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Towards an integrated water modelling toolbox

Report on contribution to a scoping study on available modelling tools, strategy on modelling and Model toolbox including potential use of FATE in the toolbox.

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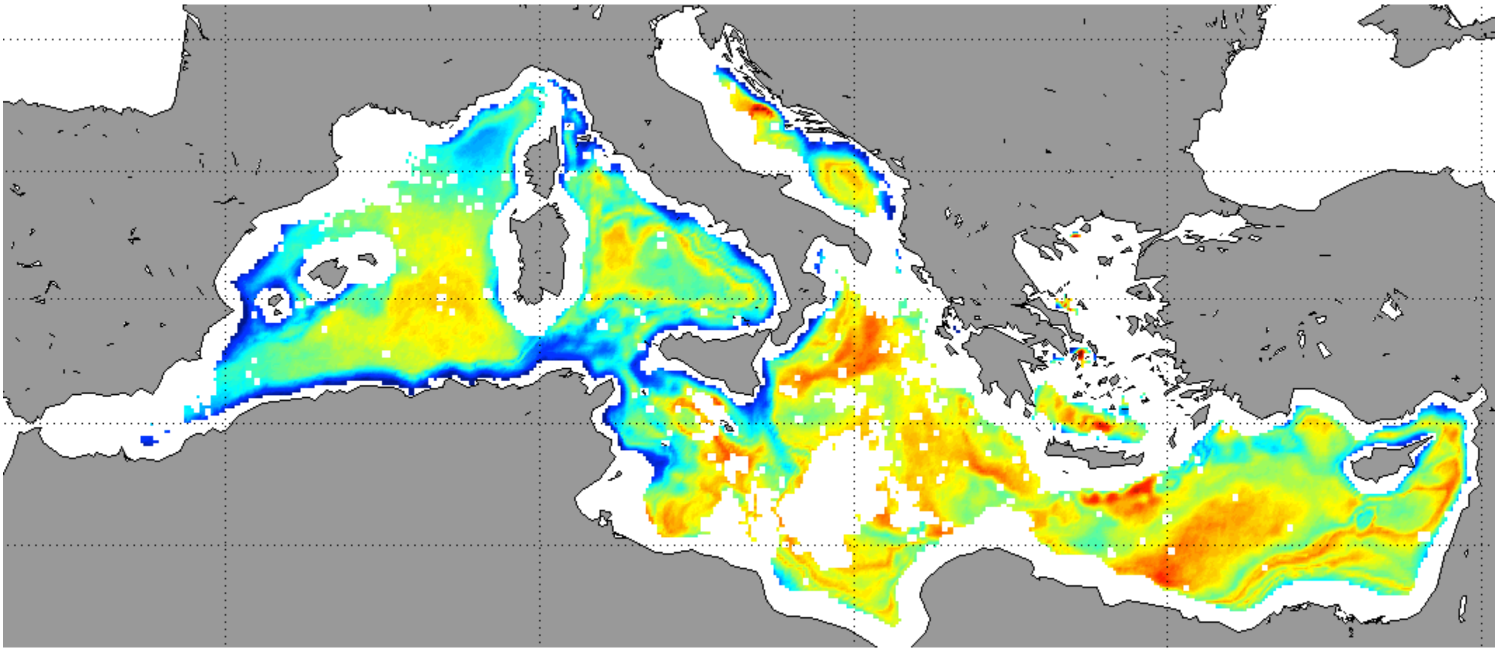

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Abstract

Hydrological and marine models can be useful for several MSFD related purposes and Blue Growth action plans, such as to determine baseline conditions in the past and to estimate the impact of pressures and the suitability of measures in the future (scenario analysis), to complement scarce datasets and inform on prioritization of sampling activities.

We define an integrated water and marine ecosystem modelling toolbox as a suite of selected types of modelling codes, relevant to MFSD, implemented and validated on different spatial (regional and sub-regional) and temporal (past and future) scales, complemented by essential data (topography, bathymetry, initial, boundary forcing, in and outflows) that are inherently coupled to each other. The experienced modeller would be able to select the relevant tools from the toolbox and to perform simulations to answer science or policy relevant questions in a significantly shorter time period as to date.

The modelling toolbox proposes end-to-end modelling, which tries to represent the entire system by including all relevant processes in the system, from hydrology and physics to chemistry, and plankton to fish. The suite of models considered represent a comprehensive toolbox, addressing the complex impact of drivers and assessing ecosystem responses necessary to address the requirements of descriptors in the MSFD and be useful for impact analyses of Blue Growth strategies. Such numerical models can simulate and predict changes in the state of the marine environment and ecosystems in response to different drivers and scenarios, and should ultimately be accessible to provide explicit support to the decision-making process.

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TOWARDS AN INTEGRATED MODELLING APPROACH

Modelling is becoming a priority are of development at the JRC. The MIDAS portal (midas.jrc.it), a database of models that are in use in the JRC, has been recently launched. Accessible from within the Commission Network, MIDAS allows model users and policy makers from JRC and other DGs to find models and their descriptions, to assess the use of these models for impact assessment and policy support, and to access related datasets, model descriptions and documents.

As a contribution to this advancement, the JRC has been developing an integrated water modelling platform to investigate implications for water resources availability and use under different policy scenarios by bringing together climate, land-use and socio-economic scenarios. Integration of the different models is already quite advanced on the inland–freshwater side, while links with the marine models is occurring with an offline approach. The present section summarises the advancement for both types of water compartments, while the following parts of the document focus mainly on the marine side, which is the agreed deliverable in the Administrative Arrangement. For more details on the integrated freshwater modelling, also in terms of applications, reference is made to the reports produced in the context of the Blueprint impact assessment and of the assessment of the Programmes of Measures submitted by Member States in compliance with the Water Framework Directive[1] [2]. At present, the hydro-economic modelling platform feeds the marine models by providing inputs on e.g. water discharges and nutrient loads to coastal waters. The plan is to develop a more dynamic approach in order to test impacts of Programmes of Measures on the descriptors of Good Environmental Status, as requested by the implementation of the MSFD-Marine Strategy Framework Directive, and assess impacts of action plans in the Blue Growth Strategy. All this fits into a broader JRC initiative in the context of the 2015 Work Programme to develop a sustainability assessment modelling platform (LUISA), which is bringing together other types of models in addition to the water compartments, e.g. air, soil.

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[1] De Roo, A.P.J. , Burek, P., Gentile, A., Udias, A., Bouraoui, F., Aloe, A., Bianchi, A., La Notte, A., Kuik, O., Elorza, J., Vandecasteele, I., Mubareka, S., Baranzelli, C., Van Der Perk, M. , Lavalle, C. , Bidoglio, G., 2012. A multi-criteria optimisation of scenarios for the protection of water resources in Europe. Support to the EU Blueprint to Safeguard Europe's Waters. JRC Scientific and policy reports. ISBN 978-92-79-27025-3. ISSN 1831-9424 doi: 10.2788/55540. http://ec.europa.eu/environment/water/blueprint

[2] A. Pistocchi, A. Aloe, S. Bizzi, F. Bouraoui, P. Burek, A. de Roo, B. Grizzetti, W. van de Bund, C. Liquete, M. Pastori, F. Salas, A. Stips, C. Weissteiner, G. Bidoglio, 2014. Assessment of the effectiveness of reported Water Framework Directive Programmes of Measures. Part I – Pan-European scale screening of the pressures addressed by member states. JRC Scientific and policy reports (in preparation)

Freshwater hydro-economic modelling

The rationale of the hydro-economic modelling platform is:

1. To develop an optimisation model linked with dynamic, spatially explicit water quality and quantity models that allows for the selection of measures affecting water availability and water demand based on environmental and economic considerations
2. To apply this model for a baseline scenario and a number of alternative policy and socio-economic scenarios testing impacts of WFD Programmes of Measures and Nitrates Action Plans proposed by Member States, and in general an assessment of the effectiveness of water-related Directives
3. To carry out an assessment of the Water-Agriculture-Energy-Ecosystem Services Nexus for all European River Basins (and beyond, in the context of EU international initiatives).

The aim of the modelling exercise is to help maximise the net social benefits gained from the use of water by economic sectors including a range of components, such as welfare impacts for water users, valuation of key ecosystem services provision, and valuation of the external costs of degrading ecological and chemical status and energy consumption triggered by water abstraction and return.

To achieve this, the hydro-economic model platform is based on the following elements (schematized in Figure 1):

- A pan-European, biophysical modelling tool that allows the assessment of alternative scenarios of water management in connection with socio-economic drivers. The following modelling tools, maintained and used at the JRC, will be primarily used: the JRC LISFLOOD model for water quantity, the SWAT/GREEN/EPIC models for water quality, and LUMP (the JRC Land Use Modelling Platform) for land use change scenarios. Agri-economic scenarios are provided by the CAPRI model following on the work performed for the CAP assessment
- A multi-objective optimisation tool based on multi-criteria analysis and a genetic algorithm to address issues of conflicting management goals and objectives
- A set of economic functions representing water demand and supply that account for the economic profits or losses at each water demand site and the benefits to, for example, ecological and environmental uses, and that allows the impacts of strategic measures to be assessed, defined and discussed with stakeholders.

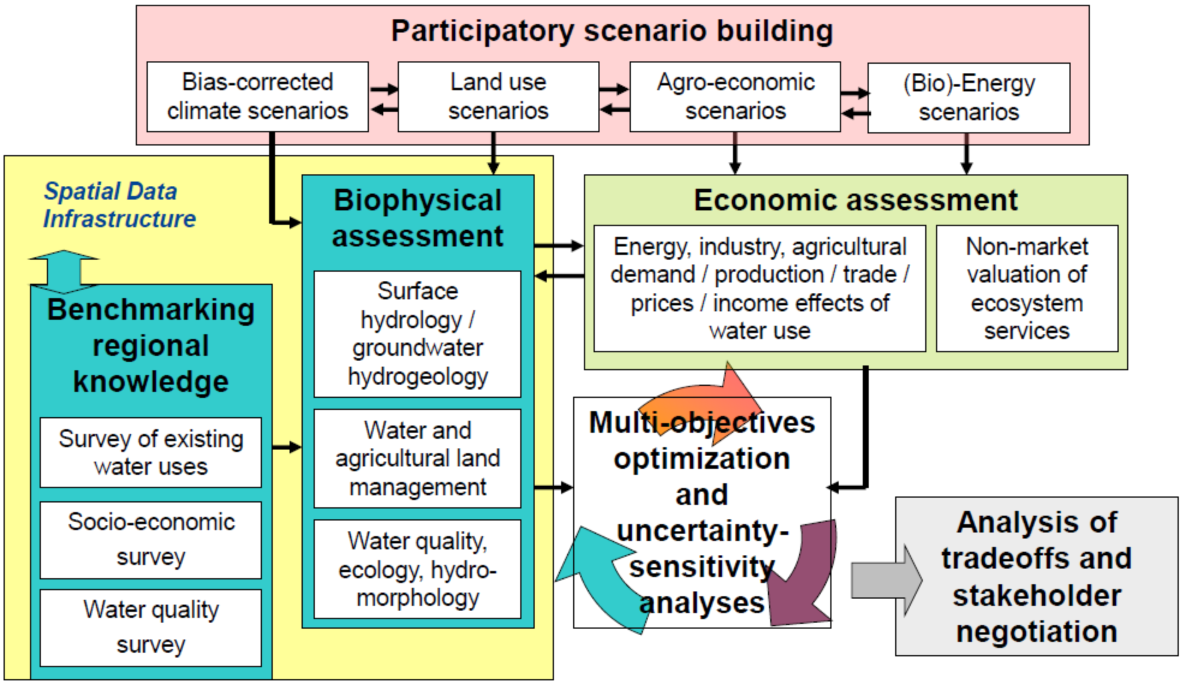

Figure 1 – Schematic of the integrated hydro-economic modelling

The suite of models allows the variability of the quantity and quality of water resources to be accounted for. All hydrologic elements are linked to a network of sources and demand sites for urban and industrial water uses, for energy production, for ecological and environmental flows, and for agricultural needs. The latter is based on specific modules accounting for river basin scale agricultural practices and their impacts on water. Withdrawals and return flows are developed for each of these demand nodes, or determined using empirical relations between water and type of productive uses. Taking economic and environmental constraints into account, the optimisation module is envisaged to allocate available water to all end users while ensuring the best trade-offs for economic and environmental sustainability.

