OSPAR COMMISSION

"Distance to target" modelling assessment

Eutrophication Series

2013

OSPAR Convention

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. The Contracting Parties are Belgium, Denmark, the European Union, Finland, France, Germany, Iceland, Ireland, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Convention OSPAR

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. Les Parties contractantes sont l'Allemagne, la Belgique, le Danemark, l’Espagne, 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, la Suisse et l’Union européenne.

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Executive Summary

Eutrophication is still a problem in many areas of the North Sea. OSPAR Contracting Parties committed in the 2010 North-East Atlantic Environment Strategy to cooperate to set appropriate nutrient reduction targets to combat eutrophication. The Intersessional Correspondence Group on Eutrophication Modelling (ICG-EMO) has built on previous eutrophication modeling work to estimate “distance to target”[1], that is for modelling purposes, the nutrient input reductions required to move eutrophication effect parameters below their assessment levels in problem areas. The method required several complex technical steps and the application of expert judgement.

This is a first attempt to merge existing information into one consistent model setup and without further sensitivity testing, the results can only be seen as a first estimate of “distance to target”. The harmonized approach using numerical models shows that both direct and transboundary nutrient inputs to problem areas need to be taken into account when considering nutrient reductions and that their relative contribution can now be quantified. Therefore, with respect to Eutrophication Problem Areas, all contributing Transboundary Nutrient Transport (TBNT) areas should be included in future modelling and assessments. In general, it can be concluded that further reductions in nutrient releases are required by Contracting Parties bordering the North Sea to achieve the currently set eutrophication targets. However, there are still considerable uncertainties concerning the levels of reductions needed.

Modelling has the potential to quantify nutrient-related targets and inform measures

Earlier work reported by OSPAR (OSPAR 2001) using scenarios of reductions in nutrient loads showed a strong reduction in average winter nutrient concentration in coastal areas. But the simulation results did not display a linear decrease in the direct effect parameters of eutrophication. In order to obtain justifiable model results for such non-linear problems, iterative scenario runs are needed to bring all these effect indicators below assessment levels. But due to lack of financial resources this iterative approach was not possible here. Also the models had to be utilised based on previous ICG-EMO work with the focus on the (wet) year 2002.

Promising new method for cost-efficient approach

Despite the constraints mentioned above, the present work of ICG-EMO is an important step forward in developing a novel cost effective linear optimization method and improving our understanding of how Transboundary Nutrient Transport studies can be combined with nutrient reduction scenario studies.

Expert judgement was still required to produce first estimates for nutrient input reductions for the main rivers in the southern North Sea. There are a number of short-comings as would be expected when applying a new method to such a complex question for the first time and when relying on previous model results for which limitations had already been identified. A number of those restrictions can only be rectified through novel model runs which would require adequate financing. Limitations relate, for example, to the reference year 2002 and to the focus of the study on the response of nutrient concentrations rather than eutrophication effects parameters to nutrient load reductions.

Consistent assessment levels are a prerequisite for meaningful modelling

The study also showed that estimates for nutrient input reductions are strongly influenced by the differences in Contracting Parties’ assessment levels for eutrophication effect parameters, recalling that those assessment levels are the basis for estimating “distance to target”.

Way forward

The work undertaken for this estimation of “distance to target” reduction levels has helped to further identify elements in the set-up of model procedures to foster the steady development towards justifiable statements

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[1] EUC(2) 2009 (see EUC(2) 09/9/1-E, Annex 4) agreed that the further work of ICG-EMO would include “preparing additional data products to support clarification of “distance to target” in terms of reductions of nutrient loads to the maritime area required to achieve non-problem area status in areas affected by eutrophication.

on nutrient reduction. The new optimization procedure is particularly encouraging in developing a reliable and cost-efficient approach to support Contracting Parties in answering the question of “distance to target”.

Récapitulatif

L’eutrophisation présente encore un problème dans de nombreuses zones de la mer du Nord. Les Parties contractantes OSPAR se sont engagées, dans la Stratégie pour le milieu marin de l’Atlantique du Nord-Est de 2010, à coopérer afin de déterminer des cibles appropriées de réduction des nutriments pour lutter contre l’eutrophisation. L’ICG-EMO s’est inspiré de travaux antérieurs de modélisation de l’eutrophisation pour estimer « l’écart par rapport à l’objectif »[2], c’est-à-dire aux fins de la modélisation, les réductions des apports de nutriments requises pour que les paramètres des effets d’eutrophisation soient inférieurs aux niveaux d’évaluation dans les zones à problème. La méthode exige plusieurs étapes techniques complexes et l’application de jugement d’expert.

Il s’agit d’une première tentative de fusionner les informations existantes en un système cohérent de modèles et sans tests de sensibilité supplémentaires, les résultats doivent être considérés uniquement comme une estimation préliminaire de l’écart par rapport à l’objectif ». L’approche harmonisée utilisant des modèles numériques montre qu’il faut prendre en compte les apports de nutriments, aussi bien directs que transfrontaliers, dans les zones à problème lorsque l’on envisage de réduire les nutriments et que l’on peut désormais quantifier leur contribution relative. Il faudra donc inclure toutes les zones contribuant au transport transfrontalier de nutriments (TBNT) dans les futures modélisations et évaluations, dans le cas des zones à problèmes d’eutrophisation. On peut conclure dans l’ensemble que des réductions supplémentaires des rejets de nutriments sont requises de la part des Parties contractantes en bordure de la mer du Nord afin de parvenir aux cibles déterminées actuellement pour l’eutrophisation. Cependant de grandes incertitudes subsistent quant aux niveaux de réduction nécessaires.

La modélisation peut potentiellement permettre de quantifier les cibles liées aux nutriments et d’informer des mesures

Des travaux antérieurs notifiés par OSPAR (OSPAR 2001), utilisant des scénarios de réduction des charges de nutriments, révèlent une réduction importante des teneurs hivernales moyennes de nutriments dans les zones côtières. Les résultats des simulations ne révèlent cependant pas de diminution linéaire des paramètres d’effets directs de l’eutrophisation. Des simulations de scénarios itératifs sont nécessaires pour ramener tous ces indicateurs des effets en dessous des niveaux d’évaluation afin d’obtenir des résultats justifiables des modèles pour de tels problèmes non linéaires. Il n’est cependant pas possible d’appliquer ici cette approche itérative en raison de l’absence de ressources financières. Les modèles doivent également être utilisés sur la base des travaux antérieurs de l’ICG-EMO en insistant sur l’année 2002 (pluvieuse).

Nouvelle méthode prometteuse pour une approche rentable

En dépit des contraintes mentionnées ci-avant, les travaux actuels de l’ICG-EMO représentent une étape importante du développement d’une nouvelle méthode d’optimisation linéaire rentable et de l’amélioration de notre compréhension quant à la manière de conjuguer les études sur le transport transfrontalier des nutriments et celles sur les scénarios de réduction des nutriments.

Un jugement d’expert est encore nécessaire pour réaliser les premières estimations des réductions des apports de nutriments pour les principaux fleuves de la mer du Nord méridionale. Un certain nombre de faiblesses, comme on pourrait le prévoir, affectent la première application d’une nouvelle méthode à une question aussi complexe et en s’appuyant sur les résultats des modèles antérieurs qui ont déjà été déterminés comme étant limités. Un certain nombre de ces restrictions ne peuvent être rectifiées que par de nouvelles simulations de modèles qui exigeraient un financement adéquat. Les limites portent par exemple

[2] EUC(2) 2009 (voir EUC(2) 09/9/1-F, annexe 4) est convenu que les travaux supplémentaires de l’ICG-EMO consisteraient notamment à « préparer des produits de données supplémentaires pour étayer la clarification de « l’écart par rapport à l’objectif » au titre des réductions des charges de nutriments dans la zone maritime nécessaires pour que les zones affectées par l’eutrophisation parviennent au statut de zone sans problème ».

sur 2002, l'année de référence, et sur le point focal de l'étude sur les réactions des teneurs en nutriments plutôt que les paramètres d'effet d'eutrophisation aux réductions des charges de nutriments.

Des niveaux d'évaluation cohérents sont une condition préalable à une modélisation significative

L'étude montre également que les estimations des réductions des apports de nutriments sont extrêmement influencées par les différences que présentent les niveaux d'évaluation des Parties contractantes pour les paramètres d'effets d'eutrophisation, rappelant que ces niveaux d'évaluation constituent la base de l'estimation de « l'écart par rapport à l'objectif ».

Marche à suivre

Les travaux entrepris pour cette estimation des niveaux de réduction de « l'écart par rapport à l'objectif » ont permis de mieux déterminer les éléments de la mise en place de procédures de modélisation pour favoriser le développement régulier dans le sens de déclarations justifiables sur la réduction des nutriments. La nouvelle procédure d'optimisation est particulièrement encourageante lorsqu'il s'agit de développer une approche fiable et rentable permettant aux Parties contractantes de traiter la question de « l'écart par rapport à l'objectif ».

Technical Summary

The aim of the modelling work presented in this report is to estimate "distance to target" reduction levels, which in OSPAR terms refer to those nutrient reductions required in eutrophication problem areas to move eutrophication effect parameters below their assessment levels. The work to carry out "distance to target" calculation consolidated prior ICG-EMO work in relation to nutrient reduction and Transboundary Nutrient Transport (TBNT) studies. A stepwise approach was used, first by comparing results from a reference run and a so-called assessment level reduction scenario. In a second step, the reduction levels of these simulations were further reworked within a linear optimization method, which was used to "redistribute" these nutrient load reductions over groups of rivers by taking into account TBNT information. Finally, complementary expert judgement has been used to produce first quantitative estimates for nutrient reductions for the main rivers in the Region.

Eutrophication is still a problem in many areas of the North Sea. OSPAR Contracting Parties committed in the 2010 North-East Atlantic Environment Strategy to cooperate to set appropriate nutrient reduction targets to combat eutrophication. This is a first attempt to merge existing information into one consistent model setup and without further sensitivity testing, the resulting "distance to target" reductions can only be seen as a first estimate of "distance to target and nutrient reductions".

Modelling has the potential to quantify nutrient-related targets and inform measures

Earlier work reported by OSPAR (OSPAR 2001) using scenarios of reductions in nutrient loads showed a strong reduction in average winter nutrient concentration in coastal areas. But the simulation results did not display a linear decrease in the direct effect parameters of eutrophication. In order to obtain justifiable model results for such non-linear problems, iterative scenario runs are needed to bring all these effect indicators (such as chl. a and phytoplankton indicator species) below assessment levels. But due to lack of financial resources this iterative approach was not possible here. Also the models had to be utilised based on previous ICG-EMO work with the focus on the (wet) year 2002.

Promising new method for cost-efficient approach

Despite the constraints mentioned above, the present work of ICG-EMO is an important step forward in developing a novel [linear optimization] cost–effective method and improving our understanding how Transboundary Nutrient Transport studies can be combined with nutrient reduction scenario studies.

Expert judgement was still required to produce first estimates for nutrient input reductions for the main rivers in the southern North Sea. There are a number of short-comings as would be expected when applying a new method to such a complex question for the first time and when relying on previous model results for which limitations had already been identified. A number of those restrictions can only be rectified through novel model runs which would require adequate financing. Limitations relate, for example, to the reference year 2002 and to the focus of the study on the response of nutrient concentrations rather than eutrophication effects parameters to nutrient load reductions.

Consistent assessment levels are a prerequisite for meaningful modelling

The study also showed that estimates for nutrient input reductions are strongly influenced by the differences in Contracting Parties’ assessment levels for eutrophication effect parameters, recalling that those assessment levels are the basis for estimating “distance to target”.

Way forward

The work undertaken for this estimation of “distance to target” reduction levels has helped to further identify elements in the set-up of model procedures to foster the steady development towards justifiable statements on nutrient reduction. The new optimization procedure is particularly encouraging in developing a reliable and cost-efficient approach to support Contracting Parties in answering the question of “distance to target”.

In the following text the restrictions to the model runs and assessment are explained in detail and recommendations are extracted for future work on “distance to target” modelling.

Method to define “distance to target” reduction

For this approach earlier reduction scenarios, as have been calculated during the 2007 Lowestoft workshop (Lenhart *et al*., 2010), were augmented by the information from the Transboundary Nutrient Transport (TBNT) work reported in the ICG-EMO workshop in Brussels in 2009 (http://www.cefas.defra.gov.uk/eutmod3). This approach calculates the far-field effects of nutrient loads on the ecosystem, by combining the influence of nutrient load reduction of individual rivers with information about TBNT.

