Implementing the European Marine Strategy Framework Directive: scientific challenges and opportunities

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Background: The Marine Strategy Framework Directive (MSFD; EC, 2008) is an ambitious European policy instrument that aims to achieve Good Environmental Status (GES) in the 5 720 000 km^2 of European seas by 2020, using an Ecosystem Approach. GES is to be assessed using 11 descriptors and up to 56 indicators (European Commission, 2010), and the goal is for clean, healthy and productive seas that are the basis for marine-based development, known as Blue-Growth. The MSFD is one of many policy instruments, such as the Water Framework Directive, the Common Fisheries Policy and the Habitats Directive that together should result in "*Healthy Oceans and Productive Ecosystems*-HOPE". Researchers working together with stakeholders such as the Member States environmental agencies, the European Environmental Agency, and the Regional Sea Conventions, are to provide the scientific knowledge basis for the implementation of the MSFD. This represents both a fascinating challenge and a stimulating opportunity.

Context: Scientists have not been idle since the publication of the MSFD in 2008, and even before (Borja, 2006). A SCOPUS search of journals (July 2015) found more than 300 articles related to the MSFD. Several research projects both at EU and national level address the scientific challenges (*e.g.* DEVOTES –www.devotes-project.eu-, KnowSeas, STAGES, Perseus and many more). Furthermore, special sessions have been organized at conferences, including *"Impacts of anthropogenic pressures on coastal ecosystem functioning and services"* organized in May 2014 at the European Geosciences Union (EGU) and the June 2014 special session "*Marine environmental status and biodiversity: from structure to functionality, delivering ecosystem services*" at the Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) conference.

The papers following this short editorial illustrate some of the discussions that took place at these meetings. They especially address descriptor 5, eutrophication (Ciglenecki *et al.*, 2015; Cristina *et al.*, 2015; and Pavlidou *et al.*, 2015). Together the papers present an interesting gradient of eutrophication assessment from a sheltered bay (Rogoznica Lake in the Adriatic, Croatia (Ciglenecki *et al.*, 2015), to coastal examples in the Eastern Mediterranean (Pavlidou *et al.*, 2015) and moving to offshore locations in the Iberian Sea (Cristina *et al.*, 2015). This represents a gradient from the Water Framework Directive transitional waters, to coastal waters and then offshore to the Marine Strategy Framework Directive.

Definitions and vocabulary: The text of the MSFD includes many terms and concepts that lacked precise scientific or operational definitions (Andersen *et al*., 2013). McLeod and Leslie (2009) offered a definition of Ecosystem Based Management, but there are still "pitfalls" to this approach (Berg *et al*., 2015). Borja *et al*. (2013) contributed to define GES and the terminology used in the D-P-S-I-R (Driver-Pressure-State-Impact-Response) is being revised and improved (Gari *et al*., 2015).

Social and economic relevance: The integration of the ecological, economic and social aspects is a pillar of the implementation of the ecosystem approach to management of environmental resources. However, the actual implementation of this paradigm faces many challenges, including the need to involve stakeholders (Hendriks *et al*., 2014), despite the difficulty of engaging stakeholders in a really cooperative way (Melaku Canu and Solidoro 2014). Other obstacles are related to (i) issues of scales (Swaney *et al*., 2012), (ii) spatial issues (Zaucha, 2014), that should be addressed by the Marine Spatial Planning Directive, (iii) temporal issues (O'Higgins *et al*., 2014) and, (iv) issues related to the institutional framework. The different directives, legislative tools and the governance are interwoven (Boyes and Elliot, 2014) with obvious overlaps, but also opportunities for synergies, such as the Mediterranean example given by Cinnirella *et al*. (2014).

Progress on the Scientific Knowledge Basis: Monitoring large areas of the regional seas is scientifically challenging and expensive but necessary, in spite of the economic crisis, (Borja and Elliott, 2013). New technological tools such as autonomous submarine gliders may gain increasing importance in monitoring (Suberg *et al*., 2014). Meanwhile, remote sensing can also make an important contribution to monitoring large areas of the regional seas that would be prohibitively expensive using research vessels. Cristina et al (this issue) describes how Medium Resolution Imaging Spectrometer (MERIS) Algal Pigment Index 1 products can be used in order to support the implementation of the MSFD with respect the Descriptor 5 (Eutrophication). The study is applied in SW Iberia and underlines the importance of performing an error estimation of the satellite product before using it for GES assessment and model verification. Combining tools such as Ocean colour with existing techniques such as CHEMTAX (Goela et al., 2014) can be particularly effective, as can innovative tools such as genomics (Bourlat et al., 2013).

In complement to observations, numerical ocean models are widely used tools to describe and project changes in the physical and biogeochemical status of the ocean over time scales of days to several decades (*e.g.* IPCC predictions at the 2100 horizon, IPCC (2013)). During the last twenty years, due to the substantial increase in computing power and based on a better understanding of marine ecosystems, ocean models and coupled hydrodynamical-biogeochemical models have evolved towards increasingly complexity, and can now contribute to integrated ecosystem assessments (Pastres and Solidoro, 2012). Ocean models are now used in operational mode (~7days forecast, *e.g.* http://www.myocean.eu), in the frame of Copernicus, for the prediction of physical and biogeochemical processes (*e.g.* Teruzzi *et al*., 2014). Models allow for space-time inter-extrapolation of observed data and run on the knowledge of physical and ecological processes that is embedded within the model (Cossarini *et al*., 2012). They also provide estimates of indicators and parameters that cannot be measured routinely in monitoring programs. Examples are secondary production and parameters in deep seas that can be used to identify ideal conditions to be used as a reference. Piroddi *et al*. (2015) have reviewed available ecological models to assess status according to the MSFD. Models can also be used to evaluate the effectiveness of alternative restoration management (Melaku Canu *et al*., 2012), and have been used to predict how climate variability and change may be an obstacle to achieving GES (Elliott *et al*., 2015).

However, the assessment of potential changes in some GES indicators, such as biodiversity, poses a perennial problem for ecosystem modellers. These challenges were discussed during the EGU and IMBER thematic sessions that lead to this section of Continental Shelf Research. The main limitation is that biodiversity is usually defined by species richness and/or evenness, whereas at present, ocean biogeochemical models are based on a predefined structure in which the number of species does not change, and actually aggregate large number of species into a single or few state variables. Furthermore, a refined representation of ecosystem models to the species level would increase model uncertainty due to the substantial lack of information to parameterize this type of models (*e.g.* Ruiz and Kuikka, 2012; Bruggerman and Kooijman, 2007). Hence, ocean models are still considered as poor predictors of biodiversity, whereas there is a crucial need to produce reliable projections of the effects of human interventions on living communities (*e.g.* IPBES projections). In conclusion, ocean models are very powerful for the physics, chemistry and low trophic levels but there is a need for innovation so that existing models connect with GES and ecosystem and services. It is therefore urgent to develop specific approaches that are able to connect the outputs of ocean models to some descriptors of GES that are poorly addressed so far. For example, the integration of ecological and end-to-end models (Rose *et al*., 2010) giving quasi real-time assessments of ecological conditions is one of the next steps.

Some studies have a regional sea focus (Fleming-Lehtinen et al., 2015), while some especially focus on one descriptor, for example descriptor 1 (biodiversity) (Strong *et al*., 2015). Thus, another important challenge is how to best aggregate the multiple indicators, descriptors and spatial-temporal scales (Borja *et al*., 2014) and how to assess the environmental status using an integrated tool (Andersen *et al*., 2014). Harmonizing such a tool across the European regional seas will be a pivotal advance in the near future for the timely implementation of the MSFD.

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