The optimisation tool as described above can only work if it is fully and dynamically linked to a biophysical model. Most of the existing biophysical models that are coupled with optimisation tools only address individual sectoral aspects of the water management cycle, e.g. water distribution networks or selected water quality components only. In the short term, the existing JRC biophysical models (LISFLOOD, SWAT, etc.) are too complex to achieve this dynamic coupling. Therefore, to meet the 2012 Blueprint time schedule we used a simplified pragmatic approach with simulations at pan-European scale on a 5x5 km regular grid and with a daily simulation time step. This approach offered two advantages: 1) continental coverage and dynamic coupling with the optimisation model, 2) the taking into account of specific measures which are modelled at higher resolution with models such as LUMP, the Land Use Modelling Platform.

The current modelling is focusing on smaller scales. In the 2012 Blueprint, this was identified as a priority area for improvement in order to better account for regional specificities. Moreover, this also allows a more realistic assessment of the Programmes of Measures proposed by Member States in the River Basin Management Plans submitted to the Commission in compliance with the Water Framework Directive.

The Danube river basin is the main pilot for testing the current modelling approach. Agreement has been reached with the ICPDR and a wide range of researchers and stakeholders in the Danube Region. In December 2012, the ICPDR General Assembly adopted a resolution asking the Secretariat to continue the dialogue with the JRC on basin wide modelling and pollution load assessment. The common roadmap foresees:

- Establishment of a joint research agenda addressing commonly identified knowledge gaps in the field of the transboundary Water Nexus assessment in the Danube river basin
- Strengthening of crosscutting research efforts linking inland water bodies, the Danube Delta region, coastal and marine waters
- Establishment of a transboundary modelling partnership aiming at the development of a multi-model ensemble and comparison of results integrating quantity, quality, ecology and hydro-morphology, in coordination with other tools at national and river basin level and extension to non-EU countries of the Danube Region
- Analysis of scenarios of socio-economic impacts of alternative water allocation measures across competing water-using sectors (agriculture, energy, industry, human consumption, environment, transport) for the years 2030-2050, including an assessment of the provision/valuation of ecosystem services provided by aquatic ecosystems
- Building of a common transboundary database as a component of the Danube Reference Data and Service Infrastructure (DRDSI)
- Seminars for dissemination and training addressing stakeholders and scientists in the Danube region.

Modelling of the marine environment

Hydrological and marine models can be useful for several MSFD related purposes and Blue Growth action plans, such as to determine baseline conditions in the past and to estimate the impact of pressures and the suitability of measures in the future (scenario analysis), to complement scarce datasets and inform on prioritization of sampling activities.

We define an integrated water and marine ecosystem modeling toolbox as a suite of selected types of modeling codes, relevant to MFSD, implemented and validated on different spatial (regional and sub-regional) and temporal (past and future) scales, complemented by essential data (topography, bathymetry, initial, boundary forcing, in and outflows) that are inherently coupled to each other. The experienced modeler would be able to select the relevant tools from the toolbox and to perform simulations to answer science or policy relevant questions in a significantly shorter time period as to date.

The modelling toolbox proposes end-to-end modelling, which tries to represent the entire system by including all relevant processes in the system, from hydrology and physics to chemistry, and plankton to fish. The optimum architecture for the toolbox will be developed, clearly specifying the individual contributing components and the associated EU policies.

To achieve the overall objective, four basic types of models are considered: hydrological models providing information on diffusive and river discharge in terms of flow and nutrients, hydrodynamic models (simulating marine water transport), lower trophic level biogeochemical models (including phytoplankton and zooplankton) and higher trophic level food-web models (from phytoplankton to marine mammals/seabirds) into a single modeling framework/toolbox (see Figure 2). In a later stage also atmospheric models as well as hydro-economic models shall be included into the overall modeling framework.

The suite of models considered represents a comprehensive toolbox, addressing the complex impact of drivers, pressures (e.g. nutrients from agriculture) and assessing ecosystem responses necessary to address the requirements of descriptors in the relevant EU legislation (e.g. MSFD). When embedded into a common framework/interface such numerical models can simulate and predict likely changes in the state of the marine environment and ecosystems in response to different drivers, pressures and scenarios.

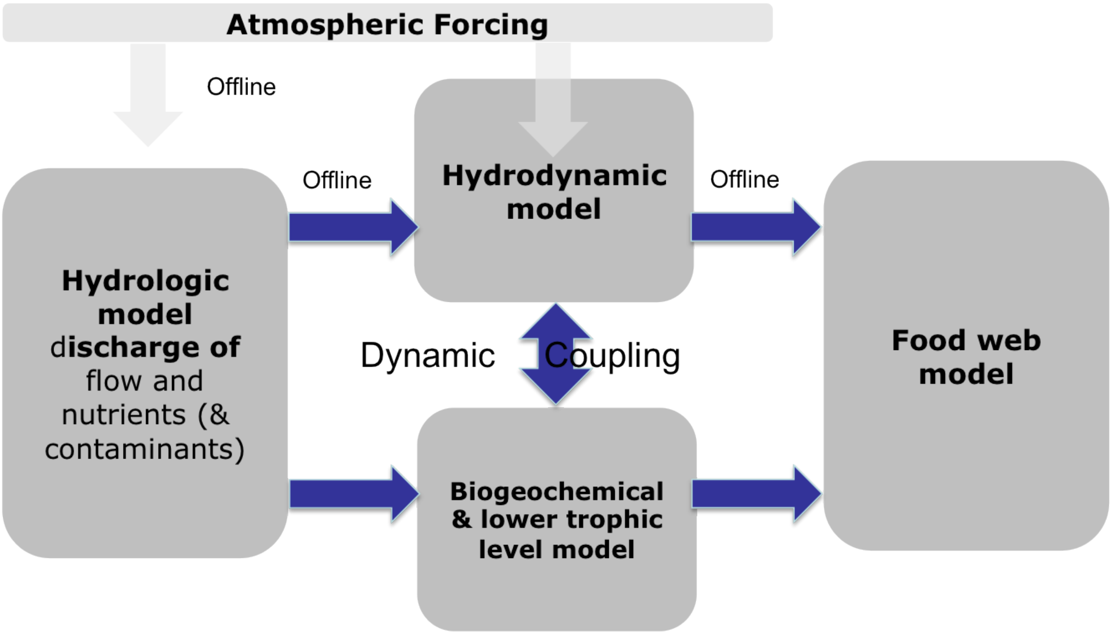

Figure 2. Marine modeling toolbox general structure.

The considered model classes have a quite different degree of maturity and scales of applicability. Whereas the geophysics based model classes (hydrological and hydrodynamic models) are generally applicable for the European or regional scale (possibly downscaled to sub-regional scale) the situation for biochemical and food-web models is fundamentally different. Currently no single existing ecosystem or food-web model can adequately describe all the different European Seas. Instead, specific regional or sub-regional models are developed and implemented to describe the different ecosystems.

This integrated water-ecosystem modelling platform shall be developed to investigate implications for the marine environment under different policy scenarios by bringing together climate, land-use, water use and socio-economic scenarios.

For the implementation of the model toolbox a multi-stage approach is proposed that would begin with running a regional setup covering the coupled core modeling components in hind- and forecast as proof of concept.

Finally, we perform a gap analysis with respect to relevant EU legislation (e.g. MSFD descriptors) and briefly address some specific implementation issues associated with the development and long-term maintenance of the modelling toolbox (including data needs and IT infrastructure requirements) and conclude with a draft roadmap indicating subsequent steps and an initial timeline for the marine ecosystem toolbox implementation process.

What this report isn't: Although where necessary the report will address relevant developments within specific EU research laboratories, the emphasis is not on providing a comprehensive overview of all possible contributions from Member State institutions. On the contrary the report will focus on those investments, and the resulting competences, matured at the EU-level through the institutional work of the JRC as well as EC funding through the Framework Programme.

Additionally, this report would not aim, at this stage, to document potential long-term maintainers to the modelling toolbox activity (i.e. the governance), but will preferably document the more abstract type of contributions required and leave concrete discussion on roadmap, role and responsibilities to a later stage.

MARINE MODELLING TOOLBOX

1.0 BACKGROUND AND CONTEXT

Several pieces of environmental European legislation apply to inland, coastal and marine waters of the EU, such as the Water Framework Directive, Flood Directive, the Environmental Quality Standards Directive, the Common Agricultural Policy (CAP), the Nitrate Directive (ND), the Urban Waste Water Treatment Directive (UWWTD), the Bathing and Shellfish Waters Directives, the Habitats and Birds Directives, the Common Fisheries Policy and the Marine Framework Strategy Directive (MFSD). All these Directives and Regulations require monitoring and assessment of specific components of hydrology and marine environment with the ultimate aim to achieve and maintain a good environmental status. The European long term strategy "Blue Growth" is intended to support sustainable growth in the marine and maritime sectors as a whole. Seas and oceans are drivers for the European economy and have great potential for innovation and growth but they are neither inexhaustible nor immune to damage so their uncontrolled exploitation could pose a great risk to the marine environment. Marine models can be useful for several MSFD related purposes, such as to determine baseline conditions in the past and to estimate the impact of pressures and the suitability of measures in the future, to complement scarce datasets and inform on prioritization of sampling activities.

We define a marine ecosystem modeling toolbox as a suite of selected types of modeling codes, relevant to MFSD, implemented on different spatial (sub-regional and regional) and temporal (hindcast and scenarios) scales, complemented by essential data (bathymetry, initial, boundary forcing, in and output) that are inherently coupled to each other. The experienced modeler would be able to select the relevant tools from the toolbox and to perform simulations to answer science or policy relevant questions in a significant shorter time period as to date.

The modelling toolbox proposes end-to-end modeling which tries to represent the entire system by including all relevant processes in the system, from physics to chemistry, and plankton to fish, and explicitly linked to the descriptors of the Marine Strategy Framework Directive.

To achieve this objective, four types of models are considered: hydrological models providing information on river discharge in terms of flow and nutrients, hydrodynamic models (simulating marine water transport), lower trophic level biogeochemical models (including phytoplankton and zooplankton) and higher trophic level food-web models (from phytoplankton to marine mammals/seabirds) into a single modelling framework/toolbox.

The suite of models considered represent a comprehensive toolbox, addressing the complex impact of drivers and assessing ecosystem responses necessary to address the requirements of descriptors in the MSFD and be useful for impact analyses of Blue Growth strategies. Such numerical models can simulate and predict changes in the state of the marine environment and ecosystems in response to different drivers and scenarios, and should ultimately be accessible to provide explicit support to the decision-making process.

This report will propose an initial strategy for the development of a modelling toolbox in support of the Marine Strategy Framework Directive (MSFD) and associated marine policies. In defining this strategy, toolbox requirements will be clearly described in the context of EU Policy and several expected scenarios will be introduced. Based on these requirements, and the associated "boundary conditions", we will propose an optimum architecture for the toolbox, clearly specifying the individual contributing components. Subsequently we shall document existing community models available through the JRC, and relevant FP projects and, as a consequence, perform a gap analysis with respect to the MSFD descriptors, criteria and associated indicators. The results of this gap-analysis will identify any required model components or competences not currently available/mature, so as to enable targeted resourcing of activities to rectify this. Finally, we will briefly address some specific implementation issues associated with the development and long-term maintenance of the modelling toolbox (including data needs and IT infrastructure requirements) and we will conclude with a proposed roadmap indicating subsequent steps for possible toolbox implementation.

A critical aspect will be the clear definition of the requirement and needs for the modelling toolbox, as this will in turn have implications on the definition of the optimum architecture and the resulting gap-analysis. Where necessary, iterations with ENV will be undertaken to ensure that the specific requirements are adequately captured. That said, efforts will be made to ensure that the process proposed is as flexible and reproducible as possible, so that it can be updated as new requirements become available.