Since a number of preparation and modelling steps are needed to achieve a distance to target reduction scenario, Figure A provides a graphical overview.

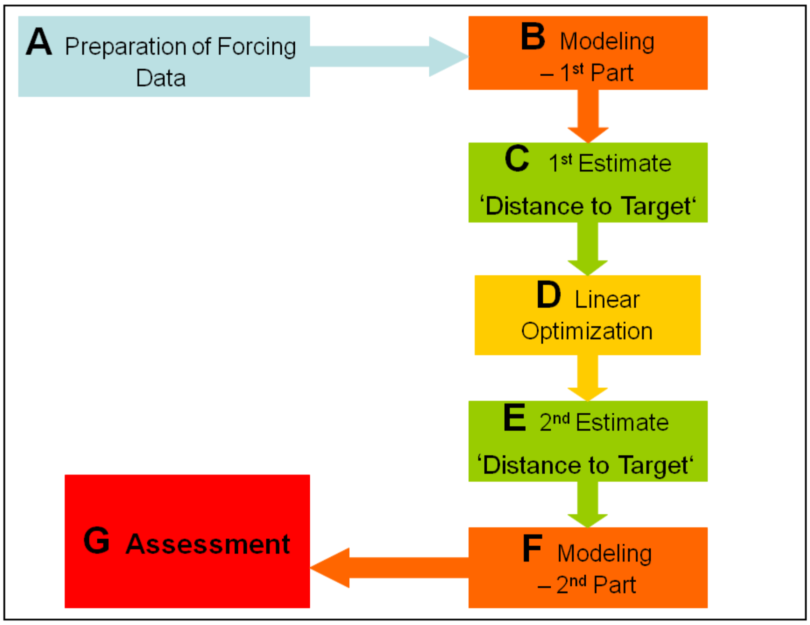

Figure A. Flow diagram representing the various steps of model activities and related results to achieve distance to target simulation results and assessment.

The first step (A) was the preparation of the forcing data to drive the models with a common data set of atmospheric nitrogen deposition and river load data. The next step (B) was to define the “distance to target” reduction level based on the reference run for 2002 and an 85% reduction run. The results of the 85% reduction run were needed to calculate the minimum reduction percentage of the nutrient concentrations in a specific target area necessary to reach a nutrient concentration below the assessment level. The results from these two runs were used as first estimate of the “distance to target” reduction level (step C).

The reduction levels of these simulations were further reworked within a linear optimization method (step D), which was meant to “redistribute” these nutrient loads by taking into account the information from the TBNT. The final reduction levels representing “distance to target” reduction were achieved by expert judgement combining the outcome of this linear optimization procedure in combination with the previous “distance to target” reduction levels (step E). This final reduction level is applied as scenario by the ecosystem models (step F9) and the outcome of these model simulations form the basis of the final assessment (step G).

Constraints of the method used

The focus was to achieve comparable results between the models, in order to generate a “crucial mass” of model results from different marine ecosystem models from a number of institutes of Contracting Parties (CPs) around the North Sea. This was difficult given the very different funding situations of the modelling partners, but also for practical reasons. The following constraints influenced the set-up of the common model analysis:

• Choice of reference year (2002)

Since the start of the ICG-EMO modelling group, the year 2002 has served as a reference year, for which the models have been used repeatedly and thoroughly validated. To use another, more recent, year as a reference year for the simulations would have required all partners to update their model, validate it and apply common forcing. This would have taken a substantial amount of time and budget that was not available for all partners. Therefore, the ICG-EMO group decided to keep the year 2002 as the reference year.

• Number of scenarios

The status of the areas and their “distance to target” was to be based mainly on chlorophyll and *Phaeocystis* concentrations (category II variables). However, the considered management measures consisted of reducing riverine inputs, which affects category II variables indirectly and non-linearly. As a result, to find river load reductions that achieve the desired assessment level for these variables, a number of iterative target reduction runs would have been required. However, there was only budget to carry out one such run. Therefore, an alternative strategy was chosen: since DIN and DIP ambient concentrations are assumed to behave more linearly to riverine inputs than the category II variables, it was decided to focus mainly on these two variables in estimating the river load reductions, and use the linear optimisation method to reduce the number of iterations.

• Chlorophyll concentrations: means instead of 90th percentiles

In the ICG-EMO group, the standard assessment variable for chlorophyll has long been the mean summer concentration. As a consequence, most results in the underlying report are presented in terms of mean summer concentrations. Since within OSPAR the 90th percentiles are increasingly used this was adopted in the pre-processing of the model results. Assessment level for the 90th percentile was set to twice the values of the assessment level for the mean concentrations.

Results from “distance to target” run

An overview of the study is given in Table A, showing whether the assessment variables are above or below the area specific assessment level for the OSPAR problem areas.

Chlorophyll

In the “distance to target” run (2) **chlorophyll-mean (C-m)** and/or **chlorophyll-90-percentile (C-90)** were above assessment level in three target areas. This is the case in area FC2 according to Delft3D-GEM, and in NLO2 and NLC2a according to ECOHAM. In FC2 this can be due to continued nutrient enrichment, because in this area Delft3D-GEM predicts also DIN levels above assessment level. This is also the case in NLC2, where ECOHAM predicts nutrient enrichment by DIP. In NLO2, however the situation is different. Here ECOHAM does not predict nutrient concentrations above assessment level, while chlorophyll exceeds the assessment level.

Phaeocystis

Two of the participating institutes, Deltares and MUMM, were able to deliver model results for *Phaeocystis* cells*.* For all countries an assessment level of 10^7 cells/l is used, assuming an extreme bloom. MIRO&CO-3D model calculated concentrations of *Phaeocystis* cells (*Phaeo*) above assessment level in all target areas included in their model domain. In contrast the Delft3D-GEM calculated concentrations of *Phaeocystis* cells above assessment level for NLC1, NLC3, GC1 and UKC1.

DIN and DIP

The ECOHAM model simulation resulted in two areas that showed enrichment, one for DIN (NL-C2a) and one for DIP (NL-C2b). In the remaining areas there was no enrichment.

The Delft3D-GEM simulation for the target scenario results (2) in three target areas with DIP above assessment level (NLC2a, NLC2b and NLC3), two with DIN + DIP above assessment level (BC1 and NLC1).

The model domain of ECO-MARS3D contained six of the target areas, which were above assessment level for at least one of the variables, four areas due to DIN values above assessment level (FC2, BC1, NLC1 and NLC2b) and two with a DIP and DIN above assessment level (NLC2a, UKC1), indicating enrichment but non-problem area status.

The model domain of MIRO&CO-3D contained five of the target areas. All these areas had nutrient levels above assessment level according to the MIRO&CO-3D model, one area with only DIN above assessment level (FC2), two areas with only DIP above assessment level (NLC1 and NLC2a) and two with DIP + DIN above assessment level (BC1, UKC1), indicating enrichment and problem area status due to high concentrations of *Phaeocystis* in all areas.

Table A. Summary of the results of the reference runs for 2002, the target run and the 85 reduction run, according to all participating models, as presented in the Figures12-14; "blue" is under the assessment level and "red" is above. For the white cells no model results are available, because these areas are outside the model domain. 1 = 2002 reference run; 2 = target run (cf. Table 10); 3 = 85% reduction run.

Target area		ECOHAM			Delft3D-GEM			ECO-MARS3D			MIRO&CO-3D			POLCOM-ERSEM		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
FC2	DIN	blue	blue	blue	red	red	blue	red	red	blue	red	red		red		red
	DIP	blue	blue	blue	blue	blue	blue	red	blue	blue	blue	blue		blue		blue
	C-m	blue	blue	blue	red	red	red	blue	blue	blue	blue	blue		blue		blue
	C-90	blue	blue	blue	red	red	red	blue	blue	blue	red	blue		blue		blue
	Phaeo				blue	blue	blue				red	red				
BC1	DIN	blue	blue	blue	red	red	blue	red	red	blue	red	red		red		blue
	DIP	blue	blue	blue	red	red	blue	red	blue	blue	red	red		red		blue
	C-m	blue	blue	blue	red	blue	blue	blue	blue	blue	blue	blue		blue		blue
	C-90	red	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue		blue		blue
	Phaeo				red	blue	blue				red	red				
NLC1	DIN	blue	blue	blue	red	red	blue	red	red	blue	red	blue		red		blue
	DIP	blue	blue	blue	red	red	blue	red	blue	blue	red	red		red		blue
	C-m	blue	blue	blue	red	blue	blue	blue	blue	blue	blue	blue		blue		blue
	C-90	red	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue		blue		blue
	Phaeo				red	red	blue				red	red				
NLC2a	DIN	red	blue	blue	red	blue	blue	red	red	blue	red	blue		red		blue
	DIP	red	red	blue	red	red	red	red	red	blue	red	red		red		blue
	C-m	blue	blue	blue	red	blue	blue	blue	blue	blue	red	blue		blue		blue
	C-90	red	red	blue	blue	blue	blue	blue	blue	blue	red	blue		blue		blue
	Phaeo				red	blue	blue				red	red				
NLC2b	DIN	red	blue	blue	red	blue	blue	red	red	blue				blue		blue
	DIP	red	red	blue	red	red	red	red	blue	blue				red		blue
	C-m	blue	blue	blue	blue	blue	blue	blue	blue	blue				blue		blue
	C-90	red	red	blue	blue	blue	blue	blue	blue	blue				blue		blue
	Phaeo				red	blue	blue									
NLC3	DIN	blue	blue	blue	blue	blue	blue							blue		blue
	DIP	red	blue	blue	red	red	red							red		blue
	C-m	blue	blue	blue	blue	blue	blue							blue		blue
	C-90	blue	blue	blue	blue	blue	blue							blue		blue
	Phaeo				red	red	blue									
GC1	DIN	red	blue	blue	red	blue	blue							red		blue
	DIP	red	blue	blue	blue	blue	blue							red		blue
	C-m	blue	blue	blue	red	blue	blue							blue		blue
	C-90	blue	blue	blue	blue	blue	blue							blue		blue
	Phaeo				red	red	red									
UKC1	DIN	red	blue	blue	red	blue	blue	red	red	blue	red	red		red		red
	DIP	red	blue	blue	red	blue	blue	red	red	blue	red	red		red		red
	C-m	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue		blue		blue
	C-90	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue		blue		blue
	Phaeo				red	red	blue				red	red				
NLO2	DIN	blue	blue	blue	blue	blue	blue							blue		blue
	DIP	blue	blue	blue	blue	blue	blue							blue		blue
	C-m	red	red	blue	blue	blue	blue							blue		blue
	C-90	red	blue	blue	blue	blue	blue							blue		blue
	Phaeo				blue	blue	blue									
GO2	DIN	blue	blue	blue	blue	blue	blue							blue		blue
	DIP	blue	blue	blue	blue	blue	blue							blue		blue
	C-m	blue	blue	blue	red	blue	blue							blue		blue
	C-90	blue	blue	blue	red	blue	blue							blue		blue
	Phaeo				blue	blue	blue									

Evaluation of results

Despite the high reduction levels defined for the target scenario (especially for phosphorus), some indicators still remained above the assessment level in a number of areas for a number of model applications. However the results should be interpreted with care for a number of reasons:

- Inconsistencies in the OSPAR assessment levels
- The use of the expert judgement
- Natural variability
- Model constraints

OSPAR assessment levels

Since the OSPAR assessment levels play an important role in the assessment procedure, a critical view of them is needed in combination with the experiences from the OSPAR modelling activities. A difficulty herein is that the OSPAR assessment levels for the various assessment variables do not have a clear scientific basis. Inconsistencies exist between assessment levels of neighbouring areas, as well as between the assessment levels for related assessment variables. For instance, it may occur that in a certain area assessment levels for DIN and DIP concentrations are achieved, but not those for chlorophyll, or vice versa. As a result, it is not straightforward to translate the findings for nutrients into chlorophyll. These inconsistencies have only become apparent during the analysis, and they form a handicap to the chosen strategy of focusing the analysis on nutrients instead of on chlorophyll. As a result, for some areas, and depending on the balance of the target levels, the reduction levels found in this study may be more (or less) severe than necessary to achieve non-problem status. Similarly, the assessment levels for the mean chlorophyll concentration and its 90th percentile lead to differences in area status.

