Eutrophication Series

Interim Report on the Use of Eutrophication Modelling for Predicting Expected Eutrophication Status of the OSPAR Maritime Area Following the Implementation of Agreed Measures

OSPAR Commission

2006

The Convention for the Protection of the Marine Environment of the North-East Atlantic (the "OSPAR Convention") was opened for signature at the Ministerial Meeting of the former Oslo and Paris Commissions in Paris on 22 September 1992. The Convention entered into force on 25 March 1998. It has been ratified by Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Portugal, Sweden, Switzerland and the United Kingdom and approved by the European Community and Spain.

La Convention pour la protection du milieu marin de l'Atlantique du Nord-Est, dite Convention OSPAR, a été ouverte à la signature à la réunion ministérielle des anciennes Commissions d'Oslo et de Paris, à Paris le 22 septembre 1992. La Convention est entrée en vigueur le 25 mars 1998. La Convention a été ratifiée par l'Allemagne, la Belgique, le Danemark, la Finlande, la France, l'Irlande, l'Islande, le Luxembourg, la Norvège, les Pays-Bas, le Portugal, le Royaume-Uni de Grande Bretagne et d'Irlande du Nord, la Suède et la Suisse et approuvée par la Communauté européenne et l'Espagne.

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Executive Summary

This report summarises the status of OSPAR work on modelling tools for predictive eutrophication assessments of the OSPAR maritime area and nutrient reduction scenarios, and the results of an OSPAR workshop on eutrophication modelling held in 2005.

This work takes place under the Eutrophication Strategy which requires, as part of its target-oriented approach, an evaluation from time to time of the eutrophication situation in the maritime area that is expected following the implementation of agreed measures. In essence, these measures require Contracting Parties to put in place effective national steps to achieve a substantial reduction, of the order of 50% compared to input levels in 1985, in inputs of phosphorus and nitrogen into areas where these inputs area likely, directly or indirectly, to cause pollution. Such areas are characterised by the Common Procedure for the Identification of the Eutrophication Status of the OSPAR Maritime Area (the Common Procedure) in terms of problem areas with regard to eutrophication.

A first evaluation of the expected eutrophication status following the implementation of the agreed measures was done in 2001. A further assessment was scheduled in the Joint Assessment and Monitoring Programme for 2006, the preparation of which should be assisted by the OSPAR workshop on eutrophication modelling.

The workshop showed that the capability and performance of models have well developed since the last evaluation but that further work is needed to address identified key factors required for a reliable and robust prediction of the environmental consequences of nutrient reduction. Amongst the most important of these was the likely time lag between nutrient reduction and system response and the implications for the length of simulation required and the way in which the reduction scenarios are imposed on the models. The workshop also showed that tools for modelling tansboundary transport of nutrients have well progressed and provide a good basis for further work with a view to developing tools to support the assessment of the eutrophication status of the OSPAR maritime area under the Common Procedure.

OSPAR 2006 agreed to defer the assessment of the eutrophication status of the OSPAR maritime area following the implementation of agreed measures scheduled for 2006 to 2008 and to carry out more intersessional work in the preparation for that assessment.

Récapitulatif

Le présent rapport résume l’état des travaux OSPAR sur les outils de modélisation utilisés dans les évaluations prédictives de l’eutrophisation de la zone maritime OSPAR et les scénarios de réduction des nutriments. Il comporte également le résultat des travaux d’un atelier OSPAR sur la modélisation de l’eutrophisation qui s’est tenu en 2005.

Ces travaux se déroulent dans le cadre de la Stratégie eutrophisation qui exige de temps à autre, dans le cadre de son approche ciblée, une évaluation de la situation qui devrait se présenter dans la zone maritime à la suite de la mise en œuvre des mesures convenues. Ces mesures exigent essentiellement de la part des Parties contractantes de mettre en place des dispositions nationales efficaces afin de parvenir à une réduction notable, de l’ordre de 50% par rapport aux niveaux des apports de 1985, des apports de phosphore et d’azote dans les zones où ces apports risquent directement ou indirectement d’entraîner une pollution. De telles zones sont définies dans la Procédure commune de détermination de l’état d’eutrophisation de la zone maritime OSPAR (la Procédure commune) comme des zones à problème d’eutrophisation.

