE	12 op		12 op	12 op								11
SMS	2 op		2 op	2 op								7
SPBEM	7 op			5 op	3 op		2 op					16

* New proposals for Descriptor 4 *Food Webs*, not yet considered under the set of Criteria / Indicators outlined in the Com Dec. 2010.

The models could be grouped into six main broad categories (Table 4), from which Coupled models, Food webs and Niche/habitat suitability related models are those more capable of informing on a higher number of descriptors, including the four biodiversity related descriptors.

Table 4. Type of models identified (highlighted in grey) by Descriptor; biodiversity related descriptors highlighted in blue.

Type of Models	D1 Biological diversity	D2 Non-indigenous species	D3 Commercial fish	D4 Food webs	D5 Human induced eutrophication	D6 Seafloor integrity	D7 Hydrological alteration	D8 Contaminants	D9 Contaminants in food	D10 Marine litter	D11 Energy/Noise
Biogeochemical	■			■	■						
Food webs	■	■	■	■	■	■					
Niche-space/habitat suitability/community	■	■	■	■	■	■					
Remote sensing	■			■	■						
Coupled models (integrating at least 2 of the above approaches)	■	■	■	■	■	■	■		■		

The models' potential to address MSFD GEnS assessment criteria and indicators specifically for D1/D2/D4/D6 was evaluated by extracting the number of indicators outlined in the Com Dec. (2010) that each model can inform on (Table 3). Every model documented can address multiple indicators, from the set of 27 indicators, under these 4 descriptors. In fact, 20 models in the catalogue have the potential to address at least half of these indicators. Despite the models high potential to address MSDF Com. Dec. criteria/indicators, not all of the model-derived indicators available are fully operational. An overview of the operational indicators available in the catalogue *per* criteria/indicators and the number of models providing those indicators is provided in Table 5. Our analysis also revealed that there are three criteria/indicators required under the biodiversity descriptors for which no model derived indicators are available in the catalogue (Table 5). On the other hand, it should be noticed that the potential of modelling approaches to address ecosystem fundamental properties such as "Interactions between structural components" and "Services provided" (respectively D1C8I1 and D1C8I2 in Table 5) is high. These aspects despite being clearly mentioned in the Com Dec. text are not part of the criteria/indicators set due to the difficulty to define them through specific indicators. Nevertheless, the majority of the model-derived indicators included in this catalogue (189 out of the 201 model-derived indicators) do have the capability to inform on these complex, integrative ecosystem dimensions.

Table 5. Indicators and models available per Descriptor / Criteria / Indicator for biodiversity related descriptors (D1, D2, D4, D6), with particular emphasis on the number of operational indicators (op) out of the indicators available for each Com. Dec. indicator (I).

Descriptor	**Criteria**	**Indicator**	**Model derived indicators from DEVOTES catalogue**		**comments**
			operational/available indicators	# models	
D1	C1	I1 Distributional range	33 op / 45	27	
D1	C1	I2 Distributional pattern within range	4 op / 10	15	
D1	C1	I3 Area covered by the species (for sessile/benthic species)	1 op / 2	5	
D1	C2	I1 Population (1) abundance and/or (2) biomass	93 op / 163	37	
D1	C3	I1 Population demographic characteristics: (1) body size; (2) age class structure; (3) sex ratio; (4) fecundity rates; (5) survival/mortality rates; (6) other	14 op / 37	15	
D1	C3	I2 Population genetic structure	no indicators available	no models available	*D1 Biodiversity/C3 Population condition*
D1	C4	I1 Distributional range	6 op / 9	21	*The exact same indicators are proposed as suitable to address both I1 and I2 from D1C4 Com Dec.*
D1	C4	I2 Distributional pattern	6 op / 9	21	
D1	C5	I1 Area	6 op / 7	20	*Practically the same indicators as above are also indicated as suitable to address both I1 and I2 from D1C5 Com Dec.*
D1	C5	I2 Volume	4 op / 4	15	
D1	C6	I1 Condition of the typical (1) species and (2) communities	89 op / 174	39	
D1	C6	I2 Relative (1) abundance and/or (2) biomass	11 op / 25	7	
D1	C6	I3 (1) Physical, (2) Hydrological and (3) Chemical conditions	12 op / 39	23	
D1	C7	I1 Composition of ecosystem components: (1) habitats and (2) species	96 op / 168	39	
D1	C7	I2 Relative proportions of ecosystem components: (1) habitats and (2) species	100 op / 186	43	
D1	(C8)	I1 Interactions between structural components	108 op / 198	44	*Not defined but guidance extracted from text under Com Dec.*
D1	(C8)	I2 Services provided	105 op / 183	39	

scr ipt	Cri ter ia	Indicator	Model derived indicators from DEVOTES catalogue		comments
D2	C1	I1 Trends in: (1) abundance; (2) temporal occurrence; (3) spatial distribution	1 op / 4	3	
D2	C2	I1 Ratio between invasive non-indigenous species and native species	no indicators available	no models available	*D2 Non-indigenous species/ C2 Environmental impact of invasive non-indigenous species*
D2	C2	I2 Impacts of non-indigenous invasive species at the level of (1) species, (2) habitats and (3) ecosystem	no indicators available	no models available	
D4	C1	I1 Performance of (1) key predator species determined from their productivity; (2) other trophic group	3 op / 7	19	
D4	C2	I1 (1) Large fish (by weight); (2) other species	18 op / 40	10	
D4	C3	I1 Abundance trends of functionally important selected: (1) groups with fast turnover rates; (2) groups/species that are targeted by human activities or that are indirectly affected by them; (3) habitat-defining groups/species; (4) groups/species at the top of the food web; (5) long-distance anadromous and catadromous migrating species; (6) groups/species that are tightly linked to specific groups/species at another trophic level	100 op / 181	42	
D4	*(C4)**	*(not defined)**	none operational / 3	2	*D4 Food webs: new proposals*
D6	C1	I1 Biogenic substrate: (1) type; (2) abundance; (3) biomass; (4) areal extent	2 op / 5	6	
D6	C1	I2 Extent of seabed significantly affect by human activities for the different substrate types	none operational / 1	1	
D6	C2	I1 Presence of particularly sensitive and/or tolerant species	none operational / 1	1	
D6	C2	I2 Multi-metric indexes assessing benthic community condition and functionality, such as (1) species diversity and (2) richness, (3) proportion of opportunistic to sensitive species	1 op / 4	6	
D6	C2	I3 Proportion of (1) biomass or (2) number of individuals in the macrobenthos above some specified length/size	17 op / 38	3	
D6	C2	I4 Parameters describing the characteristics (shape, slope and intercept) of the size spectrum of the benthic community	none operational / 1	1	

* New proposals for Descriptor 4 Food webs, not considered under the set of Criteria / Indicators outlined in the Com Dec. 2010.