Expert Judgement

The model results of all participants were combined and converted into one set of common results consisting of a reduction estimate per river. This was done by means of interpolation and averaging, but also included a certain amount of expert judgment. It is recommended to further objectify this process, e.g. by means of improvement and further use of the proposed optimization routine. This method has proven to be a powerful tool to determine the required reductions in riverine loads, although its settings (cost-function and constraints) should be further developed in co-operation with OSPAR national representatives. This includes the implementation of this combined method of ecosystem model information (including TBNT) and linear optimization by more models.

Natural variability

The fact that the year 2002 was a very wet year (implying high nutrient loads to the North Sea) causes the “distance to target” reduction estimates to represent an upper limit of reductions needed. In other words, when considering the interannual variability in the river loads, one could also interpret the reduction levels associated with the 2002 river loads as a worst case scenario. Similar scenarios could then be performed on typically dry years, with the present report as an important contribution to the other end of the spectrum of the interannual river load variability in terms of wet years.

Model constraints

The strong differences in the nutrient concentrations between the models, especially in the reference run, are not related to the assessment year 2002 but represent the characteristics of the individual model setup and its calibration. One reason is assumed to be the use of the individual boundary conditions by the different models in this study. One exception is the MUMM model (MIRO&CO-3D) which used boundary conditions provided by the UHAM model (ECOHAM) for all simulations. The use of a common set of boundary conditions was a major achievement for the Lowestoft workshop 2007 (Lenhart *et al*., 2010) on the way to gain comparable results from the different models. But it also caused problems since the regional differences could not always be taken into account by the wider domain model, which resulted in inconsistencies within the individual model setup. Taking into account the drawbacks from the use of common boundary condition, new ways have to been followed when each model uses its own boundary condition in terms of presenting the model results as weighted ensemble averages (Almroth and Skogen, 2010).

Recommendations

The underlying study makes clear that inconsistencies of the OSPAR assessment levels may contribute to unexpectedly high (or low) reduction estimates for the river loads. Therefore, it is recommended to re-evaluate these assessment levels, and replace them with values that are based on hydrodynamic, biological, and stoichiometric aspects, such that they are consistent across areas and variables. River load reductions recalculated on the basis of this new set of assessment levels will be more sensible both from a biological and a socio-economic point of view.

There is a need to further understand and reduce the differences between the models. However as this could result in a major effort per model, and differences between the models would never be entirely eliminated, there is also a need for developing a method to calculate weighted ensemble averages depending on model performance per target area at validation (Almroth and Skogen, 2010). However this requires the availability of a critical amount of validation data.

The linear optimization method offers the opportunity to calculate a large number of different reduction estimates rather fast. In addition it is important to notice, that for the extraction of the TBNT information, all target areas have to be taken into account. Within the linear optimization method, constrains can be formulated to include or to exclude target areas for the calculation of the “distance to target” reduction estimates. From a scientific point of view a number of reduction estimates with a variety of treatments of target areas (problem and non-problem areas) should be calculated. Those reduction estimates that offer a balanced approach should then be implemented as reduction scenarios by the ecosystem models to obtain a final assessment if the reduction targets can be achieved.

It is also recommended to further objectify the process by which the modeled concentrations of assessment variables are translated into required river loads reductions. A useful method could be the proposed optimization routine (see Annex 1), which has proven a powerful tool in determining the required river load reductions. Since new scenarios can be set up and run in a matter of minutes, it can be used to quickly test a range of assessment level values and/or cost functions. Ideally, the method should be applied on basis of the results of each of the models, which would require TBNT results from each of the individual models. Also, as the linear optimization method by its nature cannot account for nonlinearities, full model runs will be required to confirm the most interesting scenarios.

To make the optimization tool optimally suitable for management and policy related questions its settings (especially those with respect to the socio-economic aspects) should be further developed in cooperation with OSPAR national representatives. These developments could for instance include a further refinement of the cost-function, to enable a differentiation between (the costs associated with) reducing point sources or diffusive sources. Another possibility would be to differentiate between the contributions of the various countries upstream to the total river load and express the reduction estimate per country instead of per river.

Finally, in view of the large natural variability in river loads, it should be considered to evaluate the status of the system on the basis of a larger time period, rather than on one particular year. Depending on the legal framework one could for instance evaluate the system on the basis of a worst-case approach (i.e. by evaluating the wettest year in the period) or on the basis of an average approach (i.e. by evaluating an ‘average’ year).

Introduction

This report presents the results of model calculations for the North Sea to support estimation of “distance to target” by Contracting Parties. The calculations build on results from earlier work of the OSPAR Intersessional Correspondence Group on Eutrophication Modelling (ICG-EMO), and aim to estimate “target” nutrient reduction levels to advise “quantification by Contracting Parties of nutrient reduction targets required for eutrophication problem areas to move to non-problem area status”. In this report relevant parts from earlier ICG-EMO reports, user guides, OSPAR documents, Terms of Reference, etc. have been included with adaptations, where necessary.

1.1 Policy context

The objective of OSPAR’s Eutrophication Strategy, reinforced by the 2010 North-East Atlantic Environment Strategy, is *“to combat eutrophication in the OSPAR maritime area, in order to achieve and maintain a healthy marine environment where eutrophication does not occur”.*

The Eutrophication Strategy (OSPAR, 2010) builds on long-standing work of OSPAR on eutrophication. This includes the commitment of Contracting Parties to achieve a reduction at source, in the order of 50% relative to 1985, in inputs of phosphorus and nitrogen into areas where these inputs are likely, directly or indirectly, to cause eutrophication (OSPAR, 1988). OSPAR countries with problem areas have made substantial progress towards the OSPAR target of 50% reductions in nutrient discharges and losses compared to 1985. By 2005, reductions of up to 85% have been achieved for phosphorus while progress for nitrogen has been less successful with only few reductions of up to 50%. Despite the substantial reductions in nutrient inputs, the latest eutrophication assessment shows that eutrophication is still a problem in Regions II, III and IV and the objective of no eutrophication will only be partly achieved by 2010 (OSPAR, 2008b). Region II is the most widely affected Region with large areas along the continental coast from France to Norway and Sweden and a number of estuarine areas on the UK North Sea coast still adversely affected by eutrophication. Modelling studies suggest that significant further reductions of nutrient inputs, beyond 50% to some problem areas, will be required to eliminate eutrophication problems.

Based on the recommendations of the Quality Status Report 2010 (OSPAR, 2010), OSPAR Ministers agreed in the 2010 North-East Atlantic Environment Strategy the strategic direction to cooperate to set appropriate nutrient reduction targets that are required to move individual eutrophication problem areas to non-problem area status. The Strategy requires the quantification of the nutrient reduction and of nutrient sources, including transboundary nutrient loads.

1.2 OSPAR work on eutrophication modelling

A first assessment of the expected eutrophication status of the OSPAR maritime area following implementation of agreed measures was carried out by OSPAR in 2001 (OSPAR, 2001). That assessment built partly on model results of a 1996 OSPAR-ASMO workshop (Villars *et al*., 1998) and other model results from literature. In general the various models showed good performance with regard to hindcast. In 2005 OSPAR decided to form an intersessional group on ecological modelling, the so-called Intersessional Correspondence Group for Eutrophication Modelling (ICG-EMO)[3].

The ICG-EMO has performed three OSPAR workshops in 2005, 2007 and 2009 to predict responses of eutrophication effects parameters to reductions of riverine nutrient loads and to quantify the relative contributions of nutrient loads of various rivers to transboundary nutrient transport. In the course of this work, ICG-EMO has developed definitions, data sets and protocols for model applications that have been compared with each other. The links are presented individually for each workshop in the description below.

[3] Hermann Lenhart (Germany, Convener), Hans Los, Tineke Troost (NL), Geneviève Lacroix, Xavier Desmit (Belgium), Alain Ménesguen (France), David Mills, Johan van der Molen, Sonja van Leeuwen, Sarah Wakelin (UK), Morten Skogen (Norway), Ramiro Neves (Portugal), Sverker Evans, Pia Andersson (Sweden).

1.2.1 The OSPAR Common Procedure

In order to appreciate the scope of the intersessional work it is important to outline the Common Procedure (COMP) for the identification of the eutrophication status of OSPAR maritime areas. The Common Procedure was developed by the OSPAR Contracting Parties in order to aid a harmonised assessment of eutrophication status for the OSPAR maritime region. The assessment is carried out by firstly differentiating water bodies into estuarine, coastal and offshore types on the basis of catchments, salinity ranges and hydrography. Secondly, a comparison is made between the levels of a range of indicators of eutrophication (arranged within categories i – iii) that include winter concentration of DIN and DIP, N:P ratios, growing season chlorophyll concentration, dissolved oxygen concentration and concentrations of phytoplankton biomass and indicator species related to assessment levels defined by Contracting Parties. Thirdly, an appraisal of all relevant information (concerning the harmonised assessment criteria, their respective assessment levels and the supporting environmental factors) is made in order to provide a sufficiently sound and transparent account of the reasons for giving a particular status to an area. The aim of the OSPAR COMP is to enable the national authorities to classify regions in their maritime area as either a) problem area (PA), b) potential problem area (PPA) or c) non-problem area (NPA). The integrated report on the second application of the Common Procedure was agreed by OSPAR in 2008 (OSPAR publication 372/2008).

OSPAR recommends that measures should be taken to improve eutrophication status for areas classified as a PA under the COMP. Since OSPAR treats eutrophication as a source-oriented problem this implies that measures should be taken within the national catchment areas. The potential effectiveness of such measures, related to reductions of nitrogen and phosphorus riverine loads within the catchment area, can only be determined through the application of models. This task of prescribing reduction levels for river DIN and DIP loads and the assessment of the model results from these scenarios has been the primary focus of the first two workshops. The third workshop was focused on Transboundary Nutrient Transports (TBNT). The work on TBNT was related to the fact that various transport mechanisms in the North Sea in combination with multiple nutrient sources exclude the possibility to directly link effects of individual anthropogenic nutrient sources to specific affected maritime areas. The models were used to determine the relative contribution of different national riverine nutrient sources to nutrient concentration of national maritime areas and specific water bodies within them. After the third workshop intersessional work was carried out in 2011 and 2012 by combining river load reduction with TBNT modelling work. The results of this work are described in this report.

As Table 1 shows, for the present study only a subset of the parameters used for the Common Procedure are taken into account. However there is a much wider coverage of parameters where information can be extracted from the models.

For the winter DIN and DIP concentration winter is regarded as the months January and February, although for a standard application of the OSPAR COMP this would also include November and December. Chlorophyll concentration is calculated as the mean summer concentration related to the growing season from March to September, while for Belgium and France it covers the months March to October. For *Phaeocystis* the assessment level is set to > 10^6 cells/l, depending on the assumption of the carbon content per *Phaeocystis* cell the assessment level 10^7 cells/l corresponds to a concentration of 0.15 to 0.3 mg C l^{-1} (based on Rousseau *et al*., 1990 and Jahnke, 1989). The oxygen deficiency is related to the bottom oxygen concentration with a concentration below 6 mg/l, which is still under reconsideration within OSPAR.

Table 1: Agreed harmonised assessment parameters (shaded) and additional voluntary parameters (*) applied and reported by Contracting Parties in the second application of the Comprehensive (OSPAR, 2008a). The table compares the parameters used in the present ICG-EMO study with the overall coverage of parameters by models.

Category	Parameter	Present ICG- EMO study	Covered by models
Cat. I	**Riverine inputs and direct discharges**	+	+
	Winter DIN and DIP Concentrations	+	+
	N/P ratio	-	+
	*Total nitrogen, total phosphorus	-	+
	*Transboundary nutrient transport	+	+
	*Atmospheric nitrogen deposition	+	+
	*Silicate (and Si ratios)	-	+
Cat. II	**Chlorophyll *a***	+	+
	Phytoplankton indicator species	+	+
	Macrophytes including macroalgae	-	-
Cat. III	**Oxygen deficiency and lowered % saturation**	+	+
	Kills in fish and zoobenthos	-	-
	Long-term changes in zoobenthos biomass and species composition	-	-
	Organic carbon	-	+
	*Secchi depth	-	+
Cat. IV	**Algal toxins**	-	-

*additional voluntary assessment parameters

1.2.2 2005 OSPAR workshop

The OSPAR workshop held in Hamburg in September 2005 produced an assessment of eutrophication parameters, compiled in the format of the Common Procedure, with tables, maps and text, showing the predicted environmental consequences for effects parameters when the 50% nutrient reduction target was achieved. Where 50% reduction did not move eutrophication parameters below the assessment level, the workshop estimated the reduction target needed to achieve that effects parameters return below assessment levels. For the results of this workshop see http://www.cefas.defra.gov.uk/eutmod. The workshop identified a number of issues to improve confidence in model results (OSPAR, 2006 minimum requirements were that the models used the same forcing data *e.g.* riverine inputs, open boundary conditions) and that they all used similar spin-up procedure.