Une évaluation préliminaire de l’état d’eutrophisation, qui devrait se présenter à la suite de la mise en œuvre des mesures convenues, a été effectuée en 2001. Le Programme conjoint d’évaluation et de surveillance continue prévoit une autre évaluation en 2006. L’atelier OSPAR sur la modélisation de l’eutrophisation contribuera à la préparation de cette évaluation.

L’atelier a démontré que le potentiel et la performance des modèles ont bien progressé depuis la dernière évaluation mais qu’il est nécessaire de poursuivre les travaux afin d’aborder les facteurs clés déterminés qui permettent une prédiction fiable et solide des conséquences que la réduction des nutriments a sur l’environnement. L’un des plus importants est le laps de temps probable qui s’écoule entre la réduction des nutriments et la réaction des systèmes d’une part, et, d’autre part, les conséquences en ce qui concerne la durée requise pour la simulation et la manière dont les scénarios de réduction sont imposés aux modèles. L’atelier a également démontré que les outils de modélisation du transport transfrontière des nutriments ont eux aussi progressé et constituent une bonne base pour les travaux futurs sur le développement d’outils à

l'appui de l'évaluation de l'état d'eutrophisation de la zone maritime OSPAR dans le cadre de la Procédure commune.

OSPAR 2006 est convenue de reporter à 2008 l'évaluation de l'état d'eutrophisation de la zone maritime OSPAR qui devrait résulter de la mise en œuvre des mesures convenues et prévues pour 2006. Elle est également convenue d'entreprendre, durant l'intersession, des travaux supplémentaires relatifs à la préparation de cette évaluation.

1. Workshop on eutrophication modelling

The Joint Assessment and Monitoring Programme (JAMP) requires a further assessment in 2006 of the expected status of the OSPAR maritime area following the implementation of agreed measures (JAMP product EA-5). To foster a scientifically more robust assessment than the one undertaken in 2001 (OSPAR publication 140/2001) and to advance OSPAR work on the development and use of predictive (e.g. modelling) assessment tools, the JAMP requires an overview by 2006 of predictive models for eutrophication assessment and nutrient reduction scenarios (JAMP product ET-7).

To support these activities, an OSPAR workshop on eutrophication modelling was held in Hamburg (Germany), on 26 – 28 September 2005. The workshop was attended by representatives from eight Contracting Parties: Belgium, France, Germany, the Netherlands, Norway, Portugal, Sweden and the United Kingdom.

According to the terms of reference, the workshop should prepare evidence based on model applications, including an assessment in the format of the Common Procedure for the Identification of the Eutrophication Status of the OSPAR Maritime Area (reference number 2005-3), showing how the various models predict:

a. the environmental consequences for problem areas if the 50% nutrient reduction target agreed by OSPAR is achieved, and;

b. the nutrient reduction target needed to indicate non-problem area status (expressed in terms of the Common Procedure) where this is not achieved by a 50% reduction in nutrient inputs.

In carrying out these tasks, the workshop reviewed the models used and their capability, assessed model reliability and uncertainties in prediction, evaluated model performance based on scenario testing and identified needs for further work.

The models were first applied by participants to water bodies in marine waters under their jurisdiction, which in most cases had been classified as problem areas by the first application of the Comprehensive Procedure of the Common Procedure in 2002. In addition, Contracting Parties with model domains that included German and Dutch waters performed model applications in target areas defined by the organisers of the workshop representing coastal and offshore problem areas in German and Dutch waters.

To aid the application of the models to the defined target areas riverine load data and boundary conditions were collated for the specific purposes of the workshop. In addition, data was made available for the target areas for 1989 to calibrate the models, and for 2002 to validate the models in order to facilitate a review of model performance.