2.2.3. Models' geographical coverage

Ecological modelling is used worldwide and models have been implemented for the marine environment at a range of spatial scales. The models contained in the DEVOTES catalogue have not been applied with the same intensity to all regional seas (Table 6). The majority of indicators reported relate to the Mediterranean Sea, with more than half of the indicators entered in the catalogue (137), followed by the North-East Atlantic Ocean (78 indicators), Black Sea (29), Baltic Sea (18), non-EU regional seas (11) and EU scale (2) (Table 6).

Table 6. Number of model-derived indicators in the different mandatory EU regional seas as in MSFD.

Baltic sea	
Model	Indicators
BALTSEM	7
Ecopath with Ecosim	6
ECOSMO	6
ECOSMO-SMS	2
ERGOM+MOM	7
ERGOM+MOM+fish model	2
NEMO-BFM	10
RCO-SCOBI	7
SMS	2
SPBEM	7
Grant Total	18

Mediterranean Sea	
Model	Indicators
BFM-POM	5
Ecopath with Ecosim	122
ERSEM-POM	11
ERSEM-POM-OSMOSE	10
GETM-ERGOM	8
Grand Total	137

North-East Atlantic Ocean	
Model	Indicators
Ecopath with Ecosim	26
ECOSMO	6
ENFA	1
ERSEM	2
Bay of Biscay GAM	1
GETM-ERSEM	16
Bay of Biscay GLM	1
GOTM-ERSEM-EWE	6
LeMANS	2
MaxEnt (Maximum Entropy)	1
MOHID - LIFE	4
North Sea optical properties	1
North Sea tGAM	4
NORWECOM.E2E	6
NTM	1
PDMM	1
POLCOMS-ERSEM	6
Process-driven habitat template	1
Qualitative models	1
ROMS-$N_2P_2Z_2D_2$	12
ROMS-$N_2P_2Z_2D_2$-OSMOSE	12
SMS	2
Grand Total	78

Black Sea	
Model	Indicators
Black Sea coupled hydrodynamics and biogeochemical model	13
IOPs model	3
POM-BIMS-ECO	4
POM-BIMS-ECO-EwE	3
PSD (PSC) model	3
regional Chl model	4
Regional model of downwelling radiance	1
regional spectral PP model	1
Grand Total	29

Non-EU regional seas	
Model	Indicators
ECOSMO	6
ROMS-BioEBUS	6
ROMS-BioEBUS-OSMOSE	5
Grand Total	11

All European Seas	
Model	Indicators
EU Hubbell's neutral model	1
MaxEnt (Maximum Entropy)	1
Grand Total	2

The EwE software is the most widely used model and has been applied in each regional seas area and for most subregions with the exception of the non-EU subregions of the North-East Atlantic Ocean and other non-regional seas (Table 7). The second most commonly used model was ECOSMO, which has been implemented for the Baltic Sea, the North-East Atlantic Ocean and one non-EU regional Sea (Barents Sea). In most regional seas the proportion of model derived indicators considered operational was high (varying between 60 and 80%) but in the Black Sea a suite of ecological models are being developed and thus model derived indicators were generally under development (about 70%; Table 7). Conceptual models were underrepresented and mainly reported for the North-East Atlantic Region. As stated by the MSFD, Member States need to cooperate to ensure a coordinated effort in the study and development of management strategies for the different marine regions and subregions. This is the case of ecological models developed for understanding and forecasting the marine ecosystem response to pressure. The Devotes catalogue demonstrates that the geographical coverage of the ecological models in European marine waters is great and that the assessment of GEnS can benefit greatly from greater use of ecological modelling.

Table 7. Model derived indicators per each model type and per each marine region/subregion in relation to their state of development (Op: operational, Ud: under development, Co: conceptual).

Marine Region	Marine sub-region	Model name	Op	Ud	Co	Total
Baltic Sea	All Baltic Sea	BALTSEM	7			18
		Ecopath with Ecosim	6			
		ECOSMO	6			
		ECOSMO-SMS		2		
		ERGOM+MOM	7			
		ERGOM+MOM+fish model	2			
		NEMO-BFM		10		
		RCO-SCOBI	7			
		SMS	2			
		SPBEM	7			
North-East Atlantic Ocean	Greater North Sea, incl.Kattegat, English Channel	Ecopath with Ecosim		11	3	46
		ECOSMO	6			
		ERSEM		2		
		GETM-ERSEM		16		
		GOTM-ERSEM-EWE		6		
		LeMANS	2			
		North Sea optical properties		1		
		North Sea tGAM		4		
		PDMM	1			
		POLCOMS-ERSEM	6			
		SMS	2			
	Celtic Seas	Ecopath with Ecosim			2	3
		PDMM	1			
	Bay of Biscay and Iberian Coast	Ecopath with Ecosim		15	5	53
		ENFA (Ecological Niche Factor Analysis)	1			
		Bay of Biscay GAM	1			
		Bay of Biscay GLM	1			