1.2.3 2007 OSPAR workshop

The aim of the 2nd workshop, held at Cefas in Lowestoft in 2007, was to compare the results of a number of North Sea ecosystem models under different reduction scenarios and the requirements derived from the previous Hamburg workshop in 2005. To meet OSPAR requirements, river loads used for the reduction scenarios took into account the river load reductions already achieved between 1985 and 2002**.** In order to achieve a consistent set of boundary conditions, as requested from the 2005 workshop in Hamburg, data were extracted from a wider area model that covered the domain of all other models. The data were provided by the Atlantic Margin Model POLCOMS-ERSEM (NOC, UK) for each boundary of the different national models. This consistent dataset was not only provided for the reference run, but also for both reduction runs. The provision of these boundary conditions in combination with a sufficient spin-up by the individual models was the key to achieve comparable model results for the standard run and the reduction runs. To validate the results of the various models with observations, cost function calculations for the different target areas have been introduced.

The conclusion from the workshop was that models could be usefully applied to support the application of the OSPAR reduction measures. It was concluded that model results for parameter level determination provides a prognostic method for establishing the effectiveness of nutrient reduction measures in the North Sea catchment.

Further work was identified and proposed as a result of this workshop to enhance confidence in the results. A general limitation was acknowledged to be the lack of good SPM time series or dynamic SPM modelling leading to inaccurate calculation of the underwater light climate.

The workshop results are summarised in Lenhart *et al*., (2010) and the details can be found in the workshop report at http://www.cefas.defra.gov.uk/eutmod2.

1.2.4 2009 OSPAR workshop (TBNT)

In 2009 a workshop was organised in Brussels at MUMM. The aim of this workshop was to quantify the Transboundary Nutrient Transports (TBNT) from the rivers of France, Belgium, the Netherlands, Germany and the UK and from the Atlantic Ocean boundaries to national maritime areas and water bodies. **Note that the rivers are named after the country in which they reach the sea.** Figure 1 shows a summary of the results of this workshop. Unfortunately not all models took into account the nitrogen load from atmospheric deposition. The report of the TBNT workshop in 2009 is available at http://www.cefas.defra.gov.uk/eutmod3.

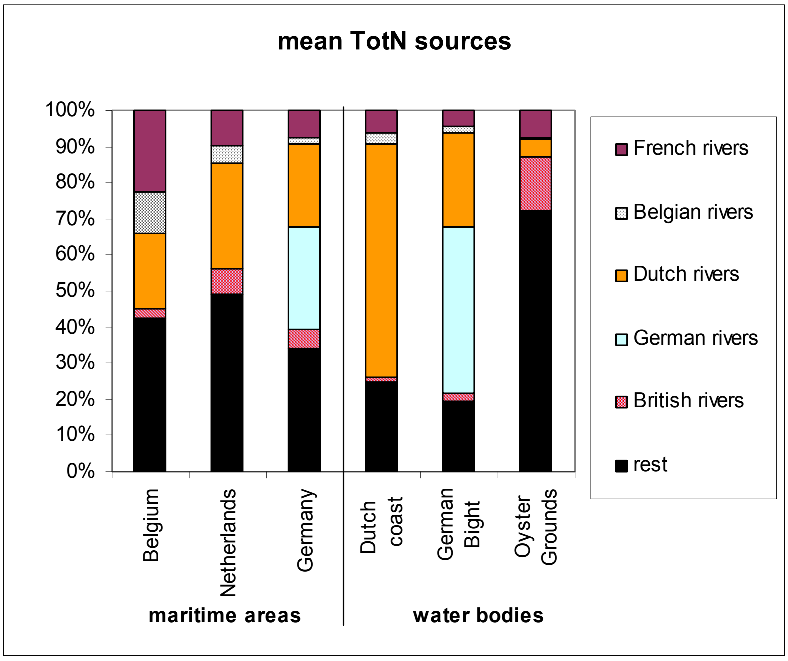

Figure 1. The percentage contributions from the different national river groups to total nitrogen in maritime areas and specific water bodies averaged over the relevant models. Because the category ‘rest’ is different for each model used in calculating the mean, the contribution of Atlantic Ocean, Channel, atmospheric deposition and the ‘rest’ are taken together.

1.2.5 Conclusions from the 2007 and 2009 workshops

The last ICG-EMO workshops, 2007 in Lowestoft on reduction scenarios and 2009 in Brussels on transboundary nutrient transport, have led to the following conclusions:

a. The participants expressed, within the limitations of models, confidence in the model results regarding imposed nutrient reductions in the model (50% and 70% vs. levels of 1985), in terms of indicating the direction of changes in levels and effects. For more details on the conclusions see Lenhart *et al*., 2010.

b. On transboundary nutrient transport (TBNT), for areas where the various model domains overlap, all the models agreed on the direction of water and nutrient fluxes, and to within a factor of three on the magnitude of the riverine water and nutrient exchanges between areas. In terms of relative riverine nutrient content of areas, the model results agreed mostly to within a factor two or better. These levels of agreement give reasonable confidence in the averaged results.

1.3 Objectives for the intersessional work in 2012

EUC(2) 2009 developed further terms of reference that required additional work on eutrophication modelling, building on the results and experience gathered from previous workshops and the last application of the Common Procedure (OSPAR, 2008a). Further work of the ICG-EMO would include:

a. by 2011 to further post-process the 2009 results from model runs on transboundary nutrient transport with a view to

(i) *consolidating the workshop results;*

(ii) *preparing additional data products to support clarification of “distance to target” in terms of reductions of nutrient loads to the maritime area required to achieve non-problem area status in areas affected by eutrophication;*

b. *by 2011 to model the effects of different nutrient reduction scenarios, subject to securing resources for the work;*

c. *by 2013 to prepare model products supporting the assessment of eutrophication status in the next application of the Common Procedure;*

d. *Priority focus for ICG-EMO for the 2011/2012 meeting cycle will be tasks delivering on "distance to target".*

The light printed tasks have not been carried out: task a(i) due to lack of resources, and task c because it is not due for execution yet.

The conclusions of the former workshops led to intersessional work to carry out a "distance to target" calculation in order to estimate nutrient reductions required to move selected parameters below the assessment levels, taking into account transboundary nutrient transport. The estimates are aimed to advise "quantification by Contracting Parties of nutrient reduction targets required for eutrophication problem areas to move to non-problem area status". However, non-linearities in system response make it inappropriate to extrapolate the results from the TBNT work (based on 2002 river loads), to estimate the overall reduction likely to be required to reclassify problem areas as non-problem areas.

2. Methods

The aim of the modelling work presented in this report is to estimate the nutrient reduction required in eutrophication problem areas to move nutrient concentrations below their assessment levels. The state of eutrophication effect parameters, as the determining criterion for eutrophication assessment according to the Common Procedure, is represented in the ecosystem models by the chlorophyll concentration. However, the chlorophyll concentration can only be changed by nutrient levels in the marine waters via reductions of river nutrient loads. Therefore, the focus of this study is mostly on DIN and DIP, assuming that a reduction in these variables would also drive the direct and indirect eutrophication effect parameters below their assessment levels.

2.1 The model runs

To achieve reliable estimates for the distance to target request by OSPAR, the ICG-EMO organising group proposed three model simulations. First the technical setup of the model simulation is described, followed by the method of defining the distance to target reduction (2.3) and the description of the models that take part in this exercise (2.4). The three proposed model simulations are:

a. Hindcast for the years 1997 – 2002

b. 85% reduction run[4] for 2002.

c. Distance to target run for 2002.

2.1.1 Hindcast for 1997 - 2002 and reference run 2002

The models have been run from Jan 1th 1997 to Dec 31th 2002 in order to provide information about interannual variability and to have the last year in the run, 2002, as the reference year. This run included atmospheric nutrient deposition and detailed information on river loads.

[4] In the user guide this run is called assessment level run, which is incorrect. In the Terms of Reference for eutrophication modelling (OSPAR, 2011) it is called pristine model run. To avoid misunderstanding, it is called the 85% reduction run in this report.

2.1.2 85% reduction run

The basic hypothesis is that background concentrations for nutrients in seawater should be achieved. A 100% reduction of anthropogenic nutrient loads is not realistic in light of the different nutrient loads of rivers in the Region and the loading within the system. Therefore an approximation was sought. It is assumed that 85% of the river loads in the simulation period (1997-2002) was anthropogenic. The 85% reduction run is therefore the maximum possible reduction of the river loads. The results of this 85% reduction run, representing the maximum possible reduction of the river loads, were needed to calculate the minimum reduction percentage of the nutrient concentrations in a specific target area necessary to reach a nutrient concentration below the assessment level.

2.1.3 “Distance to target” run

The “distance to target” run was a run with reduced river loads, aiming to bring nutrient concentrations in all problem areas below the assessment levels. The state of eutrophication effect parameters, as the determining criterion for eutrophication assessment according to the Common Procedure, is represented in the ecosystem models by the chlorophyll concentration. The chlorophyll concentration is to a large extent determined by the ambient nutrient levels, and only the riverine contribution to these nutrient levels can be effectively reduced. Therefore, the focus of this study is mostly on DIN and DIP, assuming that a reduction in these variables would also drive the direct and indirect eutrophication effect parameters below their assessment levels.

The extent to which the loads of the individual rivers were reduced to achieve this in the models is dependent on the results from the reference run and the 85% reduction run. The description of how the appropriate reduction level for the individual rivers is extracted from the two previous model simulation results is provided in Section 2.3.

2.2 Harmonised approach

2.2.1. River loads

Daily nutrient loads of 249 rivers around the North Sea for the years 1985 to 2009 have been collected in a database by CEFAS. These rivers include the European continental rivers as well as all UK rivers. The database provides the freshwater discharge and the concentrations of total nitrogen, nitrite, nitrate, ammonium, total phosphorus, orthophosphate, silicate, chloride, dissolved inorganic and organic carbon. Figure 2 shows the rivers included. In each model the rivers relevant for its model domain were used.

CEFAS also provided the river loads for the reference run, as well as for the 85% reduction run and the loads for the target reduction scenario runs, based on the optimized reduction percentages per river as described in Section 3.3.

For the model calculation high frequency measurements of river concentrations are required. For this reason the aggregated RID data were not fit for purpose and were replaced, where possible by the underlying original data sets or otherwise by additional high frequency data sets. While this means that the absolute values for inputs used in this work differs from those of the RID data, the direction of trends and the general conclusions of this study and the RID assessment (such as on 2002 being a very wet year for some rivers) are consistent. For this general information reference is therefore made to the latest RID assessment on trends in waterborne inputs to the OSPAR maritime area (http://qsr2010.ospar.org/media/assessments/p00448_RID_Assessment.pdf)

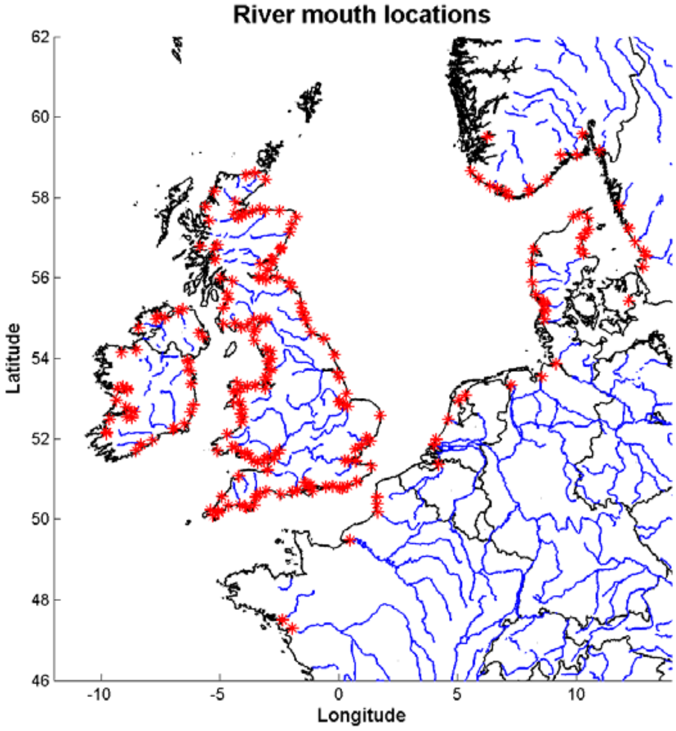

Figure 2. Map of the North Sea and beyond with the rivers within this domain that are included in the Cefas database. Baltic rivers are included but not shown.