Nutrient reduction scenarios were carried out for defined target areas in the North Sea based on reduction in nutrient inputs by 20%, 30%, 50%, 70% and 90% beginning on 1 January 2002 and predicting the environmental consequences of these reductions in the same year. A number of participants ran their models for some extended period of time prior to the simulation of the reduction scenarios, in order to allow the effects of reduction to propagate through the model system. Many participants had an “initialization” period of one year but this varied based on factors such as simulation run-time or the expected influence of the initialization. Forcing data sets had been provided for the model runs but the meteorological forcing data and open boundary conditions used for some models differed. There were agreements and contradictions between the various model results indicating the need for further consideration of the results and the possible refinement and further development of models before such an approach could be used with confidence.

2. Models used

The results from the application of seven coupled hydrodynamic-ecological models were presented at the OSPAR workshop. The models varied in the level of maturity and ranged from more physically dominated to more ecologically dominated model systems. An overview of their characteristics is given in Annex 1.

Belgium presented results from a complex biogeochemical model that simulated annual cycles of a range of key variables under realistic meteorological forcing. The model was designed to study eutrophication in the Channel and the Southern Bight of the North Sea and was continuously run for 1991 to 2003. The model showed good agreement with monitoring data (including data from remote sensing) tending to underestimate chlorophyll maximum concentration, to predict spring bloom with a slight delay and not to reproduce the very high peaks observed in *Phaeocystis* concentration. The model allowed tracing of possible transport of nutrients, based on passive tracer experiments, and showed that the origin of water mass could be determined and transboundary inputs estimated.

France presented two models, a two-layer box model and a complex 3D-hydrodynamic-biogeochemical model. Both were designed to simulate primary production and the blooms of two harmful algal species, including *Phaeocystis* relevant for the eastern English Channel and the Southern Bight of the North Sea. The models quantified the contribution of the main river inputs along the French and Belgian coast to primary production. Validation included comparison with data from remote sensing. The complex model showed very good results for temperature and salinity in both mixed and less mixed waters but overestimated chlorophyll in April and May in the Bay of the Seine. The model produced *Phaeocystis* levels which were too low in the French/Belgian coastal strip and the Northern coast of France, but too high in the Thames outer estuary. France introduced a new technique to track the path of any river-originated element through the trophic network in order to estimate the contribution of nitrogen from French rivers to the nutrient winter level as well as to the annual primary production.

The model presented by Germany included a limited number of (state) variables and was complemented by a simple benthic component. The model performed better in off-shore areas than in coastal areas. Validation of the model showed overestimation of oxygen in summer and overestimation of chlorophyll. Overall there was a reasonable agreement between model and observations. A more complex model with more state variables and including a more refined treatment of phytoplankton and zooplankton was presently under development. Further developments are also planned for the benthic module and a dynamic silt module.

The Netherlands presented a coupled hydrodynamical-ecological model with a curvilinear grid with the possibility for domain-decomposition. Four groups of phytoplankton and the nutrients nitrogen, phosphorus and silicon were modeled dynamically and for various grazers forcing functions were used. The model was forced with daily fluctuation of suspended sediment concentrations, derived from satellite remote sensing data, influencing the availability of light for phytoplankton growth. Model runs showed an adequate comparison between simulations and observations for major variables with some over-prediction, in 2002, of PO_4 at Dutch offshore stations (70 km).

The Norwegian presentation was divided into two parts. In the first part 2 ecological models, a Norwegian model (NORWECOM) and a German model (ECOHAM1), were run in the same physical setting. This was a follow-up of a previous study where the two models had been compared in a 10-year simulation in their normal setting (i.e. coupled to different physical models). The first study showed that the models agreed “in the mean”, but were negatively correlated on inter-annual variability. With the same physical model, the two models gave very similar results and agreed on inter-annual variability. The conclusion from this last study is that an accurate simulation of the physics is an essential prerequisite for the successful application of an ecosystem model. In the second part the Norwegian model results were presented for the five agreed target areas of the North Sea and the Skagerrak/Kattegat. Validation showed good agreement of the model results with observations.

The coupled 3D hydrodynamic ecological model presented by the UK is still in development and allows coupling of the hydrodynamics to a suite of biogeochemical models of which the one applied at the workshop included 9 ecological state variables. The model applications showed reasonable overall agreement with monitoring data. However, the model proved to fit better to observations in offshore than in coastal areas. Drawbacks included an underestimate of mixing with modeled density gradients too steep and (slight) stratification predicted in mixed areas. The model also gave an overestimate of background chlorophyll. The use of a constant background light extinction coefficient was a major limitation and needed to be improved.