Marine Region	Marine sub-region	Model name	Op	Ud	Co	Total
		MaxEnt (Maximum Entropy)	1			
		MOHID - LIFE	4			
		NTM		1		
		Process-driven habitat template		1		
		Qualitative models			1	
		ROMS-$N_2P_2Z_2D_2$	12			
		ROMS- $N_2P_2Z_2D_2$-OSMOSE	12			
	non-EU (Norwegian Sea)	NORWECOM.E2E	6			6
Mediterranean Sea	Northern Spain	Ecopath with Ecosim	58	23		71
	Adriatic Sea	BFM-POM	5			50
		Ecopath with Ecosim	40	7		
	Ionian Sea	Ecopath with Ecosim	17	8		24
	Aegean Sea	Ecopath with Ecosim	34	3		53
		ERSEM-POM	11			
		ERSEM-POM-OSMOSE		10		
	non-EU (Gulf of Gabes)	Ecopath with Ecosim	6	24	1	31
	All Med. Sea	Ecopath with Ecosim		23		29
		GETM-ERGOM		8		
Black Sea	All Black Sea	POM-BIMS-ECO	4			29
		POM-BIMS-ECO-EWE		3		
		Black Sea coupled hydrodynamics and biogeochemical model	5	8		
		IOPs model		3		
		PSD (PSC) model		3		
		regional Chl model Total		4		
		Regional model of downwelling radiance		1		
		regional spectral PP model		1		
non-EU regional seas	Barents Sea and Benguela	ECOSMO	6			11
		ROMS-BioEBUS	6			
		ROMS-BioEBUS-OSMOSE		5		
Europe	All EU regions	EU Hubbell's neutral model			1	2
		MaxEnt (Maximum Entropy)	1			
Grand Total			**293**	**203**	**13**	**424**

2.2.4. Models' coverage of Biodiversity components and habitats types

Habitats and species are key attributes of biological diversity, and their occurrence, distribution and abundance is used as criteria to assess GEnS. To attain GEnS for D1 no further loss of biodiversity at ecologically relevant scale should occur or if it does restoration measures should be in place. Biodiversity components and habitat types will be assessed in relation to the objectives set in the directive. The definition of GEnS is dependent on the ecological relevance and is approached at different levels, from species specific level to habitat/community and ecosystem level. Predominant habitat types should include the relevant ecological zones, seabed habitats, water column habitats and ice habitats. Specific subhabitats were analysed by the DEVOTES models (**Annex 2**); however, not all the possible subhabitats were addressed by the models. Biodiversity components included microbes, phytoplankton, zooplankton, angiosperms, macroalgae, benthic invertebrates, fish, cephalopods, marine mammals, reptiles and birds, with specific subgroups within the last four categories. These components are described in detail for the regional seas in **Annex 4** along with their inclusion in specific implementations of ecosystem models. Here we evaluate the overall coverage of such components by the available ecosystem models included in the Devotes catalogue. Of the eleven biodiversity components assessed, operational models delivered the majority of indicators for fish, phytoplankton, zooplankton, invertebrates and marine mammals (total 64, 45, 31, 23, and 17 respectively). The remaining biodiversity components were covered with less than 10 indicators each (Table 9). As expected, different models evaluated components differently. EwE model derived indicators, either operational, conceptual or still under development, accounted for all type of biodiversity component (the only exception is for microbes) with fish being the most assessed (25%) followed by benthic invertebrates (15%), marine mammals (12%) and cephalopods (11%). The microbes component was only evaluated by ERESME-POM and under development by NEMO-BFM (Table 9).

Table 9. Biodiversity components per each ecosystem models organised by their indicator status. Numbers represent derived indicators associated to a biodiversity component per each model type. Op: operational, Ud under development, Co: conceptual.

Status of indicator/ model	Model name	Microbes	Phytoplankton	Zooplankton	Angiosperms	Macroalgae	Benthic/ Pelagic invertebrates	Fish	Cephalopods	Marine mammals	Reptiles	Birds
Operational	BALTSEM		3	2								
	BFM-POM		2	1								
	Ecopath with Ecosim		11	10	4	1	19	41	11	12	5	7
	ECOSMO		2	1								
	ENFA (Ecological Niche Factor Analysis)					1	1	1		1		
	ERGOM+MOM		3	2								
	ERGOM+MOM+fish model							2				
	ERSEM-POM	1	3	2								
	Bay of Biscay GAM			1		1	1	1		1		
	Bay of Biscay GLM					1	1	1		1		
	LeMANS							2				
	MaxEnt (Maximum Entropy)					2	1	1		1		
	MOHID - LIFE		2	1								
	NORWECOM.E2E		2	1								
	PDMM							1				
	POLCOMS-ERSEM		2	1								
	POM-BIMS-ECO		2	1								
	RCO-SCOBI		3	2								
	ROMS-BioEBUS		2	1								
	ROMS-$N_2P_2Z_2D_2$		5	3								
	ROMS-$N_2P_2Z_2D_2$-OSMOSE							12				
	SMS							2		1		1
	SPBEM		3	2								
	Total	**1**	**45**	**31**	**4**	**6**	**23**	**64**	**11**	**17**	**5**	**8**
Under development	Black Sea coupled hydrodynamics and biogeochemical model		4	4								
	Ecopath with Ecosim		19	20	12	9	32	49	27	27	6	19
	ECOSMO-SMS							2				
	ERSEM		1	1								
	ERSEM-POM-OSMOSE							10				
	GETM-ERGOM		1	1								
	GETM-ERSEM		3	1			1					
	GOTM-ERSEM-EWE						1	4		1		
	IOPs model		2									
	NEMO-BFM	1	4	2								
	North Sea optical properties		1									
	North Sea tGAM		1	1				2				2
	NTM						1	1	1			
	POM-BIMS-ECO-EWE							3				
	Process-driven habitat template						1					
	PSD (PSC) model		3									
	regional Chl model		4									
	Regional spectral PP model		1									
	ROMS-BioEBUS-OSMOSE							5				
	Total	**1**	**44**	**30**	**12**	**9**	**36**	**76**	**28**	**28**	**6**	**21**
Concept ual	Ecopath with Ecosim		5	7	1	1	6	5	5	5	1	1
	EU Hubbell's neutral model		1	1			1					
	Qualitative models							1				
	Total	**0**	**6**	**8**	**1**	**1**	**7**	**6**	**5**	**5**	**1**	**1**

When models were organized regarding the type of model, food-web models were the ones that assessed most of the biodiversity components; with the exception of the microbes that were mostly evaluated by coupled models (Table 10). Coupled and niche models evaluated also a large number of the biodiversity components; the only exceptions were angiosperms, macroalgae, cephalopods, reptiles and birds for coupled models and microbes, angiosperms, reptiles and birds for niche models. Biogeochemical and remote sensing models were the least inclusive models in terms of the number of components evaluated: phytoplankton, zooplankton in biogeochemical model and only phytoplankton in remote sensing models (Table10).