2.0 REQUIREMENTS AND EXPECTED SCENARIOS

Here the specific requirements resulting from the MSFD and associated marine policies are documented. The specific context of scenarios from different policies that should be addressed with the modelling toolbox (case-studies) is documented.

2.1 Requirements resulting from the Marine Strategy Framework Directive (MSFD)

In 2012 Member States provided information on the initial assessment (article 8 of the MSFD), on the determination of good environmental status (GES - article 9) and on the establishment of environmental targets and associated indicators (article 10). As mandated by article 12 of this Directive, the Commission has produced an assessment and guidance document based on MS reporting. The assessment highlights that, five years in to the MSFD implementation, Europe is still far from the objectives set forth in the MSFD for 2020. No scenarios have yet been explicitly formulated around the implementation of the MSFD. However, a number of hypotheses might be issued based on the results of the Commission assessment: the first one could concern a Business as Usual scenario, where progress in meeting the MSFD objectives continue with the current pace. A second scenario could see a stepping-up in progress, thus actually meeting the objectives by the foreseen deadline. A third scenario could involve the partial meeting of the objectives. However, the adoption of modeling scenarios would need careful thinking and wide based endorsement before adoption. It is envisioned that a more concrete proposal of scenarios might arise from discussion with DG ENV following the finalization of this paper.

2.2 Scenario considerations

For developing scenarios several EU policies that are related to the marine environment have to be considered. Relevant scenarios were developed in the framework of the Common Agricultural Policy (CAP), the Nitrate Directive (ND), the Urban Waste Water Treatment Directive (UWWTD), the Biodiversity Strategy and the Common Fisheries Policy (see Annex 1 for details of these scenarios).
These scenarios, established under each specific policy are rather different and even independent from each other. In order to develop unified scenarios for the MFSD, these single-policy scenarios have to be combined into a single conceptual frame covering the most important aspects from the contributing policies. As stated earlier, no specific MFSD scenarios have yet been defined, although some hypotheses might arise from the results of the Commission assessment (art. 12 of the MSFD).

For example the reduction of nutrient input to the Mediterranean Sea during the last 20 years (may be a consequence of UWWTD) caused a decrease in primary productivity that led to decrease in fish catches (likely also abundance) as recently demonstrated (Macias et al. 2014). The existence of such a direct link between primary productivity and higher trophic production might actually be an indicator of an already compromised ecosystem, as it should not appear that strong in a healthy ecosystem.

Providing a clear definition of the envisaged scenarios is of fundamental importance as it has direct consequences on the optimum architecture required and the resulting gap-analysis. Scenarios with climate relevance should be based on the respective scenarios as established by the International Panel of Climate Change (IPCC) covering their 4 principal emission scenarios (RCP’s 2.6, 4.5, 6.0, 8.5).

The scenarios will be established based on previous work conducted at JRC, linking the agricultural CAPRI model, the LUMP land use model, the LISFLOOD water quantity model, the EPIC water quality model, the LISQUAL combined water quantity, quality and hydro-economic model using a multi-criteria optimization routine.

2.3 Scale considerations

For assessing all issues (as GES) in relation to the MFSD the scale of the analyzed ecosystem inherently determines the knowledge base, modeling tools and data that are needed to achieve sufficient understanding of the ecosystem in order to answer policy relevant questions. A very basic subdivision into 3 subcategories would comprise first all the European regional seas (~5000km), then the individual seas (Baltic, Mediterranean, Black Sea, North Sea and Atlantic Shelf) or their sub-basins, and finally the local scale (<50km). Considering the role of JRC as a European research institution the local scale is excluded from consideration here and left to the MS. In addition to the political context it must be considered that it is nearly impossible to obtain the necessary data and knowledge of a small-scale ecosystem required to develop a site-specific ecosystem model that is able to assess scenarios and management options at the local scale. In the context of a modelling toolbox to be developed and used for assessing European-wide MFSD measures it will not be possible to tackle local site specific problems such as aquaculture and desalination plants. Simulating a large Sea (e.g. Mediterranean Sea) or simulating specific small-scale regions (e.g. Sacco di Goro) are quite diverse tasks, requiring completely different approaches, model implementations and data. New innovative modelling approaches are currently being developed (like adaptive mesh refinement, AGRIF) but even these do not help to solve the problem of lack of understanding of small-scale local ecosystems. They might however allow in the near future (3-5 years) high-resolution simulations of selected sub-regions as defined in the MFSD.

Nevertheless several issues, for example nutrient input from point sources (aquaculture) and some of its consequences, can be accounted for in large-scale models and these will be considered in the development of the modelling tools.

Due to the inherent variety of ecosystems no single existing ecosystem model can adequately describe all the different European Seas. Instead, specific regional models are adapted to the different ecosystems.

Considering the current state of the art in ecosystem modelling we therefore conclude that developing modelling tools at the scale of the European regional seas (e.g. the Mediterranean Sea) or at sub-regional scales as defined in the MFSD is adequate and practically feasible.

3.0 FRAMEWORK AND OPTIMUM TOOLBOX STRUCTURE

It is understood that the proposed modelling toolbox should encompass end-to-end modelling which try to represent the entire system by including all relevant processes in the system, from physics to chemistry, and from plankton to fish, and explicitly linked to the descriptors of the Marine Strategy Framework Directive. To achieve this goal, four types of models must be combined into a single modelling framework/toolbox: hydrological models providing information on river discharge (in terms of flow and nutrients) to sea waters; hydrodynamic models; lower trophic level biogeochemical models (including phytoplankton and zooplankton); higher trophic level food-web models (from phytoplankton to marine mammals/seabirds). This section describes the continuous information flow across the different component models, or a so-called system architecture.

An architecture typically describes the structure of a system, as reflected in its building blocks, their relationships to each other, and to the environment. The descriptive format of the architecture is generally tailored to the particular needs of the users/stakeholders and makes use of common definitions and standards in its construction. Two main needs/usage scenarios for an architecture are apparent:

A: to promote a common understanding, amongst the various stakeholders, of the implementation implications of meeting the various marine modelling requirements. To support such a usage, the architecture should depict, in a structured and readily-accessible format, the functions, information flows and dependencies of the processes necessary to satisfy the relevant requirements and support the verification by the originators/owners of the requirements that they have been correctly interpreted. This should encompass the end-to-end marine modelling processes.

B: to support an assessment of the degree to which the current and planned systems meet the requirements, and the generation of an action plan to address any identified shortfalls/gaps. It is anticipated that such an action plan would help promote the fulfilment of policy needs. For example, this information could be used to assess the capability of the upstream processes to support both current and new decision-making processes (e.g. as part of policy-making) and, working backwards, to ensure that the appropriate model components and identified scenarios and applications are in place.

The **logical view** serves the first usage scenario. It represents the functional and data-flow implications of the requirements baseline as a set of interlinked functions and associated data-flows. Leaving aside performance considerations, the logical view could be considered as the "target" for a fully functional modelling toolbox, this representation is necessarily generic. As this view is intimately tied to the requirements (and not to the physical implementation of the system) this view is as stable as the requirements baseline and, once established, should only need to be updated when the functional aspects of the requirements change.

Before considering a possible representation of a "logical view", it is stressed that there is no unique solution, with the only measure of success being "fitness for purpose" (i.e. its ability to support the intended usage scenarios). The usage scenarios (particularly usage scenario A) require that a logical view is "end-to-end".

3.1 General optimum toolbox structure

For a description of the fundamental processes in aquatic ecosystems in the European regional waters falling under the Marine Strategy Framework Directive at least 5 different model classes (atmosphere model, hydrologic model, hydrodynamic model, biogeochemical model and food web model) are required. In this first approach for the sake of simplicity further important model classes as wave models, radiative transfer models, sediment models or underwater acoustics are not considered. The interconnections of these 5 basic model classes are depicted in Figure 2.

All connections between these 5 model classes are in nature 2 way interactions, meaning that there is always feedback between the different environmental processes. If the feedback between the processes is strong we must consider dynamic coupling between the models in order to achieve a realistic description of the processes. In the case of weak feedback offline coupling can be applied to reduce the computational effort while still achieving a valid approximation of the processes. This simplification of the coupling to offline coupling (1 way - no feedback) is described in Figure 2. As atmospheric forcing is generally available on a European scale from different meteorological services (e.g. the European Centre for Medium Term Weather Forecasting ECMWF) we propose to exclude atmosphere models from the further considerations and to rely in this case on external provided simulated data for the hindcasts and the scenarios. The climate relevant scenarios are available on a global scale from many different climate models from the Climate Model Intercomparison Project 5 (CMIP5) of the World Climate Research Programme.

3.2 Relation between MSFD and optimum toolbox structure

Figure 3 does relate the different descriptors as defined in the MSFD to the relevant model classes (underwater noise not included) and also depicts the present model implementation as available at JRC. The correspondence between the MSFD descriptors and the respective process models is only approximate as the design process of the models and the specification of the MSFD descriptors had been done independently from each other. It also becomes obvious that several descriptors fall under more than one model class, which implies that for a realistic assessment of such a descriptor all models need to be implemented with a comparable complexity.

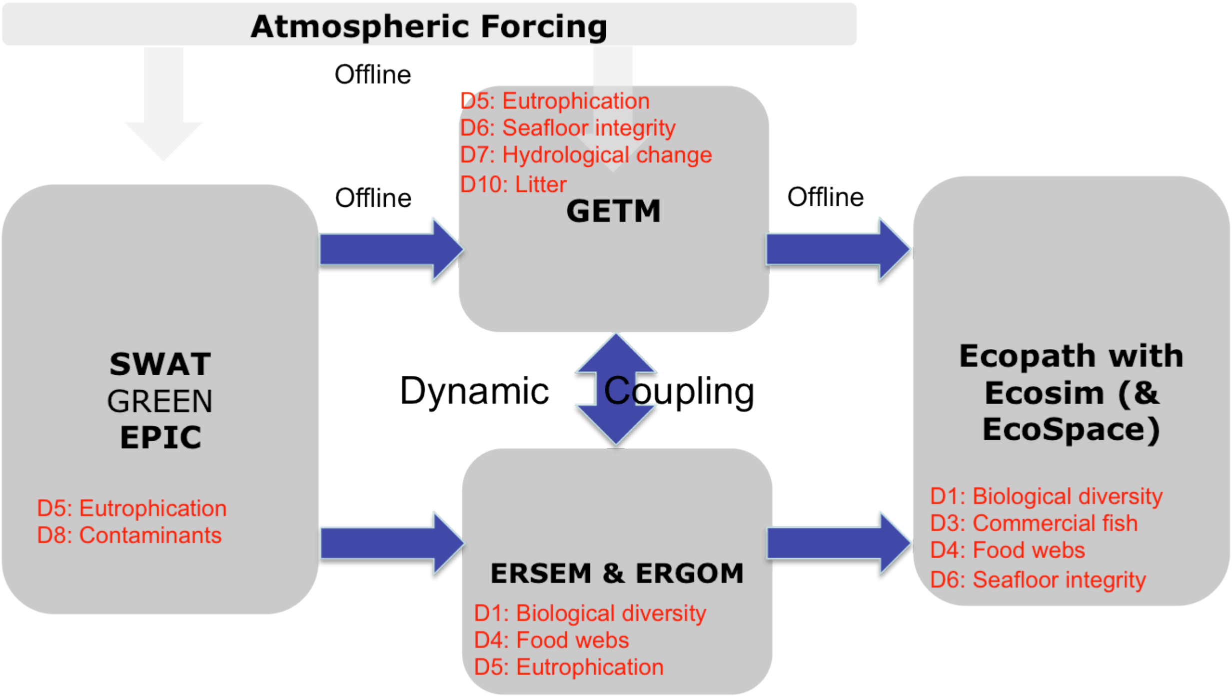

Figure 3. Basic relations of MFSD descriptors with available JRC models.

4.0 CRITERIA AND EXTERNAL DEPENDENCIES (INCL. DATASET NEEDS)

The fine tuning of the criteria and the real design of the tool-box will be only possible when its detailed purpose, including the envisaged users are much better understood. The initial focus will be on community-based models for the specified four model classes (hydrological models, hydrodynamic models, biogeochemical models and food web models). We do not include a criterion based on the ease of use by non-specialists, as non known model from the above mentioned classes could be used to produce meaningful results by non-specialists.