The rivers have been aggregated into national groups, according to Table 2.

Table 2. National aggregated nutrient sources.

Country	name	sources: rivers & boundaries
Germany	RDE	Elbe, Weser, Ems
Netherlands	RNL1	Rhine, Meuse, North Sea Canal
	RNL2	Lake IJssel
Belgium	RBE	Scheldt*
France	RFR1	Authie, Canche, Somme, Seine,
	RFR2	All other French rivers south of the Seine
UK	RUK**	Chelmer, Colne, Darent, Gipping, Medway, Stour at Harwich, Thames, Humber, Wash, Tees
Norway	---	one aggregated unit
Boundary	---	Channel
		Atlantic Ocean
Atmospheric input	---	one aggregated unit

*Although the Scheldt is entering the North Sea in The Netherlands, it has been assigned to Belgium, because its catchment is mainly in Belgium.
**For UK in addition to the river group RUK1 some rivers from RUK2 had to be taken into account. Based on the TBNT information from the Delft3D-GEM model, these UK rivers are Humber, Wash, Tees as well as the Thames. Note that some UK rivers represent river systems with more than one major river.

2.2.2 Boundary conditions

Boundary conditions for nutrients have been provided from the ECOHAM model in the representation of the Northwest European Shelf Sea Version (20 km resolution, 47.5°N -64°N, 14.2°W-15°E) that has been run with the 1997-2002 river loads and the two nutrient reduction scenarios (85% reduction and distance to target reduction scenarios), after a spin up with repeating 1996 riverine nutrients.

From the results of these runs ECOHAM has extracted boundary conditions from ECOHAM for use in the MUMM model MIRO&CO-3D. The other models used reflecting[5] boundaries or prescribed boundary data based on measurements or model results (see Section 2.5 for model descriptions).

2.2.3 Atmospheric nutrient deposition

Atmospheric nitrogen deposition data have been made available by EMEP (Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe) for the years 1996 to 2002 on a monthly basis. The data include the atmospheric dry and wet deposition of oxidized nitrogen compounds (NO_x) as well as of reduced nitrogen (NH_y), see Figure 3.

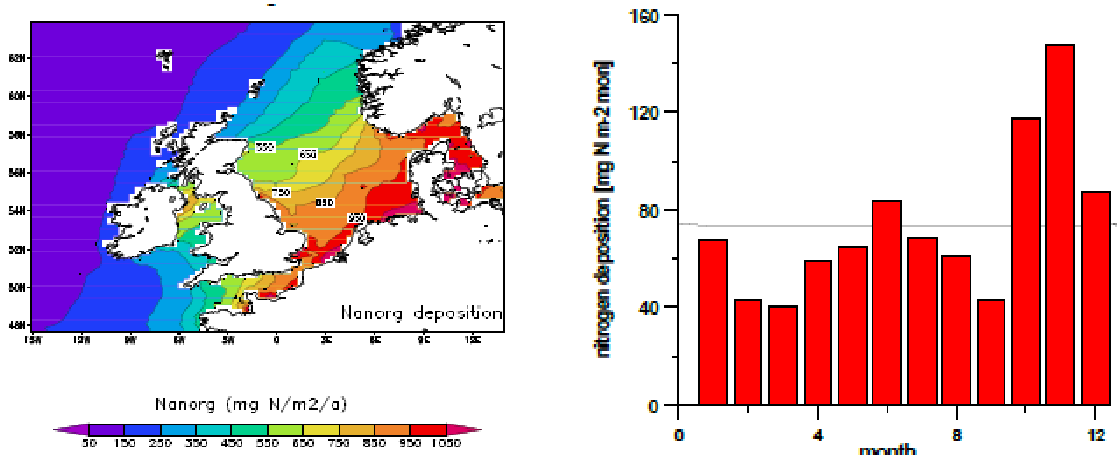

Figure 3. Atmospheric nitrogen deposition data for the whole North Sea for the years 1996 to 2002. Left: Mean annual deposition. Right: Mean monthly deposition (Courtesy of Jerzy Bartnicki of EMEP).

2.2.4 Spin-up time

Because the number of years necessary to reach a dynamical equilibrium is dependent on the model, all participants were requested to start their model spin up with repeating the forcing of 1996 for at least 3 years, in order to reach a dynamic equilibrium at 1 January 1997. The period of time that was analysed in terms of interannual variability covered the period of 1997 to 2002 (see Annex 4). The assessment of the hindcast run, the 85% reduction run and the target reduction run all have been focused on the final year 2002.

2.2.5 Initial values

After spinning-up the model the end values (Dec 31th, 1996) have been used as the initial values for 1997.

2.2.6 Target areas

The North Sea has been subdivided in a number of coastal areas and a number of, generally larger, offshore areas. Coastal areas had a salinity of up to approximately 34 (the areas were fixed, whereas salinity varied in space and time), while the offshore areas have salinities above this value (Figure 4).

The division in areas is basically the same as in previous ICG-EMO work, with one exception. The area NL-C2 has been divided into NLC2a and NLC2b, because the southern part is covered by more models than the northern part. Results will be presented for a number of selected target areas (see Figure 4, blue-coloured areas).

5 Reflecting boundaries is a term from marine modelling and refers to the fact that the simulated state variables of the grid points at the edge of the model domain are used as boundary condition for the next time step of the model.

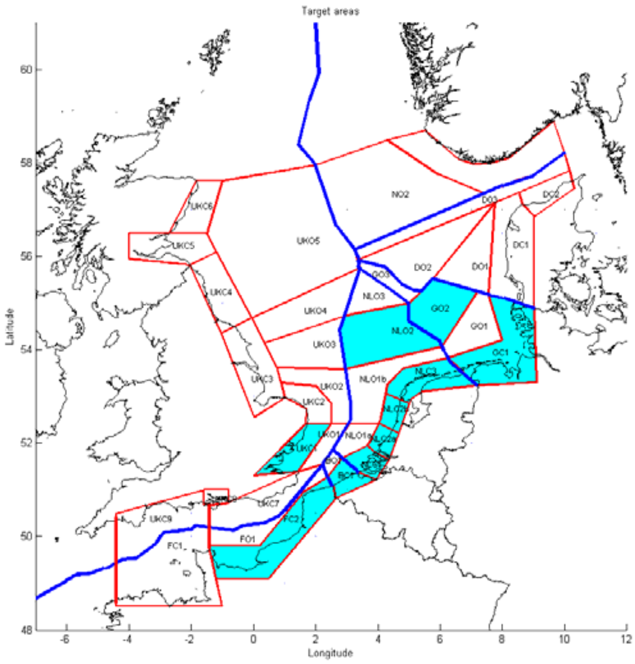

Figure 4. Map of the North Sea divided into target areas. The blue ones are the designated target areas for this report. It should be noted that target areas UKC1 and NL02 in contrast to the other target areas were not designated as Problem Areas in the last application of the OSPAR Comprehensive Procedure.

2.3 Modelling approach to calculating nutrient reduction targets

To achieve a decrease in Chlorophyll concentrations below the assessment level it is necessary to reduce the river nutrient loads for DIN and DIP by measures in the catchment area. The extent to which the nutrient concentrations in a Problem Area have to be reduced to bring nutrient concentrations below the assessment level has been calculated as illustrated in Figure 5. For each target area, in a graph representing reduction percentage (x-axis) against winter nutrient (DIN or DIP) concentrations (y-axis), a line is drawn between the nutrient concentrations of the 2002 run and the 85% reduction run (the light-blue line in Figure 5). The intersection (red arrow) between this line and the area-specific assessment level (red line) gives the reduction percentage for the nutrient concentration in that target area (blue arrow in Figure 5). Each model calculated these reduction percentages for DIN and for DIP in each target area in its model domain.

In a second step a linear optimization procedure, developed by Hans Los from Deltares and described in detail in Annex 1, was used which takes into account the previous experiences achieved from TBNT results to estimate the contribution of major nutrient sources in any area of the North Sea. This linear interpolation aimed to minimize the difference between the current nutrient concentration and the relevant assessment level in each target area.

For the calculation of the reduction percentages as well as for the optimization procedure the assessment levels for DIN and DIP in each of the target areas are of importance. Table 3 presents the nutrient assessment levels used in this modelling exercise and for the chlorophyll-a assessment levels used in the final assessment. The nutrients DIN and DIP were averaged over the winter. For the model results winter is defined as the months January and February. Chlorophyll-a was averaged over the whole water depth in the growing season. Growing season is taken as March to and including September for the northerly areas. The southern areas (France and Belgium) have a longer growing season: from March to and including October.

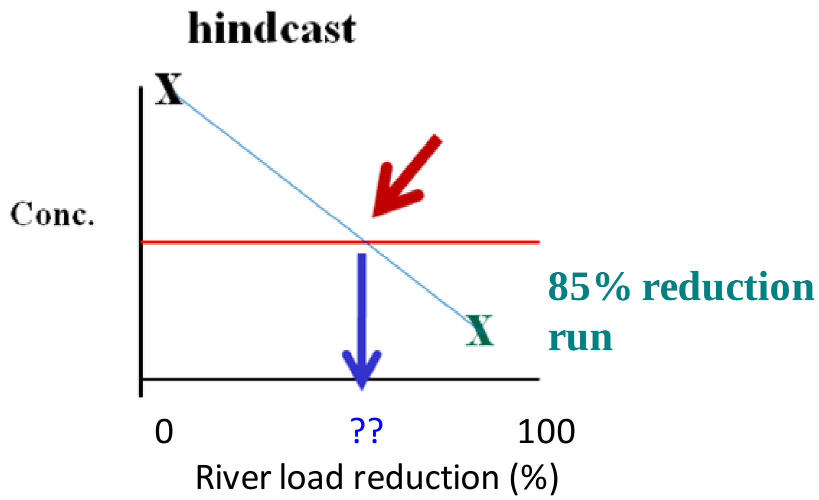

Figure 5. Estimating the “distance to target” reduction level.

Table 3. Values of the area-specific assessment levels derived for the modelling exercise. These values are in use since the “Revised draft assessment” from the 2007 Lowestoft workshop (OSPAR, 2008b). NB Numbers in red are not in correspondence with assessment levels in the second Comprehensive Procedure (OSPAR, 2008a, Appendix 1). Note that for German coastal waters/estuaries assessment levels for nutrient and chlorophyll a were chosen that are at the high end of the range defined for these waters.

country	mean winter DIN (µmol/l)		mean winter DIP (µmol/l)		mean growing season Chla (µg/l)	
	coast/ estuary	offshore	coast/ estuary	offshore	coast/ estuary	offshore
FR	15	--	1.2	--	4	--
BE	15	12	0.8	0.8	7.5	4.2
NL	30	15	0.8	0.8	7.5	2.25
DE	24	14	0.9	0.9	6	3
UK	10.8	--	0.68	--	15	--

*In OSPAR (2008a) only a value for 90-perc is given.

2.4 The participating models

Six institutes were involved in this modelling exercise, being Deltares from the Netherlands, the **I**nstitut **fr**ançais de **re**cherche pour l'exploitation de la **mer** (Ifremer) from France, the Management Unit of the North Sea Mathematical Models (MUMM) from Belgium, the University of Hamburg (UHAM) from Germany and the National Oceanographic Centre[6] (NOC) and the Centre for Environment, Fisheries & Aquaculture Science (CEFAS), both from UK.

As a number of participants had problems to get funding for the ICG-EMO modelling work from their national authorities, some of the participants were not able to carry out all, or even any, model runs. Deltares, Ifremer and UHAM did all runs, MUMM and NOC carried out two of the three runs, and CEFAS, by Sonja van Leeuwen, provided the river load data for 249 rivers, including daily nutrient load values for the years 1996 to 2002. They formed the basis for all three simulations, the reference run as well as the two reduction scenarios. Work to update and collate the riverine input data was supported by the UK.