Table 10. Types of models (see BOX 1. for definitions) evaluating the different biodiversity components; numbers represent total model derived indicators per biodiversity component and per type of model.

Biodiversity component		Model Type				
		Biog.	Coupled	Food web	Niche	Remote sensing
Microbes			**2**			
Phytoplankton		1	9	30	1	12
Zooplankton		1	8	29	2	
Angiosperms				14		
Macroalgae				11	2	
Benthic/ Pelagic invertebrates			2	46	4	
Fish	**Other**		6	30	2	
	Coastal fish		2			
	Pelagic fish		13	22		
	Pelagic elasmobranchs		1	4		
	Demersal fish		6	22		
	Demersal elasmobranchs			3		
Cephalopods	**Coastal/shelf pelagic**			20		
	Other			15	1	
Marine mammals	**Toothed whales**		1	24		
	Baleen whales			2		
	Seals			3		
	Other			9	1	
Reptiles	**Sea-turtles**			11		
Birds	**Inshore pelagic-feeding**			13		
	Offshore pelagic-feeding			2		
	Other			10		

The predominant habitat types that should be assessed within the evaluation of GEnS under the MSFD are water-column, sea-bed and ice habitats. Ecosystem models referred to one or several of these habitats. Of all predominant habitats, the water-column was the most comprehensively evaluated habitat on its own or in relation to the other two habitats. Only in two instances seabed habitats were evaluated on their own. When considering the broad model type, ice-associated habitats were assessed by coupled models and food web models while seabed habitats were evaluated in food-web and niche models. Food-web as well as coupled models were mainly used for the assessment of species that can be linked to water-column habitats (Table 11).

Table 11. Model derived indicators per type of model and predominant habitat: seabed, water-column and ice-associated habitats.

Type of the model	Seabed	Water column	Ice habitats
Biogeochemical		2	
Coupled		67	12
Food web	14	142	6
Niche	3	5	
Remote sensing		12	

Examining the intersection between model derived indicators and habitats, we note that water column was the most widely covered habitat, specifically the marine shelf where all components of biodiversity were covered. The marine oceanic water column was also widely studied; however, in this case microbes were not evaluated (Table 12). Shallow sublittoral mixed sediments were also frequently evaluated for 7 of the 11 biodiversity components. Not surprisingly, all components of biodiversity were more often modelled in the water column above the continental shelf (Table 12). In estuaries, only phyto- and zooplankton were assessed, while in ice-associated habitats those were the main components modelled. Shallow sublittoral mixed sediments was the most commonly evaluated in the seabed habitat assessing 7 out of the 11 biodiversity components (Table 12). Invertebrates were mainly studied in relation to the water column over the continental shelf (Table 12).

Table 12. Number of model-derived indicators for each biodiversity component and per habitat type. Note, only habitats addressed by the models are included.

Biodiversity components		SEABED			WATER COLUMN				ICE
		Littoral rock and biogenic reef	Shallow sublittoral mixed sediment	Shelf sublittoral mud	Marine water: coastal	Marine water: shelf	Marine water: oceanic	Variable salinity estuarine water	Ice-associated habitats
MICROBES					1	1			1
PHYTOPLANKTON			9	1	4	42	13	2	4
ZOOPLANKTON		1	10	1	3	34	12	1	2
ANGIOSPERMS						12	7		
MACROALGAE		1			1	11	1		
INVERTEBRATES		1	11	1	1	45	15		1
FISH	OTHER	1	14			34	11		
	COASTAL FISH				2				
	PELAGIC FISH				12	18	12		1
	PELAGIC ELASMOBRANCHS				1	2	2		
	DEMERSAL FISH				7	13			1
	DEMERSAL ELASMOBRANCHS					1	11		
CEPHALOPODS	COASTAL/SHELF PELAGIC		13			27	6		
	OTHER					7	1		
MARINE MAMMALS	OTHER	1				8	6		
	TOOTHED WHALES		13		1	23	2		
	BALEEN WHALES					1	1		
	SEALS					3	1		1
REPTILES	SEA TURTLES					10	1		
BIRDS	INSHORE PELAGIC FEEDING		13			13			
	OFFSHORE PELAGIC FEEDING				1	1			
	OTHER					10	5		

Taking this into consideration, the least addressed biodiversity components in relation to model derived indicators and habitat types were microbes (3 indicators in 3 out of 8 habitat types), coastal fish (2 indicators in 1 out of 8 habitat types), pelagic elasmobranchs (5 indicators in 3 out of 8 habitat types), baleen whales (2 indicators in 2 out of 8 habitat types), seals (5 indicators in 3 out of 8 habitat types) and offshore pelagic birds (2 indicators in 2 out of 8 habitat types), while ice associated habitats, estuarine water column and shelf sublittoral mud were the least in the habitat types (Table 12).

2.2.5. Pressures addressed by models

Out of the available models, 41 of them are in use to address pressure impacts on states using existing marine environmental monitoring and research programmes. Collectively, these models address all pressures. Ten models, from 3 model types, are in use in situations where they do not address any pressures specifically, although it is of note that in other circumstances, they do relate to pressure assessment. Of all the pressures listed (Table 13), ***input of nutrients and organic material*** is the most adequately (in terms of numbers of models) addressed with a total of 28 models of 4 types currently being used in monitoring or research associated with this pressure. ***Marine acidification*** (pH change), ***interference with the hydrological regime*** and ***contaminants*** (sum of synthetic, non-synthetic contaminants and acute pollution) can be addressed by 20, 19 and 17 models respectively, relating to between 1 and 3 model types (Table 13). ***Contamination by microbial pathogens, contamination by radionuclides, litter*** and ***underwater noise*** appear to be the least adequately addressed pressures with just 5 models from 1-3 model types able to inform on responses to this pressure (Table 13). However, modelling is used to some extent in monitoring and/or research to address all pressures.