4.1 Criteria for model consideration:

- The most important criterion is the unrestricted accessibility of the model source code, therefore only models that apply an open source license policy will be considered. One example of a free software license is the GNU General Public License, but there are more legitimate licenses.
- Models must follow the Earth System Modeling Framework (ESMF) conventions for model coupling, having at least the 3 basic components: initialize, run and finalize.
- Principally the coupling should be designed to allow coupling to all relevant specific model classes, they are comprising: *Hydrodynamic model, atmospheric model, wave model, surge model, tidal model, sea-ice model, turbulence model, sediment model, hydrologic model, tracer transport model, ecosystem model, food web model*.
- Should be based on a large community for model development.

- The inclusion of data assimilation capabilities (inverse modeling, adjoint models, Kalman filtering) and of specific tools for ensemble forecasting is considered as an additional advantage (operational modeling).
- Models developed and used mainly within the European Union should be prioritized, if having similar capabilities and comparable quality to outside EU developments.
- Offline or dynamic coupling of model components should be done depending on the planned application. As there are pros and cons for both methods, ideally models should have both methods implemented.

4.2 Examples of community based open source models from the 4 basic model classes relevant for MSFD for further consideration.

Policy orientated models including the water cycle

EPIC = Environmental Policy Integrated Climate (EPIC) Model

EPIC simulates approximately eighty crops using unique parameter values for each crop. EPIC models a wide range of biophysical processes to consider alternative land uses where land is becoming degraded or is putting natural ecosystems at risk. It includes a full water cycle, allowing researchers to analyze how water is moving on, above, and below the Earth's surface. epicapex.tamu.edu/epic/

Hydrological models (water cycle):

SWAT = Soil and Water Assessment Tool

SWAT is a small water shed to river basin-scale model to simulate the quality and quantity of surface and groundwater (US development). Swat.tamu.edu

Hype = Hydrological Predictions for the Environment

Hype is a dynamic, semi-distributed process-based catchment model, original development in Sweden. Hype.sourceforge.net

Hydrodynamic models:

Because of their limited ecosystem coupling capabilities the two first (oldest) ocean models POM (Princeton Ocean Model, www.ccpo.odu.edu/pomweb) and MOM (Modular Ocean Model, mom-ocean.org) are not considered here.

NEMO = Nucleus for European Modelling of the Ocean

NEMO is an ocean modelling framework which is composed of different model components (engines) that are nested in an environment. The engines provide numerical solutions of ocean, sea-ice, tracers and biochemistry equations and their related physics (chemistry/biology). The "environment" consists of the pre- and post-processing tools, the interface to the other components of the Earth System, the user interface, the computer dependent functions and the documentation of the system. www.nemo-ocean.eu

ROMS = Regional Ocean Modeling System

ROMS is an ocean modeling framework that can be used alone or coupled to atmospheric or wave models. The ROMS kernel does comprise an ocean model, biogeochemical model, sea-ice model as well as adjoint models for data assimilation. The original development was done in US. www.myroms.org

GETM = General Estuarine Transport Model

GETM is an ocean modelling framework that comprises different model components in addition to the ocean kernel. Turbulence and sea-ice are simulated by the GOTM model (General Ocean Turbulence Model) whereas biogeochemical processes are simulated via the FABM model (Framework for Aquatic Biogeochemical Models). www.getm.eu

Ecosystem models:

FABM = Framework for Aquatic Biogeochemical Models

FABM is a programming framework for biogeochemical models, not a model by itself. FABM connects with several hydrodynamic models and it is the default coupler for GOTM, GETM, GLM (General Lake Model) and MOM4. Additionally, FABM comes with a stand-alone box model driver and includes a repository of several biogeochemical process models. sourceforge.net/projects/fabm/

ERGOM = Ecological Regional Ocean Model

ERGOM is a numerical model for the simulation of the dynamics of the major biogeochemical properties (medium complexity) in marine ecosystems. www.ergom.net

BFM = Biogeochemical Flux Model

BFM is a numerical model for the simulation of the dynamics of the major biogeochemical properties (high complexity) in marine ecosystems. BFM is based on the ERSEM development see annex 2.3.2. www.bfm-community.eu

Food web models

EwE = Ecopath with Ecosim

Ecopath with Ecosim is a free ecological and ecosystem modeling framework. EwE has three main components: *Ecopath* - a static, mass-balanced snapshot of the system; *Ecosim* - a time dynamic simulation module for policy exploration; and *Ecospace* - a spatial and temporal dynamic module primarily designed for exploring impact and placement of protected areas. www.ecopath.org

4.3 Criteria for applicability

General criteria for the range of applicability should cover the geographic region, time period and temporal resolution, available bathymetry and land-ocean coupling.

Geographic region including bathymetry:
Optimally this software could be implemented at global, regional or sub-regional sea scale. Therefore it must be possible to change the spatial resolution according to the requirements of the modelling task at hand. For large scale simulations including all the European Regional Seas the resolution should be at about 5'x5', whereas for selected smaller regions it should be about 1'x1'. The implementation of different coordinate systems (geographic, curvi-linear, cartesian) should be foreseen. Ideally the models allow for nesting of different grids. The vertical resolution is depending on the depth of the simulated basin. Considering the dynamic depth range of the European continental waters and the specific importance of the coastal zone, priority should be set on models with terrain following coordinates. Bathymetric data at a resolution of at least 1'x'1 (GEBCO - General Bathymetric Chart of the Oceans, 0.5'x0.5' grid as used in Google Earth) must be available complemented by high resolution digital coastlines (GSHHG - A Global Self-consistent, Hierarchical, High-resolution Geography Database).
However for all real world applications the strong scale dependence of any specific model implementation (ch. 2.3) has to be considered and will ultimately determine what is practically feasible.

Temporal considerations:
The four typical tasks done for all model applications comprise a calibration, a validation, a hindcasting and a forecasting period. Therefore the models should be run at nearly any period from about 50(100) years in the past to about 50(100) years into the future. They should be run at quasi any possible temporal resolution depending mainly on physical/biogeochemical process considerations and input data availability. The smallest needed time step usually results from the requirement of the hydrodynamic model to resolve barotropic waves on the size of a grid cell and is typically in the order of 10-50 seconds, depending on depth and grid size.

4.4 External data sets and requirements

Practically all models mentioned so far depend on external datasets for supplying initial and boundary conditions, as required to solve the model equations (typically partial differential equations). These data must be either gathered from external data sources or alternatively these data can be provided from an in-house model generating these data. In the case of atmospheric forcing the input data could be acquired from model runs done by the different data providers (ECMWF, NCEP, CORDEX, SMHI, DWD). The direct coupling of an atmosphere model to the hydrodynamic model would increase the complexity of the overall modelling task in an unreasonable way.
Data availability is typically better for historic data, whereas access to forecast data is depending often on specific conditions (e.g. to be a member of the consortium). Climate scenarios from the CMIP5 exercise of the IPCC are principally freely available. Data availability for physical (e.g. atmospheric) data is typically much better as for chemical data and that is much better then that for biological data. Nevertheless the general situation is slowly improving.

Atmospheric forcing:
Basic external atmosphere data originate from European Centre for Medium Term Weather Forecasting (ECMWF) and from National Center for Environmental Prediction (NCEP). Forecast data are acquired from the Coordinated Downscaling Experiment (CORDEX - European Domain). The European Monitoring and Evaluation Programme (EMEP) provide atmospheric input of chemicals. To improve the consistency of the overall concept in the longer term the online coupling to an atmospheric circulation model should be foreseen

Data for calibration, validation and verification
For each model class specific data from the selected model domain and time period are required to perform the basic tasks of model calibration and validation. In the case of hydrodynamic models this would comprise in-situ data from the European regional seas covering quantities as temperature, salinity, currents and tides. Measured discharge would be required to validate hydrologic models and measured nutrients as well as oxygen, phytoplankton, zooplankton to validate the ecosystem models.

As the mentioned data centres are major international and national governmental organizations we do not expect serious problems with the sustained access to atmospheric and hydrologic datasets. The situation is not that clear with chemical and biological data (e.g. nutrient river load, zooplankton data).

Generated and processed model output data
Depending on the temporal and spatial resolution as well as on the model domain and simulation period the generated output data, eventually including post-processed data do represent a large amount of data. Considering all the models mentioned so far this does likely would go into the Petabyte range if no intelligent data reduction or selection measures are taken. The implementation of an intelligent data reduction system that would e.g. allow variable selection, spatial and temporal averaging must certainly be considered from the very beginning of the design process. The reduced output data (may be including plots and figures) should be made available via an internet data server.

5.0 EXISTING MODEL COMPONENTS AND DATA AT JRC

Applications of models provide invaluable opportunities to understand the connections within and between ecosystems and constitute fundamental tools to implement the Ecosystem Based Management. The use of models to carry out marine ecosystem comparisons includes the application of a specific model to different ecosystems as well as the application of different models to a particular ecosystem. Since no model is perfect for all purposes, a number of different models and modeling approaches are needed. Modeling components at JRC have evolved over time and reflect the significant amount of model development that has already been carried out by and in collaboration with other modeling groups. However, all components have been developed from public domain, open source software that allows for principally reproducible results. A key point for developing future strategy is that due to the high level of expertise needed to set-up, develop and post-process model outputs, and the significant computing power and storage needed run and store outputs, sustainable use of these models requires significant investment in human resources and hardware.

A principal overview of nearly all existing model classes at JRC and components including their connections and data requirements can be found at the MIDAS portal (midas.jrc.it). MIDAS stands for "Modelling Inventory Database & Access Services". It is a database of models that are in use in JRC. Accessible from within the Commission Network, MIDAS allows model users and policy makers from JRC and other DGs to find models and their descriptions, to assess the use of these models for impact assessment and policy support, and to access related datasets, model descriptions and documents.

A nearly complete overview of existing marine ecosystem models in Europe is given by the FP07 project MEECE (Marine Ecosystem Evolution in a Changing Environment), in the model library see http://www.meece.eu/Library.aspx.

5.1 Existing models at JRC

Hydrological modeling of discharge and nutrients at JRC is based on the GREEN model see Annex A2.1. GREEN is a statistical model that contains a simplified representation of nutrient transport and retention in the river basin. The GETM model (see Annex A2.2) does hydrodynamic modeling of the European regional seas. GETM calculates the horizontal transport of momentum, salt and temperature as it is affected by the tides, the wind and the river discharges. Biogeochemical processes and lower trophic levels are simulated with region specific models. Present implementations cover the ERGOM model (medium complexity, 12 state variables) for the Baltic & Mediterranean and the ERSEM model (~60 state variables) for the Self Sea, see Annex A2.3.2. A specific Black Sea model is under development. Food web modeling at JRC is done using the ecological/ecosystem modeling system Ecopath with Ecosim (EwE), see Annex A2.4. The Ecopath model is based on mass balances of the different components to provide a static description of the ecosystem. Temporal changes are then assessed via Ecosim. These EwE implementations are also region specific.

5.2 Boundary conditions and forcing

A large amount of information is required to initialise and run these models. Bathymetry is derived from GEBCO (General Bathymetric Chart of the Oceans, http://www.gebco.net/) or a relevant regional source, such as NOOS (North West European Shelf Operational Oceanographic System, http://www.noos.cc/). Initial and boundary conditions are needed for the time period of any required runs. Atmospheric forcing is derived from the European Center for Medium-Range Weather Forecast (ECMWF) operational hindcast data sets, or CORDEX for future scenarios. Boundary conditions for temperature and salinity are either based on climatologies derived from appropriate databases (World Ocean Database or MEDAR/MEDATLAS Database), or monthly modelled values from ECMWF. Biogeochemical initial and boundary conditions are computed from the World Ocean Atlas database (www.nodc.noaa.gov/OC5/indprod.html). Riverine inputs (flow, salinity, nutrients) are collected from Global River Data Center (GRDC, Germany) database. For the European Shelf model we use a riverine database collated by Cefas, UK. Tidal boundary conditions (elevations and velocities) are derived from an inverse modelled netCDF gridded data set of tidal constituents for elevation and (depth averaged) velocities developed by a group from Oregon State University, OSU (http://volkov.oce.orst.edu/tides/).