The model presented by Portugal was designed for predictive assessments in estuaries of nutrient reductions following the implementation of OSPAR and EC measures. The model was capable of simulating responses to the reduction of point source discharges of nitrogen and phosphorus from agriculture and from waste water treatment plants, and, in the light of nitrate export, to calculate the total balance for phosphorus, nitrate and ammonium.

Sweden informed the workshop of the status of development of an ecological box model. Long-term flow estimates from other models would force the model as well as observations. The final report on the model was expected to be available by 15 December 2005.

3. Achievements

3.1 Model capability

The workshop provided a successful feasibility study of models for their use in predictive assessments and to support the application of the Common Procedure.

With regard to the properties and suitability of models to support the assessment process, all ecological models appeared to be sensitive to the underlying physical models. There was some evidence to suggest that the models used were sensitive to the boundary conditions but further testing is required for firm conclusions. The number of model state variables in common with the harmonised assessment parameters of the Common Procedure varied and was dependent upon the model in use. Yet all models had a sufficient number of (state) variables in common with the Common Procedure to provide useful simulations and were capable of carrying out a model based Common Procedure.

The models presented have the capability to add value by increasing understanding of the ecosystem under assessment. They can for example be used, through extrapolation, to provide data for input to the Common Procedure where monitoring data is either sparse or non existent. The models showed that they could provide a broader perspective on biotic and abiotic states, processes (e.g. rates) and factors effecting eutrophication (e.g. residence time) than is possible from monitoring data alone. Integration of model results with new types of *in situ* monitoring data (e.g. autonomous instrumentation mounted on buoys or ferries) and remote sensing could improve the representativity of such data and could be used to further increase confidence in the assessment derived from the application of the Common Procedure.

The model applications provided evidence that innate variability within ecosystems is not accounted for with fixed assessment levels. The models are capable of simulating background conditions as a method to derive more scientifically robust assessment levels. The models can be used to analyse the robustness of current Common Procedure indicators and could also be used as a method of identifying new ones.

The models available could improve the definition of water bodies as the model variables are available on a spatial and temporal resolution that can not be obtained from monitoring.

3.2 Model performance

The performance of the models presented at the workshop in terms of their reliability, robustness and uncertainties in predictions was in general good. The calibration and validation steps adopted for the workshop were important mechanisms to reduce uncertainty in model predictions. All models were calibrated and validated using high quality data. The comparison of model data with observations showed that the range of models achieved a reasonably good to very good fit. Additional validation protocols, building on recommendations of existing initiatives such as the EU project HarmoniQua have the potential to further enhance the reliability of model applications and the comparability of model results.

For comparison of the models, objective methods would need to be employed. Cost-functions could give an indication of “goodness for fit” and indicate reliability if performed model calibration and give an indication of the level of uncertainty if applied during validation of the models.

3.3 Workshop achievements

Model performance in terms of reliability is very dependent on the availability of high quality data on which calibration, but also validation, would need to be based. For the workshop, the organisers of the workshop provided unique data sets for the defined target areas for the years 1989 and 2002. The collating and provision of access to the available boundary and forcing data, especially high quality river load data, may be considered as an achievement in itself and provides a good basis on which to build further work.

Some of the models presented at the workshop gave examples of how to address questions regarding the fate and transport of nutrients (dissolved and particulate) in the context of transboundary transport. The demonstration of techniques proposed by France gave evidence of the potential of models for showing the individual contribution of national inputs to eutrophication problems. These examples are important in providing a basis for advancing future modelling work on transboundary transport of nutrients under the Common Procedure.

The application of models in testing nutrient reduction scenarios allowed identification of a number of key factors required for a reliable and robust prediction of the environmental consequences of nutrient reduction. The results also demonstrated a role for models in determining possible time lags between nutrient reductions and response of the system.