Table 13. Number of models and model types currently used in pressure assessment.

Pressure	Total number of models	Total number of model types
Sum physical disturbance pressures	11	5
Underwater noise	5	1
Marine litter	5	1
Interference with hydrological processes	19	3
Sum contamination pressure	17	3
Contamination by radionucleids	5	3
Nutrient and organic matter enrichment	28	4
Introduction of microbial pathogens	5	1
Non-indigenous species	9	2
Sum extraction of living resources	14	3
Marine acidification	20	1

The pressures ***'physical loss of marine habitat'*** and ***physical damage to marine habitats*** (combined as 'sum of physical pressures' in Table 1 in **Annex 5**) are primarily addressed using food web and niche models. These models include Ecological Niche Factor Analysis (ENFA), Bay of Biscay GLM and GAM, Niche Trait Model (NTM) and the Maximum Entropy (MaxEnt) static models (**Annex 3**). With the exception of NTM, these models generally have not been used to address any other pressures simultaneously with physical loss or damage. However, in 3 cases, the Ecopath with Ecosim (EwE, food web model, static and dynamic) can be used to simultaneously address 4 pressures in addition to physical damage. Similarly, the POM-BIMS-EOC-EWE model (a coupled model) can be used to address 5 pressures simultaneously with physical loss and damage (Table 1 in **Annex 5**). A maximum of 92 model-derived indicators relate to individual models addressing physical pressure (with 103 indicators for all models, collectively) and these are associated with EwE. All other models have 1 or 2 associated indicators. These indicators primarily relate to biomass with a small number also relating to species distribution, primary and secondary production and physico-chemical parameters.

Underwater noise and marine litter are both addressed by the same set of 5 (coupled) models (Tables 2 & 3 in **Annex 5**). Between 6 and 8 pressures are simultaneously addressed, in addition to underwater noise with the ROMS-BioEBUS-OSMOSE model (spatial-dynamic) addressing the greatest number of pressures (Table 2 in **Annex 5**). This model also addresses the greatest number of pressures simultaneously with the pressure 'marine litter' (Table 3 in **Annex 5**). Other models used to address these pressures include: GOTM-ERSEM-EWE, POM-BIMS-ECO-EWE, ECOSMO-SMS and ERSEM-POM-OSMOSE (**Annex 3**). A total of 24 unique indicators, all relating to biomass, have been derived from these models with a maximum of 10 indicators being associated with any one model (ERSEM-POM-OSMOSE).

The pressure ***'interference with the hydrological regime'*** is addressed by a total of 19 models belonging to 3 model types (Table 4 in **Annex 5**) which address between 0 and 6 (predominantly less than 4) other pressures simultaneously. In 7 cases, pressures relating specifically to climate change are addressed although this is accounted for by other pressures listed in Tables 1-11 (in **Annex 5**). A total of 17 of these models are spatial-dynamic coupled or biogeochemical models. The remaining models (static and dynamic) include EwE and North Sea tGAM (Table 11 in **Annex 5**). A maximum of 150 unique indicators are derived from these models with most being indicators of biomass or primary/secondary production associated with Ecopath and Ecosim. Between 1 and 11 indicators were associated with all other model types.

The pressures ***'contamination by synthetic/ non-synthetic compounds' and 'acute pollution'*** (summarised as sum of contamination pressure in Table 5 in **Annex 5**) are addressed by a total of 17 models from 3 model types (food web, coupled and remote sensing). The GOTM-ERSEM-EWE and the ROMS-BioEBUS-OSMOSE (**Annex 3**) simultaneously address the greatest number of additional pressures (8), excluding only 'introduction of indigenous species' and 'interference with the hydrological regime'. Between 1 and 150 model derived indicators were identified, with the maximum number being associated with the Ecopath and Ecosim model. All other models had between 1 and 10 associated indicators. The majority of these were indicators of biomass with a small proportion of indicators relating to energy flow and primary/secondary production.

Radionuclides are addressed by 5 models (from 3 model types) with a maximum of 5 model-derived indicators/models. These models address between 3 and 8 pressures, simultaneously with radionuclide contamination (Table 6 in **Annex 5**) with the ROMS-BioEBUS-OSMOSE model (**Annex 3**) addressing the greatest number. A maximum of five unique indicators have been derived from these models (individual), the majority of them relating to measures of biomass. A total of 17 model derived indicators were applicable to models addressing radionuclide contamination collectively. A total of 28 models from 4 model types are currently used in monitoring or research programmes to assess inputs of nutrients and organic matter (Table 7 in **Annex 5**). The majority of these are spatial-dynamic models, relating to coupled models and, less frequently, biogeochemical and remote sensing models. The 'GOTM-ERSEM-EWE' model (a spatial-dynamic model) addresses the greatest number of pressures (8) in addition to nutrient and organic matter input (Table 16 in **Annex 5**). Seven of the models only relate nutrient and organic inputs (together with non-specific climate related pressures). The number of indicators associated with these models ranges from 1 to 10 but most of the models focus on various measures of primary production and parameters relating to zooplankton. Five models (from 1 model type) are relevant to microbial pathogens, all of which are dynamic or spatial dynamic coupled models (Table 8 in **Annex 5**). These models are relevant to between 6 and 8 pressures, in addition to microbial pathogens and include GOTM-ERSEM-EWE, POM-BIMS-ECO-EWE, ROMS-BioEBUS-OSMOSE, ERSEM-POM-OSMOSE and ECOSMO-SMS (**Annex 3**). Between 2 and 10 model derived indicators were associated with these models with the maximum number being associated with the ERSEM-POM-OSMOSE model. A total of 24 indicators were found for all models, collectively, all of which related to biomass.

