Ecosystem **Mo**dels as **S**upport to **E**utrophication **M**anagement In the North Atlantic Ocean (EMoSEM)

Executive Summary

One of the leading challenges in marine science and governance is to improve scientific guidance of management measures to mitigate eutrophication nuisances in the EU seas. Too few approaches integrate the eutrophication process in space (continuum river-ocean) and in time (past, present and future status). A strong need remains for (i) knowledge/identification of all the processes that control eutrophication and its consequences, (ii) consistent and harmonized reference levels assigned to each eutrophication-related indicator, (iii) identification of the main rivers directly or indirectly responsible for eutrophication nuisances in specific areas, (iv) an integrated transboundary approach and (v) realistic short term and long term nutrient reduction scenarios. As a step in this direction, the main objective of EMoSEM was to link the eutrophication nuisances in specific marine regions of the North-East Atlantic (NEA) to river anthropogenic inputs, trace back their sources up to the watersheds, then test nutrient reduction options that might be implemented in these watersheds and propose consistent indicators and reference levels to assess Good Environmental Status (GEnS).

To achieve this objective, the state-of-the-art modelling tools describing the river-ocean continuum in the NEA continental seas have been developed and combined. Three marine ecological models (BIOPCOMS, ECO-MARS3D, MIRO&CO) have been adapted and coupled to a newly developed generic ecological model for European river-basins (PyNuts-Riverstrahler). The modelling tools have been validated against observations. Numerical methods have been included in the marine models to track the origin of nutrients at sea from different sources (riverine, oceanic and atmospheric). State-of-the-art tools based on the transboundary nutrient transport (TBNT) and the distance-to-target (DTT) methods have been improved to estimate the riverine nutrient reductions necessary to reach the GEnS in the sea. Scenarios have been designed to estimate natural and anthropogenic nutrient contributions to the watersheds for the pristine conditions (simulated from a situation where Europe is covered in forests without human impact), for the contemporary situation, and for future realistic nutrient reduction scenarios (e.g. waste water treatment plants, good agricultural practices and conversion to local, organic farming and demitarian diet).

Maps of common eutrophication indicators (e.g. winter DIN, winter DIP and percentile 90 of chlorophyll concentrations (Chl P90)) have been computed from model results integrated over the whole NEA. Background values of the same indicators have been estimated and mapped, based on model results obtained for the pristine scenario. Areas subjected to anthropogenic eutrophication in the NEA have been identified from differences between contemporary and pristine situations. Based on Chl P90, these areas cover the French coastal zone of the Bay of Biscay, the Seine Plume and the Belgian and Dutch

coastal zones. Less intense eutrophication is found along the coasts of Portugal and offshore in the English Channel and the Southern Bight of the North Sea.

Mitigating the current eutrophication requires the implementation of nutrient reduction options at the level of the river watersheds. Three scenarios of nutrient reduction were examined based on realistic adaptations of human activities in the watersheds. (1) The scenario corresponding to the full implementation of the *Urban Wastewater Treatment Directive* showed that most Wastewater Treatment Plants required by the UWWTD (Directive 91/271/EEC) are already operational. (2) The *Good Agricultural Practice* scenario showed that a change to reasoned agricultural practices results in better quality drainage waters but is not sufficient to mitigate marine eutrophication nuisances. (3) The *Local Organic Demitarian* scenario implies radical changes in the agro-food system. The effect of this scenario is considerable in terms of nitrogen surplus reduction and results in significant improvement of water quality along the drainage network as well as a strong reduction of the nitrogen fluxes to the sea which in turn results in significant improvement of the marine eutrophication status.

Relative contributions from different sources of nitrogen and phosphorus to the marine ecosystem have been computed. Along the Iberian Peninsula, significant river-borne nutrient transport may be observed along the coastal zone in the south-west direction during the wet season in summer, though there is hardly any transboundary exchange of nutrients between Member States in that marine region. In the Bay of Biscay, the Loire river brings nitrogen along the coasts of Brittany and up to the English Channel. The transboundary nutrient transport is significant in the English Channel and the Southern Bight of the North Sea (SBNS), due to the combination of high nutrient loads from the rivers (e.g. Seine, Scheldt, Rhine, Meuse and Thames) and the patterns of water transport. Any marine area within the NEA would generally count different contributors in terms of nutrient enrichment. Surprisingly, in the Bay of Biscay, English Channel and SBNS, nitrogen atmospheric depositions account for about 10 to 20% of the nitrogen present in phytoplankton.

The DTT exercise provided useful information regarding the river load reductions necessary to reach the GEnS in target areas. DTT results showed that (1) dual-nutrient reduction (N,P) in the rivers is necessary to reduce the transboundary contamination and mitigate eutrophication and (2) the reduction needed to reach the GEnS depends on the target area (WFD or MSFD) and chosen threshold values for indicators. Two sets of threshold values have been tested. In the “rigorous” case, threshold values (8 µgChl L^{-1}, 9.0 µmol L^{-1} and 0.56 µmol L^{-1} for Chl P90, winter DIN and winter DIP, respectively) are representative of background values close to the pristine situation, and in the “lenient” case, threshold values (15 µgChl L^{-1}, 19.5 µmol L^{-1} and 0.65 µmol L^{-1} for Chl P90, winter DIN and winter DIP, respectively) are close to values recommended by the WFD/MSFD. Necessary dual-nutrient reductions in rivers have been computed and showed significant differences between both cases. . The optimal river loads reductions required to achieve the GEnS in the sea were compared to the nitrogen reductions in the river loads estimated by PyNuts for the *Local Organic Demitarian* scenario. The latter are generally in the range of the reductions calculated by the DTT between the rigorous and lenient cases. This suggests that the status of marine eutrophication will be significantly improved across the NEA if such a scenario is implemented in the future.

The EMoSEM project stimulated the rational to more universal and transboundary approaches to estimate the GEnS in large areas like the NEA and led to design transboundary **Ecozones** across the NEA. New sub-areas have been defined based on ecological criteria (e.g. highly eutrophic vs. oligotrophic) instead of usual political boundaries. A **new indicator** ("non-diatom chlorophyll *a"*, NDAChl) was proposed to complement the Chl P90 indicator. This new indicator reflects the phytoplankton composition and provides indications on potential nuisance or toxicity due to the presence of undesirable species. **Background values** of the ratio between winter DIN and winter DIP obtained from model results for the pristine situation equals 30 molN $molP^{-1}$ in some coastal zones, whereas the reference ratio value which is commonly accepted (OSPAR, MSFD, WFD) is set to 16 molN $molP^{-1}$. This suggests that further work is required to ensure consistency between winter DIN and winter DIP thresholds.

The EMoSEM project outcomes suggest that

- Further analysis is needed to define consistent thresholds for winter DIN, winter DIP and Chl P90 in the light of the new estimation of background values
- Significant progress towards the GEnS across the NEA will require major changes in the agro-food systems
- A reduction of the atmospheric N depositions is required in parallel to any future riverine nutrient reduction (no reduction in N depositions was tested in this study)
- Eutrophication should be assessed on areas defined on the basis of ecological criteria instead of political boundaries
- The proposed novel indicator ("non-diatom chlorophyll *a*") should be verified based on phytoplankton measurements over the whole NEA.

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