Since the ASMO workshop in 1996 the underlying physical models as well as the biochemistry (inclusion of more state variables, processes and improved understanding of these) have improved in a number of respects together with the wider availability of more powerful computers. In addition, the 2005 workshop was not restricted to simulating primary production following nutrient reductions but included the assessment of a number of other parameters.

4. Key limitations and requirements for further work

Availability of appropriate boundary conditions proved to be a critical factor effecting model performance. For the Channel and North Sea, model results presented at the workshop showed that the boundary conditions adopted by different groups were prescribed differently due to a lack of coherent data sets, particularly with regard to nutrient transport from the Atlantic. The problem is in part due to differences in the model domains and therefore location of boundaries. In addition, more work is needed to characterise the sensitivity of models to open boundary conditions in order to improve the knowledge of uncertainties in predictions.

The one year simulation used for the nutrient reduction scenarios was regarded as insufficient to allow the ecosystem in the simulation to fully respond to the nutrient reduction. Further consideration needs to be given to the necessary time scale for models to predict the full environmental response.

Not all steps set out in the Common Procedure are amenable to the use of models. While the terms of reference required prediction of the shift in classification from a problem area to a non-problem area such a reclassification based on model results alone is unlikely. Models may be used to predict the reaction of those assessment variables that are included in the model formulation and may therefore play a part in re-classification, improvement of the Common Procedure, improvement of monitoring strategies, or prediction of the effectiveness of proposed measures, but monitoring will always be necessary.

On the basis of the workshop results and in the time available for analysis of model simulations it was not possible to reach robust conclusions concerning the results from the reduction scenarios. Further analysis and interpretation of the results is required. However, the workshop allowed collective testing of models leading to interesting results that raised a number of questions. Amongst the most important of these was the likely time lag between nutrient reduction and system response and the implications for the length of simulation required and the way in which the reduction scenarios are imposed on the models. These questions need to be addressed before a meaningful assessment of the expected eutrophication status of the OSPAR maritime area following implementation of OSPAR measures can be made.

To this end intersessional work would need to address issues such as the further development of protocols for the application of models, determination of the sensitivity of models to open boundary conditions, the specification of a common format for reporting of model results, the identification of a scientifically robust conversion factor for *Phaeocystis* to carbon, the exploring of further development needs for models to provide more robust predictions, the development of a common understanding of predictive capability of models and continued efforts to compile riverine inputs and direct discharges data from national sources and to give easy access to such data derived from monitoring at the desired frequency from the river mouth.

Annex 1: Overview of models used for nutrient reduction scenarios and their characterisation

Model name (listed in sequence of presentations) / **Characteristics**	**GETM-IOW (United Kingdom)**	**Model: Delft3D-GEM (Netherlands)**	**ECOHAM3 (Germany)**	**MIRO&CO-3D (Belgium)**	**NORWECOM (Norway)**	**MOHID System (Portugal)**	**ECO-MARS3D (France)**
Spatial Resolution Δh (km)	11 km (6 nm)	Variable (curvilinear grid) ranging from 2x4 km (smallest) to 20x20 km (largest)	20 km	5.8 km (5' longitude) x 4.6 km (2.5' latitude)	20 km	0.6 Km	4x4 km
Vertical resolution	25 layers	Hydrodynamics D3D-FLOW is 3D (10 sigma layers) Ecology D3D-GEM is also 3D or Depth Averaged (1 layer)	5	5 sigma layers	11 sigma	2D (optional 3D)	12 sigma
Longitude (degree)	4°W – 12°E	-4.0°W – 10°E	-15°W – 13.9°E	4.0°W – 5.0°E	12°W – 12°E	-9.5953°	-5.5°W – 5.0°E
Latitude (degree)	51°N – 60°N	48.2°N – 57.0°N	47.7°N – 63.9°N	48.5°N – 52.5°N	48°N – 64°N	38.5331°	47.85, °N – 52.50°N
Spatial extent (km)	1000 km	950 km from North to South	1600 km	630 km x 446 km		69 km x 46 km	W-E: 750 km N-S: 520 km
Temporal resolution Δt (sec)	1 day (86400 sec)	Transport timestep (from D3D-FLOW) 1hr (3600 sec) Ecological processes timestep: 24 hrs Output written every 24 hrs or 7 days	300 sec	900 sec	900 sec	60 sec	Variable ~400 sec
Temporal range (years)	2 years	1988-89, 1998, 2001, 2002, 2003	4 years	1991 – 2003 (continuous run)	1985 – 2004	1 year	1999 – 2003
Pelagic matter cycle	N	N, P, Si, O	C, N, O	C, N, P, Si	N, P, Si, O	C, N (optional P and Si)	N, P, Si, O
No. of Pelagic state variables	9	21-22	26	32	8	9	19
Pelagic Nutrients (bulk or explicit)	Explicit	Explicit (NO_3, NH_4, DetN, PO^4, DetP, Si, DetSi)	NO_3, NH_4	Explicit (NO_3, NH_4, PO_4, SiO)	3 bulk	Explicit	Explicit
Phytoplankton	Yes	4 major functional groups: dinoflagellates, diatoms, flagellates, Phaeocystis (comprising a total of 12 types)	1	10 Diatoms (3 variables), Nanoflagellates (3 variables) and *Phaeocystis* (4 variables).	DIA,FLA	Yes (optional 2 groups: dinoflagellates and/or diatoms))	Diatoms, dinoflagellates, small phytoplankton, *Karenia mikimotoi*, *Phaeocystis globosa* (4 variables needed)
Zooplankton	Yes	Optional (not included for OSPAR simulations)	1	2 Microzooplankton,	no	Yes (optional 2 groups: microzooplankton and	Microzooplankton, mesozooplankton