A critical mass of simulations from different ecosystem models was needed to reach significant conclusions. Despite the funding problems there was a mentionable support from a considerable number of participants

[6] A couple of years ago the Proudman Oceanographic Laboratory (Pol) merged into NOC.

which did not get support from their national authorities. Table 4 provides an overview on the contributions for the ICG-EMO modelling activities.

Table 4. Overview on contributions from the participants to the ICG-EMO modelling activities. O denotes no funding; X denotes funding from the national authorities.

Participants	Preparation River Loads	Reference simulation	85% reduction scenario	Distance to Target scenario
Cefas (UK)	O			
UHAM (G)		X	X	X
Deltares (NL)		X	X	X
Ifremer (F)		O	O	O
MUMM (B)		O		O
NOC (UK)		O	O	

In addition to the three participants who could accomplish all three simulations (Deltares, Ifremer and UHAM,) the 85% reduction scenario was implemented by NOC, while the distance to target reduction scenario was completed by MUMM.

2.4.1 Model domains

The model domains of the models differ in size. The models with the largest domains are those of NOC (UK: POLCOMS-ERSEM), UHAM (DE: ECOHAM) and Deltares (NL: Delft3D-GEM), see Figure 6a.

The models with smaller domains in the North Sea are those of Ifremer (FR: ECO-MARS) and MUMM-ULB (BE: MIRO&CO-3D), see Figure 6b. NB The ECO-MARS3D model also includes the Gulf of Biscay.

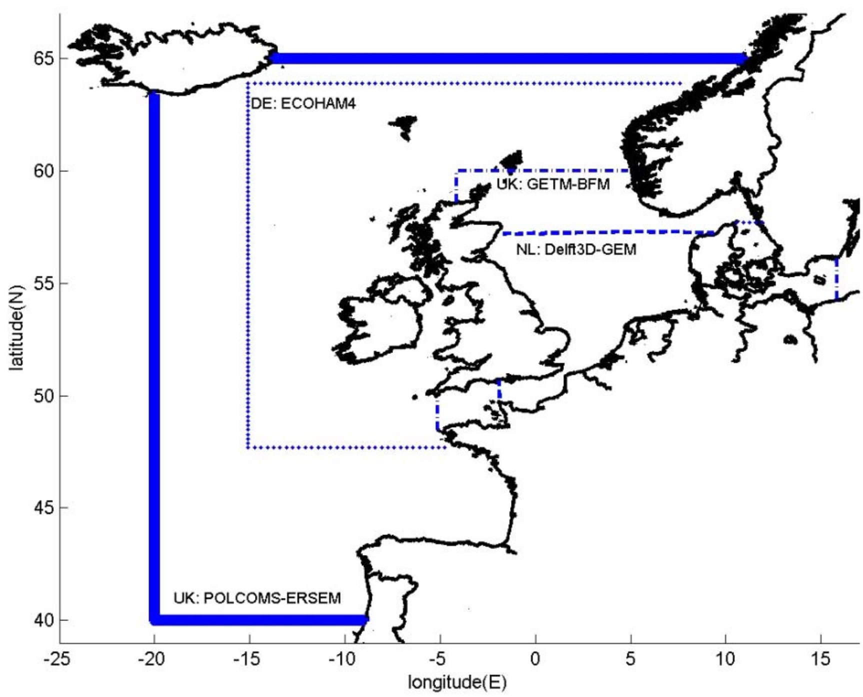

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Figure 6a. Model domains of the larger models.

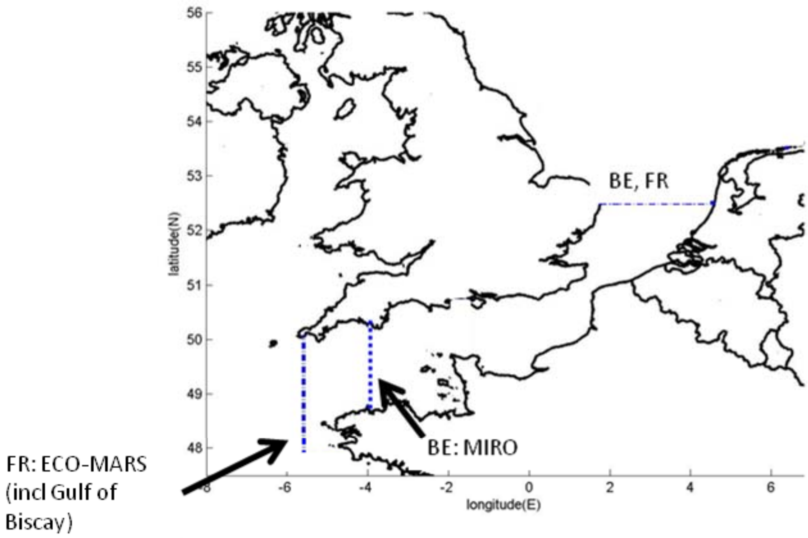


Figure 6b. Model domains of the smaller models.

2.5 Model descriptions

In Annex 2 short descriptions of the models are given. The descriptions of the five models that are used in this ICG-EMO work are copied and adapted where necessary from Lenhart *et al*., 2010. The most relevant properties of the models are summarised in Table 5.

Table 5. Overview of models used in the distance to target study.

Institute/country	**UHAM**/DE	**Deltares**/NL	**Ifremer**/FR	**MUMM**/BE	**NOC**/UK
Model name Workshop term (2007, 2009)	ECOHAM DE model	Delft3D-GEM NL model	ECO-MARS3D FR model	MIRO&CO-3D BE model	POLCOMS-ERSEM UK-pol model
Name hydrodynamic model	HAMSOM	Delft3D	MARS-3D	COHERENS	POLCOMS
Name biogeochemical model	ECOHAM4	GEM	ECO-MARS-3D	MIRO	ERSEM
Open source	yes	no	no	COHERENS : yes; MIRO: no	no
Spatial Resolution Δh (km)	20 km	Variable – curvilinear (from 1 x 1 -20 x 20km)	16 x 16 km	5' longitude (5.6 km) x 2.5' latitude (4.6 km)	1/6° longitude × 1/9° latitude (~12km)
Vertical resolution	24 z-layers	10 sigma layers	30 sigma levels	5 sigma layers	42 s-levels
Longitude (degree)	15°W – 14°E	4°W – 10°E	8.13°W – 5.0°E	4.0°W – 5.0°E	20°W-13°E
Latitude (degree)	47.5°N – 64°N	49°N – 57°N	43.17°N – 52.75°N	48.5°N – 52.5°N	40°-65°N
Temporal resolution Δt (sec)	60 s	Transport: 30 min. Ecology: 12-24 hrs	variable ~250 s	900 s	15 s (barotropic) 300s baroclinic 1200 s biochemical
Temperature & Salinity prescribed or modelled	T: prognostic S: diagnostic	T and S prognostic	T and S prognostic	Weekly 20 km x 20 km gridded SST (BSH) imposed – salinity prognostic	T and S prognostic
SPM dynamics	SiAM3D model and satellite forcing (SeaWiFS, monthly averages)	cosine function with empirically derived amplitude, adjusted to actual wind speed	satellite forcing (SeaWiFS, monthly averages) for the shelf, silt state variable in the plume areas	Daily climatology from MODIS-Aqua images (2003-2006). The DINEOF methodology has been applied to reconstruct daily time series.	assimilation of non-biotic (SPM & CDOM) absorption from SeaWiFS
Inclusion of tides	yes	yes	yes	yes	yes
Atmospheric deposition	yes	yes	no	no	yes
Boundaries, timeseries or reflecting	climatological timeseries	time series, based on Laane *et al*. 1993.	Climatological times series for salinity and temperature. Reflecting boundary conditions for all biogeochemical variables	Climatological times series for salinity. Time series from ECOHAM for nutrients and phytoplankton	hydrodynamic time series from NEMO (Smith and Haines, 2009); nutrients from climatology
River groups in model domain	RFR2, RBE, RUK1, RUK2 RNL1, RNL2, RDE	RFR2, RBE, RUK1, RUK2 RNL1, RNL2, RDE	RFR1, RFR2, RBE, RUK1, RNL1	RFR1, RBE, RUK1, RNL1	RFR1, FR2, RBE, RUK1, UK2, RNL1, RNL2, RDE

Pelagic part					
Pelagic element cycles	C, N, P, Si , O	N, P, Si (complete) C (organic part only), O	N, P, Si, O	C, N, P, Si	C, N, P, Si,O
No. of pelagic state variables	24	23	17	32	50
Pelagic nutrients (bulk or explicit)	explicit	explicit	explicit (NO3, NH4, PO4, adsorbed PO4, SiO)	Explicit	explicit
Phytoplankton	diatoms flagellates	12 groups: diatoms (3), microflagellates (3), dinoflagellates (3), *Phaeocystis* (3)	diatoms, dinoflagellates, nanoflagellates	nanoflagellates (3), diatoms (3), *Phaeocystis* (4)	diatoms, picoflagellates, flagellates, dinoflagellates
Zooplankton	micro- and mesozooplankton	none	micro- and mesozooplankton	micro- and mesozooplankton	micro- and mesozooplankton heterotrophic nanoflags
Bacterioplankton	heterotrophic bacteria	none	none	heterotrophic bacteria	heterotrophic bacteria
Pelagic POM	Slow (C, N and P) and fast sinking detritus (C, N, P, Si and $CaCO_3$)	none	yes	particulate organic C, N & P of high (1) and low(2) biodegradability, biogenic silica	yes
Benthic part					
Benthic element cycle	C, N, P, Si, O and $CaCO_3$	C, N, P, Si	N, P, Si	C, N, P,	C, N, P, Si, O
No. of benthic state variables	5	4	3 (only detrital forms of N, P and Si)	6	34
Benthic nutrients (bulk or explicit)	bulk	explicit	explicit	diagenetic model (NO_3, NH_4, PO_4). First-order kinetics dissolution for biogenic Si	explicit
References	Lorkowski *et al*., 2012.	Los and Bokhorst, 1997 De Vries *et al*., 1998 Los *et al*., 2008; Los & Blaas, 2010	Ménesguen *et al*., 2006 Vanhoutte-Brunier *et al*., 2008	Lacroix 2007a (JMS) Lacroix 2007b (CSR) Lancelot *et al*., (2005) (MEPS)	Wakelin *et al*., 2012

2.6 Validation values

The models have been calibrated and validated, as described in the national reports, as part of the report of the 2007 workshop.

Validation data for 2002 were available from different countries. The Netherlands provided data of the monitoring stations on the Dutch part of the continental shelf. The data were extracted from the Rijkswaterstaat database (DONAR). German observations came from the MUDAB and originate from various sources. For the UK the following sets of data were supplied by CEFAS for the national maritime area: analysed bottle samples; ferry box; Smart Buoy data; CTD profiles and National Marine Monitoring Programme (NMMP). Belgium provided the data for the monitoring stations on the Belgium part of the continental shelf. The data were extracted from the IDOD database held by the Belgian Marine Data Centre (BMDC).

In Figure 7 the spatial distribution of all sample locations are given. For each target area (see Figure 4) and each variable, data from 0 - 15 m depth are combined in surface data, while the deeper samples are combined in bottom samples. Monthly means have been calculated per variable and per target area.

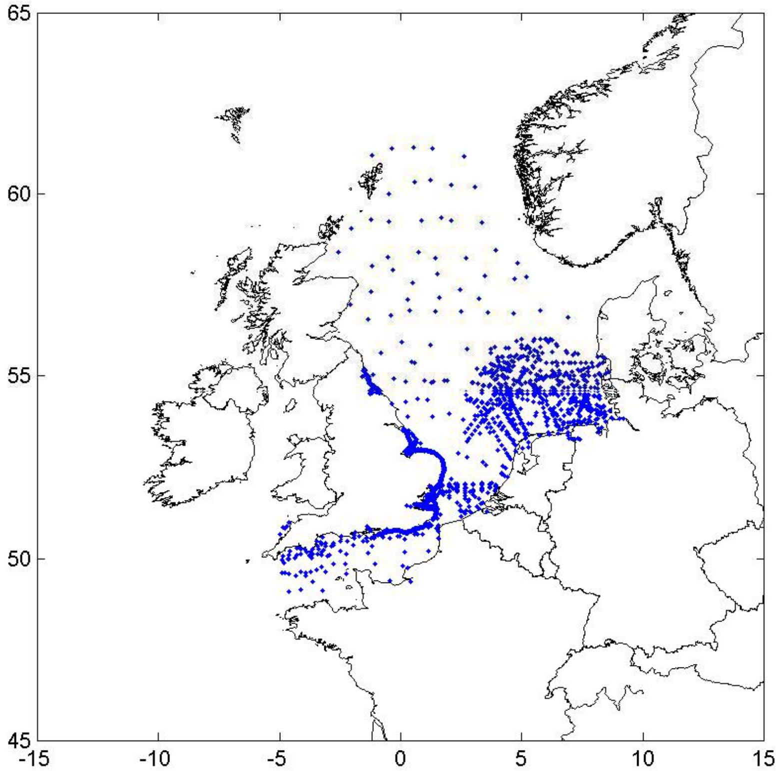


Figure 7. Spatial distribution of sampling locations from which 2002 data for validation were generated.