5.3 User interface and post-processing

JRC has a range of tools for post-processing model output, written primarily in Matlab, R and Python. These include skill test mapping tools for 3D variables such as temperature and salinity, tidal harmonic analysis and tidal validation routines, and various other generic and purpose built visualisation and analysis tools. These tools have been developed by individual modellers for analysing outputs, but could be developed for more general use. Considering that such a modeling toolbox should be possibly also used by other groups/scientists additional components that would ease the usage are required. These additional components should comprise a user interface and data pre- and post-processing tools. These software packages need to be specifically developed for the toolbox. Several additional components like a multi-objective optimisation tool based on multi-criteria analysis and a genetic algorithm to address issues of conflicting management goals and objectives need to be added during the implementation phase.

6.0 GAP ANALYSIS AND IDENTIFICATION OF MISSING COMPONENTS/COMPETENCES

Based on the optimum model architecture defined in 3 and the description of individual model components identified in 5, this section undertakes a detailed gap-analysis mapping the available component models and their potential outputs onto the specific requirements coming from the MSFD descriptors, criteria and associated indicators.

JRC ecosystem models were used to evaluate their capabilities to assess, at least partially, indicators associated with MSFD descriptors. For this reason, a model library (see Table 1 for definition of terms) was built with these models describing either lower trophic level or higher trophic level organisms and processes. This inventory intended to build on the work of the Devotes FP7 project on the state of the art of marine ecosystem models and model derived indicators that can be associated to MSFD descriptors and conducting a thorough assessment of their status and quality. The models library reveals that currently 3 models have been deployed at JRC with outputs relevant to MSFD descriptors, 2 being hydrodynamic-biogeochemical and 1 higher trophic level model and with data being primarily spatial-dynamic. A total of 73 indicators were inserted in the catalogue, of which 54% were “under development”, 27% “operational” and 19% “conceptual”. From a model perspective, Ecopath with Ecosim (EwE) stood out for the great number of model-derived biodiversity indicators produced, 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 7 major categories (Table 1): 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. Not surprisingly, because of the higher trophic level model (Ecopath), biomass indicators constituted the largest group with a percentage around 54% followed by biodiversity indices and physical, hydrological and chemical indicators. These indicators covered 6 of the 11 descriptors of the MSFD: in particular, Biological Diversity (D1), Commercial Fish and Shellfish (D3), Food webs (D4), Human Induced Eutrophication (D5), Seafloor Integrity (D6) and Hydrographical Conditions (D7).

Non-indigenous Species (D2), Contaminants (D8), Contaminants in Food (D9), Marine litter (D10) and Energy/Noise (D11) were not tackled by the models currently in the library. However, it has been shown by other studies that Ecopath with Ecosim (EwE) models can be used to assess how an ecosystem may respond to the introduction of invasive species (D2) or contaminants (D8, D9). In general, a single model is capable of addressing more than one descriptor as shown in the model library evidencing a good capability to inform on complex, integrative ecosystem dimensions. Overall it is clear that some descriptors within the MSFD are better described by higher trophic level modelling approaches (e.g. D4 Food webs) while others are better addressed by lower trophic level ones (D5 Human Induced Eutrophication, D7 Hydrographical Conditions). Also, certain habitats (e.g. ice associated habitats or shelf sublittoral mud) and biodiversity components (e.g. microbes) are still underrepresented in the modelling approaches presently here but could be added and refined for specific objectives. Yet, data availability is a constraint. This could partially explain why 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 GES 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.

Table 1. The Model derived indicators grouped into 7 major categories with their overall percentages in the Model Library.

	Types of indicators	Percent
1	Biomass	54
2	Biodiversity indices	21
3	Primary or secondary production	3
4	Species/habitat diversity, proportions in community	2
5	Species life history	1
6	Flows, energies and efficiencies	4
7	Physical, hydrological and chemical	15

7.0 MODELLING TOOLBOX IMPLEMENTATIONS ISSUES

This section is addressing some specific issues concerning the longer-term challenges of implementing the modelling toolbox.

- The intended purpose and the envisaged user group of the modelling toolbox determine to a large degree the design, the implementation, output data and the user interface of the modelling toolbox and must therefore be explicitly specified beforehand.
- There is worldwide no known physical or ecosystem model available that could be run by non-experts just pressing a button and still producing some meaningful output data. Because of the complex conditions and interactions of the Earth system such a simplified approach will principally not be feasible.
- Such a type of modelling does require High Performance Computing (HPC) capabilities for performing the modelling activities. The trend to include more processes (more model coupling), to include more detailed parameterizations and to always higher resolution does lead to an ever increasing demand on computing power and storage capacities.
- The very recent ensemble modelling approach or even more demanding the ensemble scenario modelling used for forecasting does increase the computing demand again by about 2 orders of magnitude.
- The long-term sustainability of such an initiative can only be achieved by establishing a dedicated modelling team based on the commitment of adequate funding support from the interested parties. Link with existing initiatives in Member States, Regional Sea Conventions and Horizon 2020 project would also be essential.
- When considering the actual state of the art we must conclude that only the

atmosphere and hydrology modelling parts do perform homogenous simulations of the overall European region. Marine hydrodynamic simulations (they are computationally more demanding) are still region specific with only a few first attempts to build up a European Regionals Seas model.

- The situation for biogeochemical, ecosystem and food web modelling is even much worse, as only very focused, scattered and region specific implementations are currently done and this may be even the only feasible approach at the current state of knowledge.
- The implementation and application of all current existing models (atmosphere, hydrological, hydrodynamic and ecosystem) is fundamentally depending on the spatial scale under consideration. Therefore the a priori choice of the appropriate scale relevant for investigating MFSD related policy options is very important.
- Existing models are for expert users only. To allow broader use additional components comprising a user interface and data pre- and post-processing tools need to be specifically developed for the toolbox.
- Missing data sets for a pan-European hydrodynamic model implementation are for example consistent initial and boundary conditions (temperature, salinity, currents and tides). Pan-European maps covering the bottom type, e.g. sediment, sandy, rocky and so on and with that the relevant bottom friction coefficients are missing for accurate simulations. First attempts in this direction (EMODNET, emodnet.eu, SEADATANET) are still under development and do not yet have full coverage of the European regional Seas.
- There are still many gaps in all the datasets, but this is especially valid for chemical data (nutrients, pollutants) and biological data (phytoplankton, zooplankton and higher trophic levels).
- The development of an advanced database covering relevant data on an at least pan-European scale would be required for adequate model parameterisation across the different European Basins.

All current models do suffer from incomplete knowledge of even relevant processes and therefore do require substantial investments and progress in basic research before a new level of accuracy in the simulations could be expected. Atmosphere models are belonging to the second oldest and most advanced model class (after tidal models), but there is still no physical exact cloud modelling incorporated, clouds are simulated via approximate process parameterizations. Therefore the simulation of the water cycle (precipitation and evaporation) is often inaccurate. The physical exact treatment of convection (relevant for clouds and ocean downwelling) or of turbulence is still not achieved. Serious model bias (temperature and humidity) is an unsolved problem of all current General Circulation Models (GCM). This degree of missing knowledge of even fundamental processes is much higher for the more recent model developments as biogeochemical, ecosystem and food web modelling. It must be further kept in mind that already the transformation of a model used in the scientific community to an operational model (one that is run every day) is a large task even for atmosphere and ocean models, as could be seen at the European Centre for Medium term Weather Forecasting (ECMWF).

8.0 ROADMAP/WAY FORWARD

8.1 Introduction

This document is the first step in the establishment of a strategic framework for the development of a modelling toolbox in support of EU marine and maritime policy. The initial emphasis is on the requirements available to support the descriptors for the Marine Strategy Framework Directive but eventually the toolbox should be a resource for all environmental aspects of EU marine and maritime polices, including assessment of impacts of initiatives in the Blue Growth Strategy.

The approach adopted is intentionally open and inclusive, and has been designed so that all the relevant potential contributions can be taken into account. The current report is a snapshot of current capability, but the framework proposed should be flexible and generalizable so as to be periodically updated to take into account the latest state-of-the-art (i.e. resulting from the output of FP7 and Horizon 2020 projects and activities in Member States). In the long term also the modelling of socio-economic consequences, costs/benefits, costs effective measures should be considered as features of the marine modelling toolbox.

In recognition of the need to obtain the maximum degree of consensus at this early stage in the process, the level of definition of the architecture is necessarily high-level and conceptual. That said there is opportunity to enter, subsequently, into higher level of detail on the individual model toolbox component to analyse their implementation implications as required.

Once consensus has been achieved on the overall approach, it is anticipated that work can begin relatively quickly on assessing the capabilities of the model toolbox to provide the relevant information in support of the MSFD descriptors and eventual scenarios required. Of importance, in parallel a systematic inventory of EU modelling capability for the various categories should be maintained and updated, to capture future development that may be considered for integration in the toolbox (this inventory may be hosted in the Marine Competence Centre - MCC).

In recognition of the incremental nature of the process, short and medium term activities are proposed for the development of the modelling toolbox. It is expected that short-term activities would be undertaken in the next 2 years, and medium-term activities would be undertaken in the next 2-4 years. In the short term the focus will be on achieving consensus on the general approach. This will involve engaging with the relevant entities (Universities/MS) with competence and interest on modelling activities for the marine environment.

8.2 Roadmap: draft general outline

Here we propose a general multi-stage approach that could be realized over the coming years. The basic idea is to begin (stage 1) with a regional setup, using only the core modelling components in hindcast mode. All required input and forcing data will be collected and prepared (initial and boundary conditions, discharge, nutrient inputs, atmospheric forcing).

The core modelling components will be set up (hydrodynamic model, ecosystem model (LTL)) to ensure their proper communication. We propose to use the Mediterranean Sea model as test bed for this exercise. The scenario simulations will cover the period from 1960 for hindcasts (because of highest data availability) and until 2050 for projections into the future. For assessing the baseline and for thorough model validation hindcast simulations are essential before any meaningful projections could be attempted.

Stage 1 can be considered as proof of concept and will allow early revision of the overall concept and the proposed milestones should be reviewed annually. Testing and selection of appropriate models will be carried out during this stage, as well as validation of the Mediterranean Sea setup.

Considering that such a modelling toolbox may also used by other groups/scientists, additional components to ease usage are required, such as a user interface and data pre- and post-processing tools. The user interface will also be designed and developed following a multi-stage approach, and will be tested and reviewed in tandem with the modelling tools.

During stage 2 the Mediterranean Sea setup will be extended to include a hydrological model to simulate riverine discharge and nutrient inputs, as well as the first version of the user interface.

The basic proof of concept will be extended to cover also extended validation of the system. Thereafter the system will be implemented and validated for each of the other regional seas, as well as the European Shelf area. Only after satisfactory and final approval of each of the separate systems for all the European regional seas will the final phase attempt to combine them into one large European implementation of the Marine Ecosystem Modelling Toolbox. The development of socio-economic models that are capable of considering costs/benefits of measures within the marine environment is still in its infancy, but shall be included in the longer term.

8.3 Resource planning: draft general outline

The design, development and implementation of a “ready to use” marine ecosystem modeling toolbox for European Regional Seas is a huge and challenging undertaking. The current state-of-the-art of most model classes relevant to MFSD could be characterized as individual research tools. Typically, they are designed to address one specific problem in an ecosystem and can be used by one researcher on one dedicated informatics infrastructure. Only some hydrologic and some hydrodynamic models are used in some agencies in an operational way. These operational models are tailored for a specific task, as simulating the German Bight, which means that they cannot be used of "the shelf" for other purposes. Compared to operational weather forecasting, marine ecosystem modeling comprises several more complex disciplines and is still in its very early infancy. But already the resources spent on the development of operational weather models are in the order of several 100 million Euros every year in Europe. The coupling of every single further model component to the weather model (ice model, wave model) again took many years, many scientists and many professional programmers for code optimization. By comparing the sheer size of the task "marine ecosystem modeling", it should be clear that the real solution to this task does require resources (human and IT) that are at least comparable if not larger than that of operational weather forecasting.