Non-indigenous species are addressed almost exclusively by coupled models (predominantly spatial-dynamic models) and, less frequently by food web models. A total of 9 models from 2 model types are currently in use (Table 9 in **Annex 5**). Models in use include EwE (static and dynamic), POM-BIMS-ECO (dynamic) and the spatial-dynamic models ERSEM-POM, Black Sea coupled hydrodynamic model, BFM-POM, ECOSMO, NORWECOM.E2E, POLCOMS-ERSEM and ROMS-BioEBUS (Table 9 in **Annex 5**). Pinnegar *et al.* (in review) has shown how EwE models can be used to assess how an ecosystem may respond to the introduction of an invasive species. These models also apply to between 0 and 6 pressures in addition to non-indigenous species. The Black Sea 'coupled dynamics and biogeochemical model (Oguz *et al.*, 1996) is not relevant to any additional pressures. A maximum of 6 indicators are associated with these models with up to 150 indicators being associated with the Ecopath and Ecosim model. The overwhelming majority of these are indicators of biomass with a small proportion relating to energy flow, biodiversity, life history and species distributional range. Overall, 174 unique indicators were associated with models used to assess the introduction of non-indigenous species.

A total of 14 models, relating to 3 model types have been applied in the context of ***selective extraction of living resources*** (encompassing extraction of fish and shellfish through direct catch, by-catch and discards and extraction of maerl, seaweed harvesting and the extraction of any other species) (Table 10 in **Annex 5**). The Qualitative models, LeMans, SMS and MOHID-LIFE do not relate to any other pressures (**Annex 3 and 4**). Other models simultaneously address up to 8 pressures with the ROMS-BioEBUS-OSMOSE addressing the maximum number. The number of indicators derived from these models was generally between 1 and 11 with a maximum of 150 indicators being associated with the Ecopath and Ecosim model. The majority of these were indicators of biomass. Overall, 198 unique indicators were associated with these models, collectively.

PH change (marine acidification) is currently addressed by 20 models relating to 1 model type (coupled) (Table 11 in **Annex 5**). All of these models are dynamic or spatial dynamic. Most of these models relate to between 1 and 4 pressures (in addition to marine acidification) although the ROMS-BioEBUS-OSMOSE modes relates to 8 additional pressures, and the GOTM-ERSEM-EWE ECOSMO-SMS relate to 7 additional pressures (Table 11 in **Annex 5**). A total of 34 unique indicators apply to models used to assess this pressure, with a maximum of 10 being derived from any one model (ERSEM-POM-OSMOSE). These indicators predominantly relate to biomass and primary production.

'***Other pressures', relating to climate change*** was not assessed as this category represents some degree of overlap with other pressures (pH change (marine acidification) and changes to the hydrological regime).

Summary

Through current and past research and monitoring programmes, models have been developed and are able to address all pressures in some way with many models addressing multiple pressures simultaneously. However, the vast majority of models require further work to show how sensitive and specific they are to pressures. Nutrient and organic inputs is particularly well addressed and a large number of models have been developed in relation to this pressure. Many of them target the same indicators (generally relating to measures of primary production and zooplankton) and there is likely to be some overlap, thus reducing the importance of this number of models. In contrast, underwater noise, marine litter and contamination by microbial pathogens are less well addressed by existing models and those that have been reported to produce indicators that are sensitive to the these pressures require further development. Additionally, the variety of model types currently applied to non-indigenous species is low and predominantly focuses on hydrodynamic models. None of the whole ecosystem, habitat quality or other ecological models have been used to address this pressure and this may indicate an inadequacy in the models available to address this pressure. It is emphasised that this summary of model use does not reflect model adequacy, data quality or the overall quality and effectiveness of the monitoring and research programs under which the models are applied.

2.2.6. Models relation to existing monitoring programs

A total of 19 models, relating to 5 model types, are linked to monitoring programs. A further 30 models, from 3 model types, have been developed but do not specifically relate to monitoring, even if some of the same models are linked to monitoring in other situations. The greatest number of models are relevant under national research programmes (11 models representing 4 model types) with time series data being associated with 12 models (of 5 types) (Table 14).

Table 14. Number of models and model types that benefit from monitoring programmes at a national and international scale.

Convention	Total number of models	Total number of model types.
International	7	3
Regional Sea Convention	3	2
EU Directive	5	3
National	8	3
Research	11	4
Time series	12	5

Modelling is of relevance (in the context of deriving or informing indicators used by a particular Convention) under four International Conventions (ACCOBAMS, Birdlife International, ICAAT and ICES) as a means of marine environmental assessment in relation to biodiversity (Table 12 in **Annex 5**). Seven models, of 3 model types are used. EwE (food web model) is applied in the context of static, dynamic and spatial-dynamic data and is relevant to all four conventions. The greatest variety of models is relevant in the ICES area (all other conventions benefiting from EwE only), which includes the food web models LeMANS, North Sea tGAM, PDMM and SMS, together with MOHID-LIFE (coupled) and North Sea optical properties model (remote sensing). Modelling does not appear to be widely relevant at present to the Regional Sea Conventions with OSPAR being the only RSC developing any type of modelling/model derived indicators associated with marine monitoring in the OSPAR area (Table 13 in **Annex 5**). Three models are used to inform OSPAR on the basis of model derived indiactors: EwE (static model), PDMM (dynamic model) and MOHID-LIFE (spatial-dynamic model), classed as food web and coupled models, respectively. The Ecopath with Ecosim (EwE) model (static, dynamic and spatial dynamic models) utilises monitoring under EU programmes that complies with the Habitats Directive, the Marine Strategy Framework Directive and various unspecified monitoring programmes relating to EU Directives (Table 14 in **Annex 5**). The number of indicators derived from this model (and linked to EU monitoring data) ranges from 3 to 89 but not all of these indicators are relevant to every nation/geographical area. MOHID-Life, ERSEM-POM and NORWECOM.E2E (spatial-dynamic models) are also relevant to the Water Framework Directive and have between 1 and 4 associated indicators. These are coupled models. The niche model 'Process-driven habitat template' (spatial dynamic model) also utilises an unspecified European monitoring programme (Table 14 in **Annex 5**). The food web model EwE (used as a static, dynamic and spatial-dynamic model) has between 1 and 3 associated indicators and integrates data collected under the MOM Monk seal conservation and Tethys research programmes. Twelve models, from 5 groups, have associated time series data. Of these, 3 are associated with International monitoring programmes, 2 with EU monitoring programmes, 7 with national programmes and 9 with research (Table 17 in **Annex 5**). Currently, remote sensing models (spatial-dynamic) are purely associated with research: these models include the IOPs, PSD (PSC), regional Chl and regional spectral PP models and the Regional model of downwelling radiance (Churilova and Suslin 2008). The time period covered by data sets relating to these models varies in length with some dating back to the 1950s and 1960s, others beginning in 2012 and some being based on hindcasting.