As can be seen from Table 6 the standard deviations for some of the assessment variables are very large, especially in two of the coastal boxes. A possible explanation can be the heterogeneity of these areas in terms of salinities and subsequently nutrient concentrations. In Table 6 also the ranges of the monthly salinities are given. For the areas NLC3 and GC1 the ranges are well below salinity 30, indicating the presence of low-salinity samples which can also be traced back to the sampling stations in Figure 7.

Table 6. Observation data for validation of model results in the target areas (Figure 4) giving the mean value (mean), the standard deviation (std) and the number of observations (n) for 2002. The salinity data for the areas NLC3 and GC1 were very low, which explains (partly) the high nutrient values (source: OSPAR, 2008b).

Target Areas,	Winter DIN (µmol/l)			Winter DIP (µmol/l)			Summer chl-a (µg/l)			O2 minimum (mg/l)	Salinity in January and February					
	mean	std	n	mean	std	n	mean	std	n		mean	std	n	Range		
UKC1	40.6	21.4	85	1.9	1.2	124	7.7	3.4	271	5.3	33.5	0.8	318	33.0	–	33.8
NLC2*	51.6	11.7	8	1.0	0.1	8	11.0	10.1	65	6.9	31.2	3.4	34	30.7	–	31.9
NLC3	84.9	56.5	28	1.3	0.8	28	5.0	3.8	47	6.7	24.2	6.6	27	23.6	–	24.7
NLO2	3.1	0.8	3	0.5	0.05	3	0.6	0.7	144	7.5	32.1	1.2	32	32.1	–	32.1
GC1	127.0	124.7	29	1.4	0.7	29	1.9	1.1	6	4.6	27.6	6.9	20	23.7	–	28.9
GO2	8.2	3.6	6	0.6	0.07	6	0.6	0.4	40	5.5	34.4	0.4	11	34.3	–	34.4
FC2	-	-	-	-	-	-	-	-	-	-	-	-	-			
FO1	-	-	-	-	-	-	-	-	-	-	-	-	-			
BC1	25.1	12.6	12	0.8	0.2	12	5.8	4.1	8	9.6	32.1	1.4	25			
BO1	17.9	-	1	0.7	-	1	1.6	-	1	9.4	34.1	0.6	5			

* There are only validation data available for the combined target area NLC2 (NLC2a +NLC2b)

2.6.1 Comparison with observations

Before making their runs the modellers have calibrated and validated their models in the same way as they did for the former workshops. In that procedure validation is done with data from specific locations and at specific times that have been compared with model results for the same locations and times. In this report the results are presented averaged over space and time. The space, being a target area, was covered within each model by a different number of grid cells (see for grid cell sizes Table 5). This implies that we now are reduced to comparing model results, averaged over the whole target area and over the period under consideration (winter or growing season) with observational averages over the same area and period. This method is only informative when the distribution of the observations in/over time and space is very even, which is not usually the case. In Figure 8 the average chlorophyll model results of the 2002 reference run have been summarised per target area as ranges from mean - standard deviation to mean + standard deviation, together with the same range of the observations. The ranges averaged over all models have been included as well.

As could be expected, the model results for chlorophyll provide a good representation for areas in which a wide range of chlorophyll values occurs, e.g. BC1 and NLC3. For areas where these ranges were smaller (GC1 and NLO2), the results of most models only intersected with the higher parts of the intervals. However, as was explained above, these comparisons should be interpreted with care since they make a comparison between in-situ data from specific locations and model results aggregated over target areas. The differences between model results and observations can partly be explained, in areas with high spatial variability (gradients), by the position of the measurement’s stations which are not representative of the average of a whole target area. One possibility to reduce the discrepancies is to have more stations to ensure that the average can be compared to results within target areas.

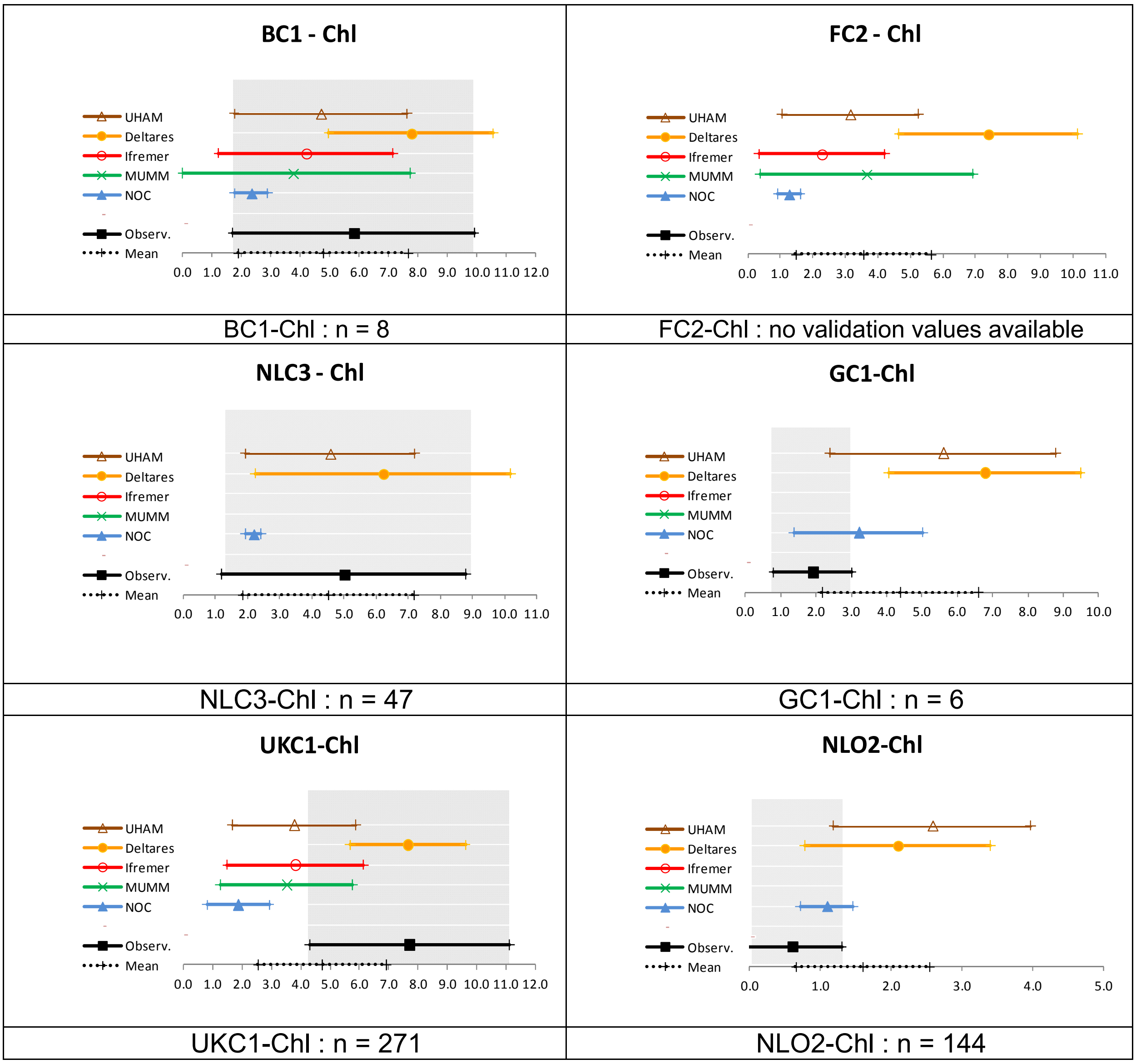


Figure 8. The lines in these figures represent the ranges (mean ± standard deviation) of chlorophyll model results in the reference (2002) run per target area, together with the range of the observations. The ranges averaged over all models (Mean) have been included as well. n = number of observations in 2002.

3. Results

Since a number of preparation and modelling steps are needed to achieve a distance to target reduction scenario, according to Section 2.3, and the final assessment, Figure 9 provides a flow diagram of the procedure and links to tables or figures representing the associated results. Part A, the preparation of forcing data, is already described in Section 2.2 of this report. Parts B to G are described in Sections 3.1 – 3.4.

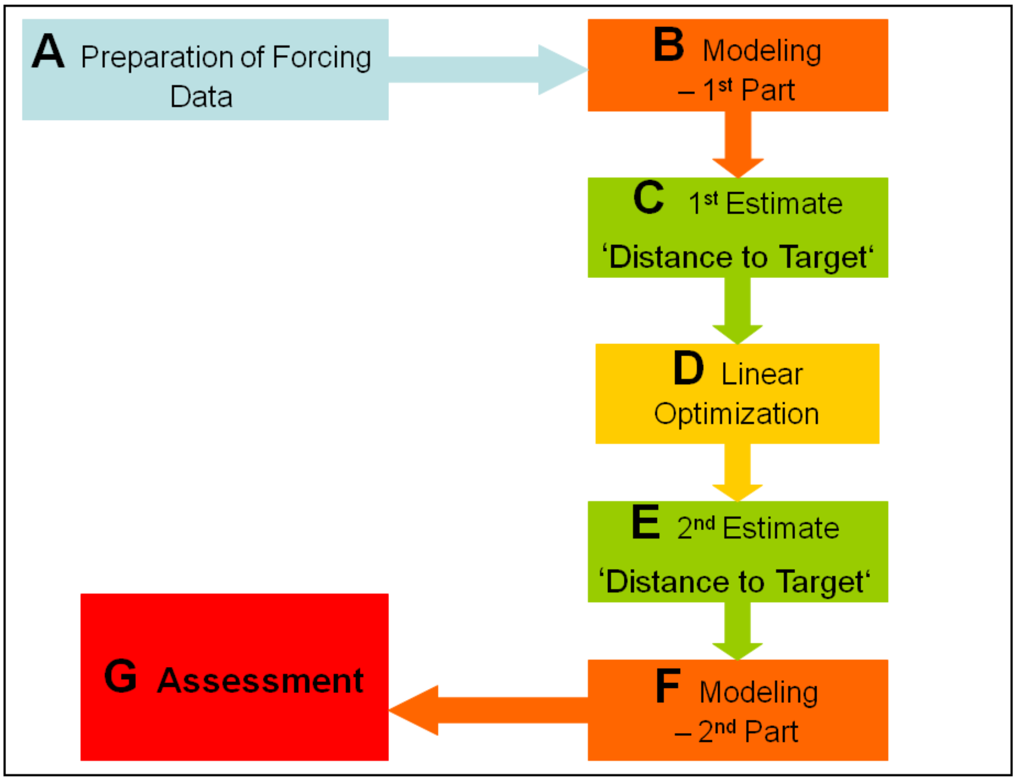


Figure 9. Flow diagram representing the various steps of model activities and related results to achieve distance to target simulation results and assessment.

Five institutes provided results for the target areas in their model domains. The detailed representation of these results in this report is restricted to the ten designated target areas from Figure 4. The results of the reference run (2002), the “distance to target” run (in short: target run) and the 85% reduction run are shown in the following sections for six of the target areas. The summary of results and the results of the reference run (1997-2002) are given for all ten target areas.

3.1 Nutrients

3.1.1. Nutrients – To define “distance to target” reduction levels

In order to calculate the required reduction percentages of the nutrient loads of the various rivers influencing each target area, four of the five models carried out the reference run (2002) and the 85% reduction run (step B Figure 9). The results for winter DIN and winter DIP are presented in Figures 10 and 11 for selected target areas with the assessment level. The target areas shown in Figures 10 and 11 were chosen mainly with respect to the countries that took part in the modelling activities.