				copepods		mesozooplankton)	
Benthic matter cycle	No	C, N, P, Si,	C,N,O	C, N, P	N, P, Si	Not used in this application (optional C, N, P, Si, O)	N, P, Si, O
No. of benthic state variables	-	4	3	6	5	8	10
Benthic Nutrients (bulk or explicit)	-	Explicit (N, P, Si)	NO_3, NH_4	Diagenetic model (NO_3, NH_4, PO_4 fluxes)	3 bulk	Explicit	Explicit
Zoobenthos	No	Optional (not included for OSPAR simulations)	No	-	No	No	One group of suspension feeders
DOM	No	Optional (not included for OSPAR simulations)	Yes	8	No	Yes	No
Bacteria	No	No (modeled as mineralization)	Yes	1	No	Yes (optional)	No
Detritus/POM	Yes	Yes (DetC, DetN, DetP, DetSi)	Yes	7	2	Yes	Yes
Spin-up time	1 year	1 year	3 years	2 first years (1991-1992) of the continuous run	15 days	1 year	2 years
Meteo: real data or climatological	Real	Real data for wind, atmospheric pressure, solar radiation, air temperature	ERA40	Real 6 hours reanalysed forecasts (UKMO)	Real data	Wind, atmospheric pressure, solar radiation and temperature from atmospheric models (MM%, ARPS) or real data (for the Tagus estuary MM5 results were used)	Real data: ARPEGE MODEL (METEO-France) + irradiance from METEOSAT/AJONC (Meteo-France)
Participant to add further characteristics if required				Surface temperature imposed from 20 km x 20 km gridded SST (BSH-GE)			
Hydrodynamics		Delft3D-FLOW (fully 3D, 10 layers), Real forcings of wind & atmospheric pressure					
Light		Light is a function of: inorganic suspended matter, yellow substances (freshwater), detritus, and phytoplankton SPM		PAR attenuation is a function of chlorophyll concentration, CDOM (function of salinity) and TSM		Light penetration in the water column is SPM concentration and phytoplankton dependent	
Area				English Channel and Southern Bight of the North Sea		Tagus Estuary	English Channel and Southern Bight of the North Sea

No. rivers		19		10		3 rivers and 14 WWTP discharges	26
SPM		Suspended particulate matter is either modelled or provided as a forcing function based on remote sensing data (For the OSPAR workshop we used remote sensing)		TSM (seasonal climatology from SeaWiFS)		Yes (sediment transport model computing settling velocity, and erosion/deposition processes)	SiAm3D model and satellite forcing (SeaWiFS, monthly averages)
Other						The model can be used using a nesting modelling approach to simulate specific areas with more resolution	