Summary

In summary, modelling uses all levels of monitoring, from national monitoring programmes to large international monitoring networks, which are generally associated with the greatest amount of time-series data. It is emphasised that this summary of model use does not reflect model adequacy, data quality or the overall quality and effectiveness of the monitoring and research programs under which the models are applied.

3. Summary of gaps and development needs

Overall it was evident from DEVOTES Models' catalogue gap analysis that some descriptors within the MSFD are better described by modelling approaches (e.g. D4 Food webs) while others are better addressed by what we could call traditional ecological indices (e.g. some Criteria within D6 Sea floor integrity). Most models addressing D6 (seafloor integrity) lacked indicators regarding biogenic substrate or the seabed extent. D2 is currently poorly addressed by the models even though some of them would have the capability to provide useful indicators for this descriptor. Similarly indicators for D7, D8, D9, D10, D11 outlined in the Com Dec are not currently addressed by any of the models reported, however these descriptors were not the target of the catalogue survey. The two DEVOTES Catalogues of Marine Biodiversity Indicators (WP3) and Model-derived Indicators (WP4) will be checked for complementarity once the WP3 catalogue is available (by January 2014). The gaps identified in this report will we be updated to provide a more accurate overview of how well the MSFD requirements are covered by the assessment tools available currently, be it ecological indices or modelling approaches. Regarding the four biodiversity related descriptors (D1, D2, D4, D6) there were three criteria/indicators for which no model-derived indicators were available in the catalogue: under Descriptor 2, as already mentioned before and "Population genetic structure" under D1 Biodiversity/C3 Population condition. As for the gaps on Pressures addressed, the vast majority of models require further work to show how sensitive and specific they are to pressures, some of which will be addressed through the remainder of DEVOTES Task 4.1.2. Underwater noise, marine litter and contamination by microbial pathogens are poorly addressed by existing models and those that have been reported to produce indicators that are sensitive to these pressures require further development. Additionally, the variety of model types currently applied to non-indigenous species is low and predominantly focuses on hydrodynamic models. It is emphasised that this summary of model use does not reflect model adequacy, data quality or the overall quality and effectiveness of the monitoring and research programs under which the models are applied. Focusing on the models' features, two main gaps were identified that require further development: one related to targets setting and the other to uncertainty associated to models' results. Because it was not clear for model developers what type of targets should be indicated or aimed for in the context of the MSFD, they often reported difficulties in setting targets and/or reference values for their models. Therefore these are missing for the majority of the model-derived indicators in our catalogue, even for those considered operational. The main barriers identified were: a) how to associate ecological meaningful targets to models' outputs (derived indicators) without a clear vision of where and what the model would be used for in a specific MSFD context; b) how demanding should those targets be? Should thresholds and/or reference values reflect the good condition of the assessed component *per se* or should they be set in function of MSFD minimum requirements? If the last is the case, then it was often argued that there is not enough information at this stage for model developers to be setting meaningful targets for MSFD purpose and such thresholds setting should be guided by clear objectives and end goals, i.e. targets to achieve. In addition, not all the models were able to address uncertainty; the majority lacked confidence intervals or an approach to evaluate uncertainty of the models' results. Further developments on this would produce more robust assessments and forecasts.

European geographical coverage of modelling capacity is also very heterogeneous with several identified marine areas with enormous potential for improvement. Also certain habitats (e.g. ice associated habitats or shelf sublittoral mud) and biodiversity components (e.g. microbes) are underrepresented in the modelling approaches presently in the catalogue. However the relative importance of modelling such components can change according to the system studied and therefore current gaps should be evaluated on a regional scale basis.

Looking at current modelling gaps from a Regional Seas perspective, one of the common limitation observed is the strong presence of certain models/areas targeted by the DEVOTES Partners that influence and reduce the inclusion of other models/model applications or even model types available. This led to a gap in the catalogue related to the coverage of other types of modelling approaches. For e.g. Bioenergetics and Dynamic Energy Budget (DEB) type of models are currently not included in the catalogue. These models would increase the potential to address MSFD Descriptors/Criteria/Indicators that focus particularly on properties at the individual level and physiological level, with higher potential to respond to pressures whose impacts operate or can primarily be detected at that scale. In addition, regional model runs identified the need of improving the existing models in regards to species diversity (e.g., adding certain species or refining below groups), spatial resolution for selected species and for better describing the direct effect of anthropogenic pressures on ecosystems. Model response towards the impact of certain pressures still requires further testing. Relevance of certain pressures differs across regional marine areas but still, those that could benefit from further research are for e.g. physical damage to marine habitats; underwater noise; marine litter; contamination by radio-nuclides;

introduction of microbial pathogens; extraction of species (maerl, seaweed and others), marine acidification and also acute pollution events, nutrient and organic matter enrichment. Data availability is also perceived as an additional constraint. This could partially explain why, in general for whole models, the number of 'under development' indicators is still quite high suggesting that this requires particular efforts to increase the potential to address MSFD descriptors. To assess GEnS descriptors and criteria adequately, the gap analysis conducted here highlights that further refining of the current models and their associated indicators as well as the adoption of new modelling techniques are needed.