As the appointing of resources in this order of magnitude is very unlikely, the major task is to tailor the whole design, development and implementation process in such pieces that can be realised with the available resources. Moreover, the informatics infrastructure must guarantee continuous access to high performance computing resources (~1000 computing cores, in-house and external). The input and validation data gathering and especially the huge amount of output data generated do require dedicated data storage and archiving capacities in the order of 0.5-1 Petabyte.

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ANNEX 1

Scenarios from the different relevant policies

A1.1 Common Agricultural Policy (CAP) scenarios

On 26 June 2013 a political agreement on the reform of the Common Agricultural Policy (CAP) has been reached between the Commission, the European Parliament and the Council. It includes some novelties, among which a number of measures aiming at improving environmental sustainability. These concern:

- 'Greening' of 30% of direct payments will be linked to three environmentally-friendly farming practices: crop diversification, maintaining permanent grassland and conserving 5%, and later 7%, of areas of ecological interest as from 2018 or measures considered to have at least equivalent environmental benefits.
- At least 30% of the rural development programmes' budget will have to be allocated to agri-environmental measures, support for organic farming or projects associated with environmentally friendly investment or innovation measures.
- Agri-environmental measures will be stepped up to complement greening practices. These programmes will have to set and meet higher environmental protection targets (guarantee against double funding).

The implementation of the measures part of the political agreement constitute the baseline (or BAU - Business As Usual) scenario.

The CAP is modelled via the CAPRI (CAP Regionalised Impact) model, a global agricultural sector model with focus on EU27, Norway, Turkey and Western Balkans. The model can be used to assess policy impact on the environment at a detailed spatial scale (clusters of 1 km cells). Within JRC, CAPRI scenarios are defined at JRC/IPTS. CAPRI results can be linked to the Land Use Modelling Platform (LUMP) available at JRC/IES/H08 (http://ec.europa.eu/environment/enveco/impact_studies/pdf/Final%20CAP_report.pdf)

Biofuels. The biofuel baseline scenario is defined by JRC/IPTS in this document: http://ftp.jrc.es/EURdoc/JRC80037.pdf. It relies on the forecast and expert knowledge provided by recent projections from the AgLink and PRIMES models, and on an established biofuel database. It is built in the CAPRI (CAP Regionalised Impact) model, which assumes a biofuel energy share of about 8.5% in total transport fuel consumption for the EU27 average in 2020. This comes approximately with 7% consisting of 1st generation biofuels and 1.5% consisting of 2nd generation biofuels. For obvious reasons, the overall assumption underlying the biofuel baseline and every biofuel scenario is predominantly CAP specifications.

The model allows for simulating a variety of biofuels scenarios, including:

- Quota obligations for ethanol and biodiesel
- Tax rates for ethanol, biodiesel, gasoline and diesel
- Import tariffs for ethanol and biodiesel
- Availability of 2nd generation biofuels
- Technical progress in 1st and 2nd generation technologies for biofuels

Other CAP scenarios. Through the CAPRI modelling platform a number of other CAP scenarios can be run. These can be very different and may concern the maximization of agricultural production, the enhancement of constraints in environmental protection, the application of specific measures linked to other environmental legislation (e.g.Nitrates Directive), a different degree of uptake of Rural Development Schemes (CAP Pillar 2) etc.

A1.2 Nitrate Directive (ND) and Urban Waste Water Treatment Directive (UWWTD)

In order to support the implementation of the Marine Strategy Framework Directive (2008/56/EC), DG Environment and the Joint Research Centre jointly developed a study on the expected cumulative impact of existing EU environmental legislation on the quality of the marine environment, with specific reference to the case of aquatic discharges from inland-based sources. The study focussed in particular on the discharges of nitrogen and phosphorus. In the first stage of the study a retrospective assessment was carried out for years 1985-2005 of N and P discharge into all European seas. The second phase focused on testing various scenarios related to the application of existing EU legislation, namely the ND and the UWWTD, already adopted by Members states or with ongoing implementation. We tested the following scenarios and their impacts on nutrient emissions to European Seas:

1. The 2020 baseline scenario (BAU) - built on a medium term outlook. The baseline incorporates moderate yield increases for crops in Europe and some input technical saving progress, so that fertilizer application at unchanged yields would drop. In this scenario both extensive and intensive grassland decrease (-5% in area), while industrial crop (+43%) or soya (+116%) greatly increase. It captures the impact of the recent CAP reform steps, the end of obligatory set-

aside (-100%) in favor of voluntary set-aside (+30%).

2. The World Health Organization (WHO) scenario. This scenario aims at mimicking the impact on agriculture of a change of human diet by decreasing the intake of animal based proteins. Total area devoted either to cropland or grassland is not greatly impacted by a hypothetical change in diet. This scenario assume a lower per capita consumption of meat and a higher consumption of proteins and fats through vegetable oils (+3.5%) and to a lesser extent fruits (+2%) and vegetables (+4.5%).

3. Optimized manure application scenario- In this scenario, an optimal use of the amount of animal manure locally produced is considered. In this optimization procedure, the available amount of manure is first applied on grassland area and the remaining part is then used as crop fertilizer. In both case, supplies of phosphorus manure and nitrogen manure cannot exceed the net demand of the plant (either grass or crop). In case of nutrient deficiency, mineral fertilizer is added.

A1.3 Common Fisheries Policy (CFP) scenarios

Regarding fisheries and the commercially exploited stocks, the CFP and its outcomes have a direct effect on MSFD Good Environmental Status. Descriptor 3 is directly related with main goals of the CFP. But also descriptor 1 and descriptor 4 of the MSFD, though not so intimately connect, given the scope goes beyond commercially exploited stocks, are directly impacted from the CFP. In parallel the CFP Reform foresees, as a technical measure, to mitigate the impact of fishing gear on the ecosystem and the environment, with particular regard to the protection of biologically sensitive stocks and habitats in agreement with the conservation of natural habitats and of wild fauna and flora and marine protected areas (MSFD).

Requirements of the MSFD: in scientific terms, Descriptor 3 has various implications. Stocks should be,(1) exploited sustainably consistent with high long-term yields, (2) have full reproductive capacity in order to maintain stock biomass, and (3) the proportion of older and larger fish/shellfish should be maintained (or increased) being an indicator of a healthy stock. In the Commission Decision 2010/477/EU three criteria including methodological standards were described for descriptor 3:

Criterion 3.1 Level of pressure of the fishing activity

- Primary indicator: Fishing mortality (F)
- Secondary indicator (if analytical assessments yielding values for F are not available): Ratio between catch and biomass index (hereinafter ‘catch/biomass ratio’)

Criterion 3.2 Reproductive capacity of the stock

- Primary indicator: Spawning Stock Biomass (SSB)
- Secondary indicator (if analytical assessments yielding values for SSB are not available): Biomass indices

Criterion 3.3 Population age and size distribution

- Primary indicator: Proportion of fish larger than the mean size of first sexual maturation
- Primary indicator: Mean maximum length across all species found in research vessel surveys
- Primary indicator: 95% percentile of the fish length distribution observed in research vessel surveys
- Secondary indicator: Size at first sexual maturation, which may reflect the extent of undesirable genetic effects of exploitation

The CFP has undergone a major reform which overarching aim is to end overfishing and make fishing sustainable environmentally, economically and socially. The new policy entered into force on January 1st, 2014. Regarding the MSFD, the elements of the new policy which are directly connected, include bringing fish stocks above sustainable levels by 1) banning discarding, 2) better management of fishing fleet capacity and 3) the setting of fishing opportunities based on scientific advice.

Given the criteria and indicators in place to measure the achievements on MSFD regarding to GES, **three generic CFP implementation scenarios can be considered (with direct impact on the achievements of GES under descriptor 3)**:

1. A **reduced implementation of long-term management plans (LTMP)**.

   The assumption of the status quo analysis is that long-term management plans will be in place for all stocks for which a LTMP has: already been adopted; is currently being developed; or, is planned to be developed. However it is not currently clear whether the European Commission will have the capacity to effectively implement this assumed number of LTMPs.

2. A **weak implementation of the technical measures and new discard policy**.

   There is a major impact of the technical measures that can be adopted to support avoiding unwanted catches. These measures can be more selective gear, restricting access to juvenile aggregation areas, real time closures, fishing quotas that take into account mix fisheries management, etc. However the effectiveness of these measures depends on the level of compliance with the measures by the fishing industry and the capacity of the Member States to effectively monitor and control fishing activities.

3. **Constraints to scientific advice due to data limitations**.

   Having a good scientific data support will improve the effectiveness of actions intended to eliminate overcapacity and overfishing, which requires having reliable data on fishing activities and population dynamics. This data availability might not improve in the way it was expected due to constraints on the implementation of the Data Collection Framework.

One appropriate modeling tool for complex scenarios testing in fisheries is the Management Strategy Evaluation (MSE). MSE is a general framework aimed at designing and testing Management Policies (MP) which specify decision rules for setting and adjusting Total Allowable Catches (TACs) or effort levels to achieve a set of fishery management objectives. Simulation testing is used to determine the extent to which a MP is robust to uncertainty, and MPs are usually selected so that there is a reasonable likelihood that the (pre-specified and quantified) management goals can be satisfied.
The in-house implementation of MSE algorithms is being done through the JRC initiative A4A (https://fishreg.jrc.ec.europa.eu/web/a4a), implemented with the FLR tool box, an open-source framework in R. A large part of the FLR developments and maintenance is being assumed by JRC/FishReg.

Regarding the protection of bottom habitat, a spatial tool is being developed using Vessel Monitoring System (VMS) data of bottom trawlers to estimate their impact and potentially to evaluate a management policy. The report on the evaluation of fishing effort regimes of Scientific, Technical and Economic Committee for Fisheries (STECF) estimates the effort by gear at low resolution (ICES regions). More detailed mapping (3' grid) was performed for the North Sea, the Celtic Sea and Scottish Shelf in the frame of the 2010 STECF Report on the Development of the Ecosystem Approach to Fisheries Management (EAFM) in European seas.

A1.4 The Biodiversity Strategy

A contribution to the definition of scenarios can also come from the work carried out under the Working Group on Mapping and Assessment of Ecosystems and the Services they provide (WG MAES), within the CIF of the Biodiversity Strategy (BD). Target 4 of the BD (Ensure the sustainable use of fisheries resources) has particular relevance for Descriptor 3 in Annex 1 of the MSFD. Within the ecosystem service mapping activities at JRC, the ECOPATH with ECOSIM (EwE) model has been adopted for the mapping and assessment of selected provisioning and regulation and maintenance service classes. The model can be used to test various hypothesis for the management of fisheries resources, allowing to evaluate of the status of each component (by individual species or functional group), from benthic organisms to large mammals, and the related effects on the trophic chain under the selected management rule. The same model can also be used to evaluate options under the CFP scenarios presented in the previous paragraph.

ANNEX 2

Detailed description of the main models used at JRC in relation to MFSD indicators

A2.1 Hydrological modelling

The models described hereafter are already integrated in the hydro-economic modelling platform described at the beginning of this document. The modules reported here are those of immediate use for the assessment of MSFD descriptors.

Under the acronym of FATE we identify activities at the JRC that aims at assessing and monitoring the fate and impacts of pollutants in terrestrial and aquatic ecosystems in Europe. Modelling is a key component of FATE. A tiered approach has been setup for addressing nutrient fate at various scales that makes use of readily available data at EU level. Firstly (tier 1) a statistical approach (GREEN) is used at large-river basin scale as a screening tool to identify catchments where nutrient losses are the highest and/or can cause a threat to water bodies. In the subsequent step (tier 2 and 3), physically-based models (SWAT, EPIC) are used to identify within those areas the major processes and pathways controlling and contributing to nutrient losses and to elaborate appropriate farming practices that could reduce pollution load without endangering the farm economic sustainability.

GREEN is a statistical model that contains a simplified representation of the processes of nutrient transport and retention in the river basin and a geospatial representation of the nutrient sources and physical characteristics that influence nutrient processes. To apply the model, the area of study is divided into a number of sub-basins that are connected according to the river network structure. GREEN distinguishes between diffuse and point sources of nutrients. The first includes mineral fertilizers, manure applications, atmospheric deposition (only for nitrogen), crop fixation (only for nitrogen), and scattered dwellings, while the latter consists of industrial and waste water treatment discharges. For each sub-basin, the model considers the input of nutrient diffuse sources and point sources and estimates the nutrient fraction retained during the transport from land to surface water and the nutrient fraction retained in the river segment. In the model, nutrient retention is computed on an annual basis and includes permanent and temporal removal. Diffuse sources are reduced both by the processes occurring in the land (crop uptake, denitrification, and soil storage), and those occurring in the aquatic system (aquatic plant and microorganism uptake, sedimentation and denitrification), while point sources are considered to reach directly the surface waters and therefore are affected only by the river retention. The model is used to calculate diffuse emissions, which are the nutrient losses reaching the surface water through different pathways after crop uptake, soil and groundwater retention, and to perform a nitrogen source apportionment, which is the sectorial allocation of nitrogen and phosphorus load to various activities or origins. In addition, the water flow was modelled for each sub-basin as the difference between the annual rainfall and the actual evapotranspiration computed according to a Budyko type of curve. The ratio between the nutrient loads and the water flow yields the concentration of nitrogen and phosphorus at any point in the river basin. Major inputs to the model include annual climatic data, hydromorphological data and annual nitrogen and phosphorus inputs.

A2.2 Hydrodynamic modelling

The hydrodynamics for all the JRC models are solved by the 3D General Estuarine Transport Model (GETM, http://www.getm.eu) interfaced with the General Ocean Turbulence Model (GOTM, http://www.gotm.net/) for turbulent mixing (figure 4). GETM was developed at the JRC and is now widely used in marine applications (see, for example, Stips et al., 2004). GETM calculates the horizontal transport as it is affected by the tides, the wind and the river discharges and GOTM calculates the vertical transport, as controlled by the meteorology (solar irradiance, wind, air temperature, evaporation, precipitation and humidity). The outputs are three dimensional fields of physical variables such as temperature, salinity, and currents for each time step.

A wide number of open source hydrodynamic models that can be linked with various biogeochemical models are used elsewhere (for example, NEMO, http://www.nemo-ocean.eu/; ROMS, http://www.myroms.org/; POM, http://www.aos.princeton.edu/WWWPUBLIC/htdocs.pom/). These models are based on similar principles to GETM and there is no obvious advantage to changing the hydrodynamic model used at JRC. Such a change would imply, however, a significant time disadvantage in terms of staff training and model development.

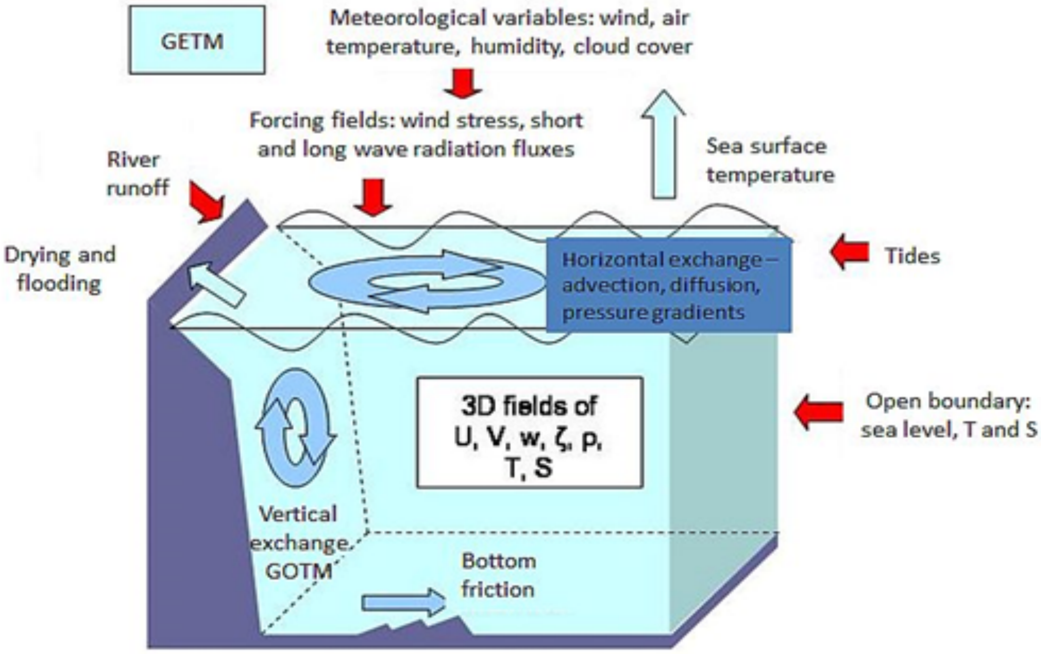

Figure 4. GETM model.

A2.3 Biogeochemical modelling

The range of available biogeochemical models extends from the simplest nutrient/phytoplankton/zooplankton/detritus (NPZD) models to complex models with 20 or more components including different types of plankton, multiple nutrients and a microbial loop (e.g. Vichi et al., 2007). Biogeochemical modelling at JRC started with simple NPZD models, but development has moved towards the more complex models including several compartments at each trophic level. Although these models are state-of-the-art research tools, they are nevertheless still a highly simplified representation of the real ecosystem and the choice of model is related to the question being asked. At JRC, the most appropriate biogeochemical model is used for each region, depending on the region's characteristics and the types of questions being answered.

GETM is coupled operatively with several biogeochemical models via the Framework for Aquatic Biogeochemical Models (FABM, Bruggeman et al., 2014). FABM is a general framework that links the physical model (GETM) with a range of biogeochemical models through two-way coupling of water column physics and biogeochemistry. The biogeochemistry is modified by vertical mixing, temperature and salinity dependence of process rates, and light availability, whereas the feedback from biogeochemistry to the water column is mainly due to modified turbidity (Burchard et al., 2006). The physical-biogeochemical coupled model produces three-dimensional fields of the physical and biogeochemical ocean variables for each time step.

Running these models requires a high level of experience and there is a significant amount of pre-processing of input data as well as output data required. Therefore the realisation process would necessarily be iterative, starting with implementing simplified demonstration cases that are based on predefined regions, data sets and scenarios.

A2.3.1 ERGOM

The Ecological Regional Ocean Model (ERGOM, Neumann et al., 2002) includes nine state variables, including three nutrients - dissolved ammonium, nitrate and phosphate (figure 5). Primary production is provided by three functional phytoplankton groups: diatoms, flagellates and blue-green algae (cyanobacteria). One zooplankton variable provides grazing pressure on phytoplankton. Dead particles are accumulated in detritus and oxygen concentration controls processes such as denitrification and nitrification.

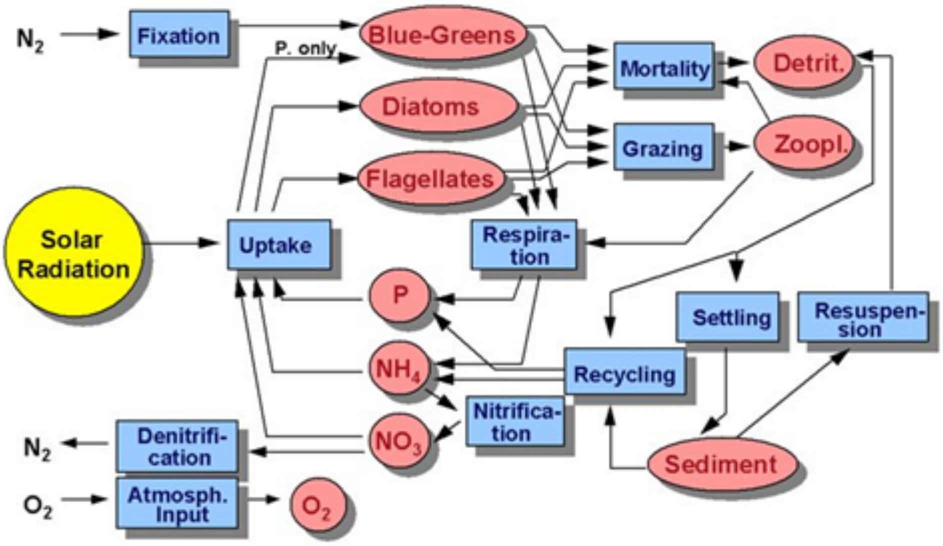

Figure 5. ERGOM.

JRC has a 5'x5', 25-layer GETM/ERGOM system for the Mediterranean Sea that has been run within a time window including January 1960 to December 2012, and a 2'x2', 25 layer Baltic model.

A2.3.2 ERSEM

The European Regional Seas Ecosystem Model (ERSEM, see Baretta et al., 1995; Ruardij & van Raaphorst, 1995; Ruardij, 1997; Vichi et al., 2004; Ruardij et al., 2005; http://www.nioz.nl/getm-ersem-setup) describes the dynamics of the biogeochemical fluxes within the pelagic and benthic environment. ERSEM is called directly from GETM (figure 6). A silt model calculates the silt content in the water, which largely determines the underwater light climate for the phytoplankton.

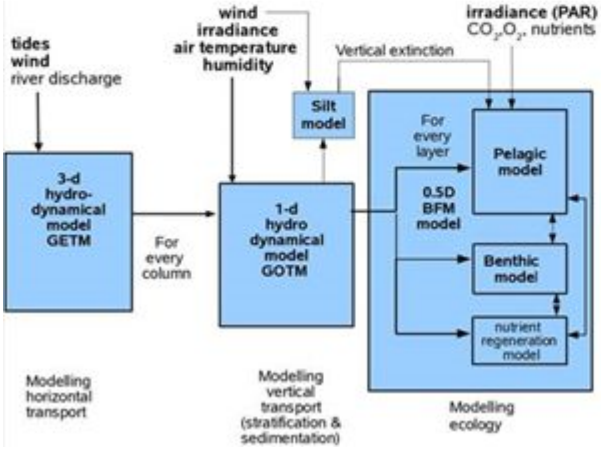

Figure 6. ERSEM and links to GETM.

ERSEM simulates the cycles of carbon, nitrogen, phosphorus, silicate and oxygen and allows for variable internal nutrient ratios inside organisms, based on external availability and physiological status. It contains four phytoplankton functional groups, four zooplankton functional groups and five benthic functional groups (Figure 7). Pelagic and benthic bacteria, both aerobic and anaerobic, are also included. The sediment is subdivided into three layers of time-varying depths: an oxic layer, a denitrification layer and an anoxic layer.

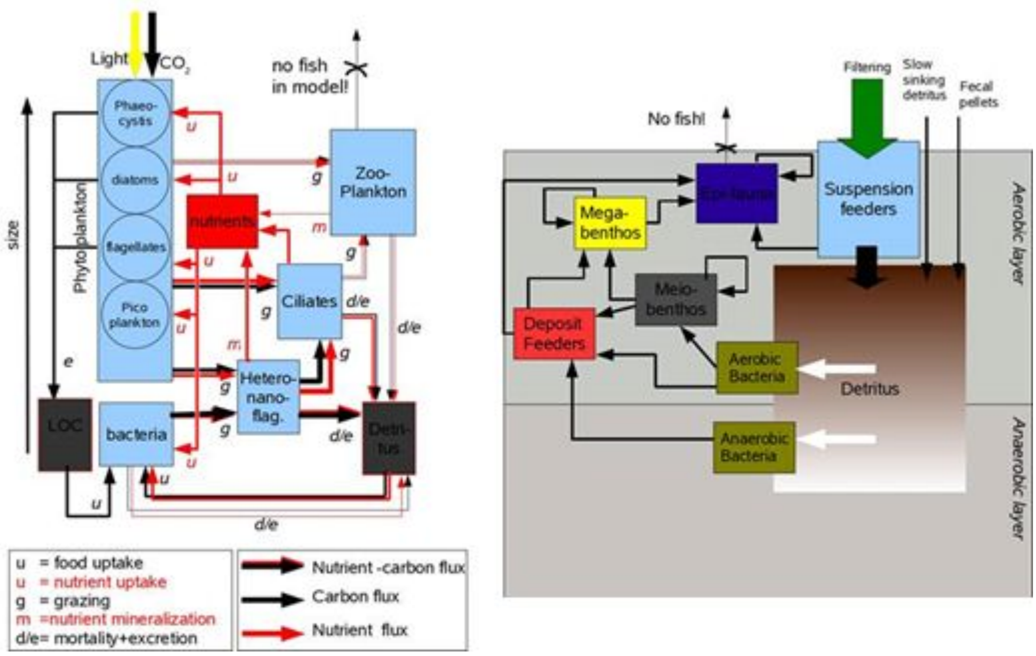

Figure 6. Pelagic food web (left) and benthic food web (right) in ERSEM.