4. Key gaps and development needs by Regional Sea

Further details for each Regional Sea, concerning the key ecosystem components and pressures contrasted against the current modelling capability is given in Annex 4. In general models focus on pressures, rather than activities, with the exception of some fisheries models that include fishing effort. Although the social and economic impacts of activities are modelled sometimes, for example in fisheries models, much more work could be done in this regard to make the scenarios more realistic. Ideally, models would be able to integrate socio-economic, environmental and ecological targets and either demonstrate the trade-offs between such targets or be able to find optimal integrative solutions. ATLANTIS models that can do such integrative modelling are in early development stages for the Baltic Sea, North Sea, The English Channel, and the Sicilian Channel by the EU FP7 project VECTORS (www.marine-vectors.eu).

Baltic Sea

Eutrophication, climate and fishing pressure can be tackled by a range of models, but other pressures are not well addressed. No model has yet been used to model specific targets for indicators or the effects of measures to meet such targets. Significant ecological gaps also remain among those models reviewed in Annex 4, in particular seabirds are not included and marine mammals are only represented by the seal group in the Ecopath with Ecosim model 'BaltProWeb' (Annex 3). Due to the shallow waters that characterize the Baltic Sea, the pelagic and benthic dynamics of the Baltic Sea are tightly coupled in time and space. However, the level of complexity and the parameterization of sediment fluxes could be improved in some of the models. The seasonal dynamics of the N and P pools in the Baltic Sea highly affect the composition of the biological community and leads to large natural variability in phytoplankton. A model that considers variable stoichiometry such as the Biogeochemical Flux Model (BFM) is currently under development for the Baltic Sea. The BFM implementation in the Baltic Sea will also provide estimation of bacterial biomass, relevant to descriptors D4 and chlorophyll concentration relevant to descriptor D1.

North Sea

The range of models developed for the North Sea region are able to model many of the key functional groups structuring the marine ecosystem and the processes that lead to the production of ecosystem services. Yet, ecological gaps do remain. The wide variety of benthic habitats is poorly represented in the models, largely due to limitations in data availability. Similarly gelatinous zooplankton is poorly modelled by all models of the North Sea due to little data. Marine mammals and seabirds are included as predatory groups in SMS and EwE, but the models are limited in skill for these groups and this could be developed given suitable data. The importance of foraging on fish by marine seabirds and mammals is well known and models that include the fish community should be more spatially resolved in order to represent the foraging range of higher predators (Ecospace and ATLANTIS could be developed in this way). Unfortunately, the ultimate resolution of spatial models is constrained by the information available on the seabed and benthic communities. Thus the ability to model effects of offshore construction, contaminants and extractive activities can not be modelled in great detail currently and further development is required in this regard.

Bay of Biscay

Most key species dynamics have been modeled, some of them as individual species and others as part of multispecies groups. Elasmobranchs (sharks and rays), for example, are sometimes included in demersal fish groups and models merit further development for such species. Indicators to evaluate Descriptors 2, 5 and 6 (Non-indigenous species, Human induced eutrophication and Seabed Integrity) could potentially be calculated by using the available models. But it will be far more difficult to obtain indicators to support Descriptors 7, 8, 9, 10 and 11 (Hydrological alterations, Contaminants, Contaminants in food, Marine litter & Energy/Noise).

The pressures ‘Extraction of fish and shellfish species as catch, by-catch or discards' is the best addressed pressure under the current modelling approaches. Habitat models also include other pressures related to the physical loss or damage to the modelled species habitats due to, for example, any dredging activities in the area. However, there is a variety of relevant pressures that occur in this ecosystem that should also be addressed i.e pressures related with contamination (input of nutrients and organic material, contamination by microbial pathogens and acute pollution), non-indigenous species, marine acidification. Climate change related pressures have been evaluated by some of the models, but the scenarios analyzed have been defined based on changes in temperature and salinity only.

Mediterranean Sea

Five ecosystem models have been used to assess/describe model derived indicators associated to GES descriptors in the Mediterranean Sea. None of these models have been used to assess descriptor 2 (non-indigenous species; only one indicator out of 137 was found for the Gulf of Gabes); 8 (contaminants); 9 (contaminants in food); 10 (marine litter) and 11 (energy/noise). Also D6 (seafloor integrity), despite the presence of 80 indicators associated to this descriptor, was only evaluated through the proportion of biomass of selected macrobenthos community and not on the actual biogenic substrate or the seabed extent. The number of 'under development' indicators is still quite high suggesting that more work is required to address MSFD descriptors. No indicators were found in relation to physical damage to marine habitats; underwater noise; marine litter; contamination by radio-nuclides; introduction of microbial pathogens; extraction of species (maerl, seaweed and others) and marine acidification and very few were observed for acute pollution events and nutrient and organic matter enrichment. In addition the type of operational indicators considered and modelled were almost all biomasses related (83%; mainly coming from food web model); only 5% were biodiversity indices and 2% (each) species diversity; species distribution; primary or secondary production and physical, hydrological and chemical. These preliminary results highlight that in order to cover and assess more GES descriptors and/or criteria further refining of the current models and their associated indicators and the adoption of new models are needed.

Black Sea

The enrichment of N and P is a crucial pressure for the Black Sea ecosystem and the Regional chlorophyll and colored dissolved/detrital matter model could be used to monitor state indicators response to this pressure. Consequently, there is a great opportunity to apply the available regional models for the assessment of GEnS and changes in state due to management measures aimed to mitigate the impact of this particular pressure.

While energy flow in the food web of the Black sea can be meaningfully modelled by the ratio between crustacean zooplankton and gelatinous zooplankton, the currently available models do not allow an assessment of the flow to upper trophic levels, for example fish, mammals and seabirds. Consequently, further development or refining of the current models is required.

5. References

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Website links:

DEVOTES link project website: http://devotes-project.eu/

MEECE link project website: http://www.meece.eu/

MEECE Atlas link: http://www.meeceatlas.eu/Menu/

6. List of annexes

Annex 1 - D4.1 Annex1_DEVOTEScatalogue-instructions (pdf)

Annex 2 – D4.1 Annex2_DEVOTEScatalogue (.xls)

Annex 3 – D4.1 Annex3_Models-description (pdf)

Annex 4 – D4.1_Annex4_Regional Seas (pdf)

Annex 5 – D4.1_Annex5_Tables_Pressures-Monitor (.xls)