JRC is currently developing a 3’x3’, 25 layer GETM/ERSEM European Shelf Sea model. ERSEM is the most appropriate biogeochemical model for this region, as large areas of the shelf are shallow and the sea bed plays an important role.

A2.4 Food web modelling

The higher trophic level model used at the JRC is a free ecological/ecosystem modeling software suite called Ecopath with Ecosim (EwE, Pauly et al. 2000; Christensen and Walters 2004; http://www.ecopath.org). The model was originally developed at the Fisheries Centre of the University of British Columbia, Vancouver (Canada) and has around 6000 registered users in 155 countries (data from 2010) and more than 600 academic publications to date (ProQuest, 2012).

EwE has three main components:

1) Ecopath, the mass balanced component of the model that provides a static description of an ecosystem at a precise period in time. It can describe principal species of autotrophs and heterotrophs individually or by aggregating them into functional groups (species with a similar ecotrophic role), while incorporating data on biomass, total food consumption rate, total biological production rate, and diet composition (expressed as a fraction of prey in the average diet of a predator). Fishing activities can also be included by adding data on landings, discards, and bycatch, as well as bioeconomic parameters (i.e. value of landings and cost of fishing). Figure 8 illustrates schematically the food web model.

2) Ecosim, the time-dynamic component of Ecopath that assesses temporal changes in biomass of selected species or group of species under several scenarios (e.g., business as usual, increase in fishing pressure, increase in temperature).

3) Ecospace, the spatial-dynamic component of Ecopath that considers all the key parameters of Ecosim; it creates habitat maps and looks at the distribution of species spatially and temporally. Ecospace allows also exploration of policies such as marine protected areas, while accounting for spatial dispersal/advection effects and migration (Christensen and Walters 2004).

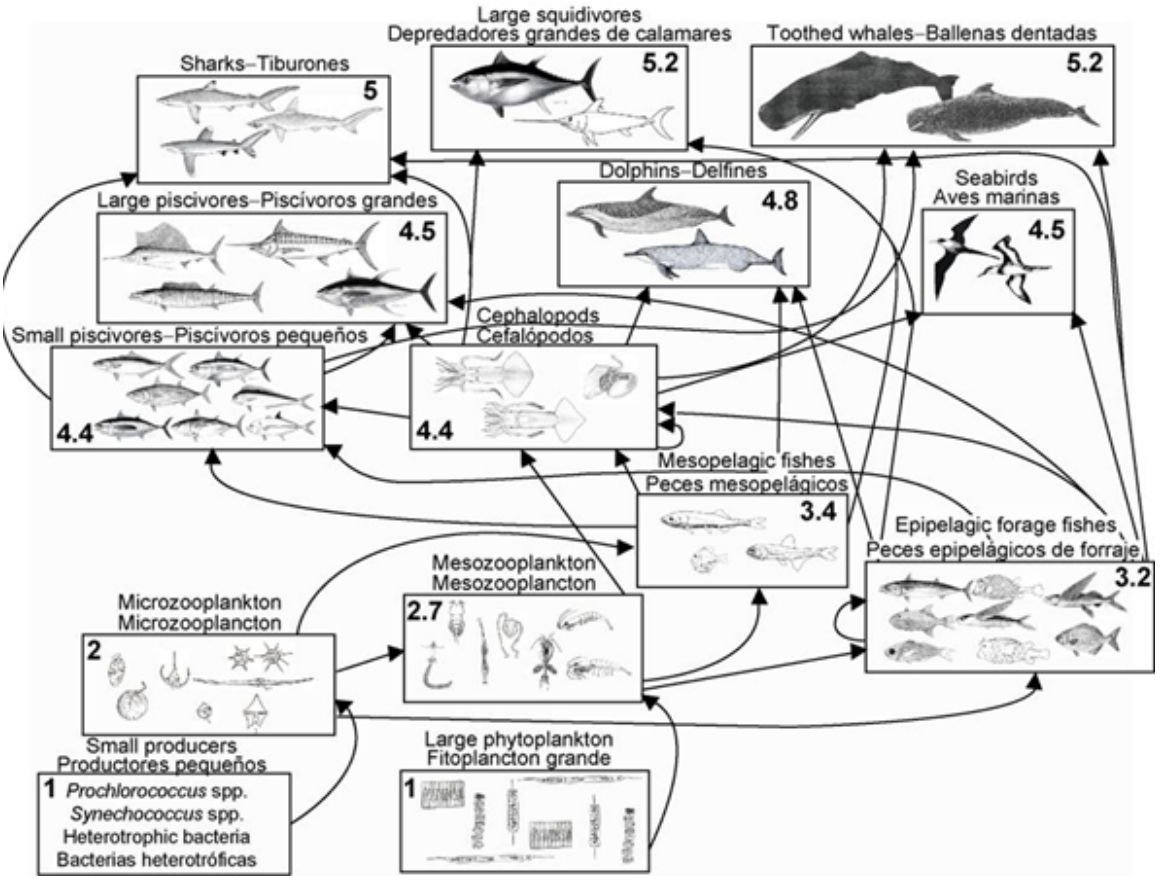

Figure 8. Graphic representation of an Ecopath food web model with trophic level numbers (in bold) per each functional group.

This software can be implemented at global, regional or subregional sea scale (examples in the literature cover all of these scales) and it can run at any temporal/spatial resolution depending mainly on input data/quality. Recently, the Institute for European Environmental Policy concluded that, among the available models of marine ecosystems, EwE was the most suitable for the development of scenarios for exploring future trends of marine biodiversity and changes in ecosystem services (Sukhdev 2008). Also in 2007, it was named as one of the ten biggest scientific breakthroughs in NOAA’s 200-year history (http://celebrating200years.noaa.gov/breakthroughs/ecopath/).

The main model outputs are the following:

1) Temporal biomasses for each species included in the ecosystem (tons x km-2)
2) Spatial distribution of species and simulation of patterns (shapefiles)
3) Ecosystem indicators (unitless), among all:
a) Cycling index: fraction of an ecosystem’s throughput that is recycled
b) Predatory cycling index: same as cycling but with detritus groups excluded.
c) Cycles and pathways: a routine presents the numerous cycles and pathways that are defined by the food web
d) Connectance index: defined for a given food web as the ratio of the number of actual links to the number of possible links. Feeding on detritus (by detritivores) is included in

the count, but the opposite links (i.e. detritus 'feeding' on other groups) are disregarded.
e) System omnivory index: defined as the average omnivory index of all consumers weighted by the logarithm of each consumer's food intake. The system omnivory index is a measure of how the feeding interactions are distributed between trophic levels.
f) Trophic level decomposition: aggregates the system into discrete trophic levels sensu Lindeman
g) Trophic transfer efficiencies: calculated for a given trophic level as the ratio between the sum of the exports plus the flow that is transferred from one trophic level to the next, and the throughput on the trophic level. The transfer efficiencies are used for construction of trophic pyramids, and others.
h) Primary production required (PPR): to estimate the PPR to sustain the catches and the consumption by the trophic groups in an ecosystem the following procedure is used.
i) Mixed trophic impact (MTI): assess the direct and indirect interactions between the species of the ecosystem.
l) Kempton Q index: species diversity index
m) Demersal/pelagic ratio
n) Top predators/total biomass
o) Total invertebrates biomass/total biomass
p) Total endangered species/total biomass

The Ewe derived indicators can be used to answer a variety of policy questions, such as:
- **CFP** by assessing the harvest of each species at maximum sustainable yield (MSY) or by evaluating the Marine Strategy Evaluation (MSE) that sets several regulatory rules like target fishing mortality (F), fixed F, escapement or TAC (total allowable catch) via input (fishing effort) or output (quota, fishing mortality) controls.
- **Biodiversity strategy** by evaluating the impact of multiple stressors on specific marine ecosystems and in particular on (target and non-target) species and megafauna.
- **MSFD strategy** by describing ecosystem resources and their interactions, evaluating ecosystem effects of fishing and/or environmental changes, predicting bioaccumulation of pollutants and exploring policy options (incorporating economic, social and ecological considerations)

At the JRC, two food web models were built for the Mediterranean Sea for the 1950s and 2000s using Ecopath with Ecosim (EwE) software. To best represent the entire Mediterranean Sea ecosystem, taking into account differences in environmental and biological characteristics, both models were divided in 4 sub models following the four sub-regions division given by the Marine Strategy Framework Directive: I) Western Mediterranean Sea (W); II) Adriatic Sea (A); III) Ionian and Central Mediterranean Sea (I); IV) Aegean and Levantine Sea (E). As for functional groups, we split marine mammals in piscivores feeding cetaceans (mainly dolphins), other feeding cetaceans (mainly whales) and pinnipeds; fish species were divided in sharks, rays and skates, deep fish (mainly mesopelagic, bathypelagic and bathydemersal), pelagic and demersal. These last two groups were further divided in 'small' (common length <30cm), 'medium' (between 30-89cm) and 'large' (≥ 90cm). Invertebrates were separated in cephalopods, crustaceans, jellyfishes, benthos, zooplankton while primary producers in phytoplankton and seagrass. Each subdivision had the same functional groups categories except for highly migratory species as other feeding cetaceans, large pelagics (e.g., tuna species and swordfish) and sea turtles groups that were allowed to move and feed in all the four areas. European hake, European pilchard and European anchovy were considered individually due to their importance in the trophic web. As result, a total of 87 functional groups were modelled. For each group, five input parameters were estimated: biomass, production per unit of biomass (P/B), consumption per unit of biomass (Q/B), diet composition (DC) and catch (Y). The biomass of each functional group, expressed as tonnes (t) of wet weight per km2, was obtained from field surveys, estimated from empirical equations of population reconstruction or assessed by biogeochemical models. The P/B and Q/B ratio were estimated using empirical equations (Christensen et al., 2004) or were taken from literature and expressed as annual rates (t km-2year-1). A diet composition matrix was constructed using either field studies (e.g., stomach contents) or diet data obtained from the literature for the same species in similar ecosystems. The official landing data by species and by country were taken from the United Nation's Food and Agriculture Organization (FAO) database (FishStat) and available from 1950 to 2010. This time series was then complemented with data from Sea Around database (www.searoundus.org) to assign species to fishing fleet. In particular we were able to consider 6 commercial types of fisheries: trawlers, dredges, mid- water trawlers, purse seiners, long liners, artisanal fisheries. Recreational fishery was also included using data coming from the Sea Around Us database (in the case of Italy, Spain) and from literature review. We estimated the percentage of discards and the species discarded mainly using reports and scientific papers available in the literature. In 2014, the Mediterranean 1950 model will be run with time series data using fishing effort and changes in primary production as drivers and future scenarios will be built. Also an Ecospace model will be built for the entire Mediterranean basin, possibly at 0.1 resolution scale. Different layers would be used to define Mediterranean habitats:

1- Depth
2- Temperature
3- Salinity
4- Primary production

The EMIS database (http://emis.jrc.ec.europa.eu) will be used to extract this information; other sources will be consulted in case of refiner habitat maps (e.g., NOAA). Each functional group will be assigned to habitats accordingly to their "likelihood" of presence and species distribution maps will be created. Catch by species will also be mapped spatially. These output maps will be extracted from Ecospace and loaded in GIS to create biodiversity maps. Last but not least indicators could be explored spatially; among all, trophic levels of community that is an important indicators for MSFD but also for ecosystem services.

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