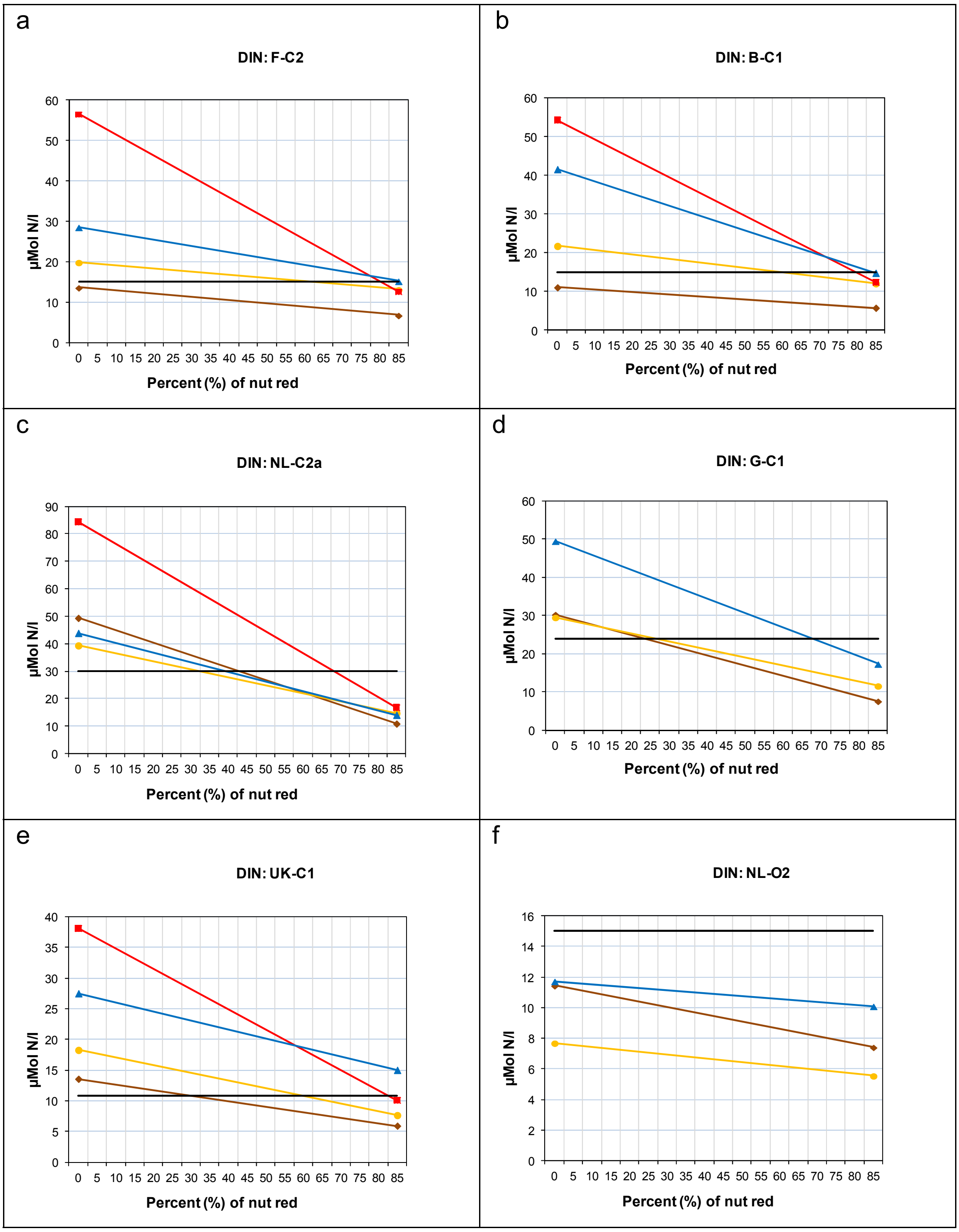


Figure 10. Winter means of DIN of reference run and 85% reduction run according to the models of ECOHAM (—◆—), Delft3d-GEM (—●—), ECO-MARS3D (—■—) POLCOM-ERSEM(—▲—) and assessment level (—).

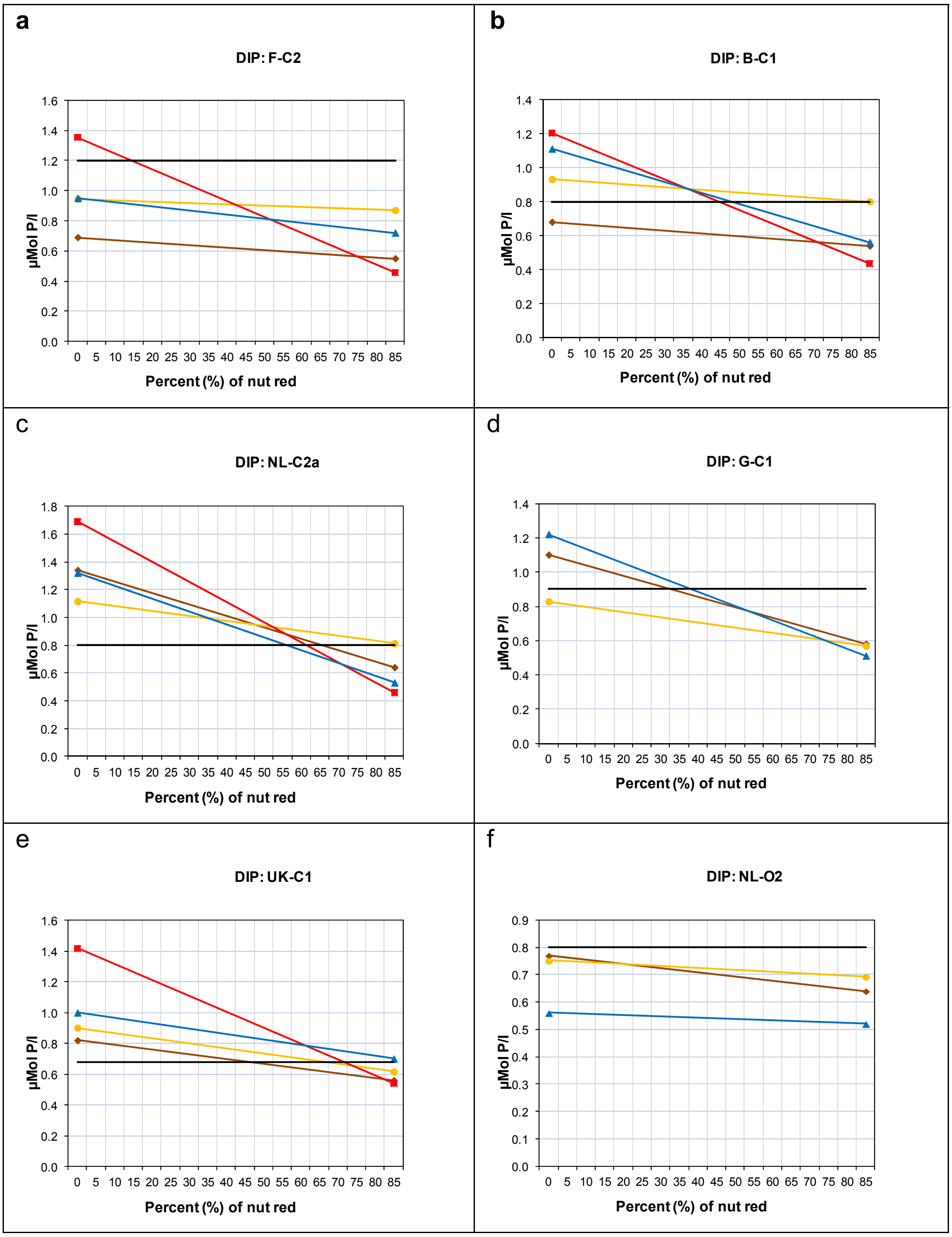


Figure 11. Winter means of DIP of reference run and 85% reduction run according to the models of ECOHAM (—◆—), Delft3d-GEM (—●—), ECO-MARS3D (—■—) POLCOM-ERSEM(—▲—) and assessment level (—).

Figures10 and 11 represent the mean winter concentration for the reference run and the 85% reduction run, with the x-axis representing the level of reduction. By connecting the mean winter concentration from both simulations by a line, the intersection with the assessment level (black line, Table 3) was found. The four different models produced different results for these intersections and hence for the required nutrient reductions.

One thing to notice is the difference in the mean winter concentration of nitrogen between the various areas for the reference run. This implies different reaction potential for the spring bloom as well as for the responsiveness to the reduction of the nutrient river loads. In addition, according to some of the models even the 85% reduction scenario would not lead to a nutrient concentration below assessment level (e.g. in target area UK-C1 the POLCOM-ERSEM results for DIN and the Delft3D-GEM results for DIP). In general, the model results for the 85% reduction scenario cluster at winter nutrient concentrations below assessment level.

The first definition of the distance to nutrient assessment levels (step C of Figure 9) associated with the results of the individual models (Figures 10 and 11) were calculated for DIN (Table 7) and DIP (Table 8). For model results where even the 85% reduction level did not result in concentrations below assessment level, a value of 100% is prescribed.

Table 7. First reduction estimates for DIN (in %) in relation to 2002 based on ICG-EMO simulation for all designated target areas.

Target Area / Parameter	ECOHAM	Delft3D-GEM	ECO-MARS3D	POLCOM-ERSEM
F-C2 DIN	-	0	80	87
B-C1 DIN	0	65	82	84
NL-C1 DIN	0	-	71	54
NL-C2a DIN	43	28	73	39
NL-C2b DIN	7	21	23	0
NL-C3 DIN	0	0	-	0
G-C1 DIN	23	26	-	67
UK-C1 DIN	30	75	83	100
B-O1 DIN	0	67	-	100
NL-O2 DIN	0	0	-	0
G-O2 DIN	0	0	-	0

Table 8. First reduction estimates for DIP (in %) in relation to 2002 based on ICG-EMO simulation for all designated target areas.

Target Area / Parameter	ECOHAM	Delft3d-GEM	ECO-MARS3D	POLCOM-ERSEM
F-C2 DIP	-	0	19	0
B-C1 DIP	0	74	43	48
NL-C1 DIP	0	-	56	61
NL-C2a DIP	66	89	58	56
NL-C2b DIP	54	100	0	26
NL-C3 DIP	33	80	-	16
G-C1 DIP	32	0	-	38
UK-C1 DIP	46	72	68	90
B-O1 DIP	0	97	-	45
NL-O2 DIP	0	0	-	0
G-O2 DIP	0	0	-	0

It should be noted that it is not possible to describe an association between high reduction levels and high winter nutrient concentration for a single model within a target area. First it is still an open question if the high winter nutrients are related to boundary conditions, model initialisation or other model constrains. Second, lower winter nutrient concentration could lead to a reduced responsiveness in the assessment level scenario. This could result in a decreased steepness in the line connecting concentration for the reference run and the assessment level scenario and therefore in a reduction estimate about the same as presented in Table 7 and 8. A technical solution could be to use the weighted ensemble mean (Almroth and Skogen, 2010), but since the weight applied in these methods is related to the cost function this is highly dependent on availability of a statistically relevant amount of validation data, which actually increases the problem of reliable data for model validation.

3.1.2 Linear Optimization

In the next step, the difference in concentration between the area-averaged DIN and DIP winter concentrations from the reference run and the assessment level were used as input for the linear optimization procedure (step D in Figure 9) by Hans Los (Deltares, NL; described in Annex 1) to calculate a single value per target area. This linear optimization procedure combines these winter nutrient concentrations with modelled TBNT results, which requires designated TBNT simulations (as were for example carried out for the 2009 workshop in Brussels (Figure 1)). This combination should take into account the effect of the circulation pattern in the North Sea, e.g. that efforts made in river load reduction in Belgium and the Netherlands will also have a positive effect to areas downstream of the continental coastal current like the German Bight. Since TBNT results were only available from the Delft3D-GEM model for the coverage of the complete North Sea domain, only the optimization results based on the Delft3D-GEM model are fully consistent. The optimization method was also applied to the results (winter nutrient concentrations) of the other models, but the underlying TBNT information was based on Delft3D-GEM model results only, resulting in a kind of “hybrid” approach. Table 9 shows the ranges of optimal reduction values resulting from the Delft3D-GEM model and from the “hybrid” approaches. Note that the DIN and DIP reduction in this table are related to the national river groups. Based on the TBNT information from the Delft3D-GEM model, the UK rivers Humber, Wash, Tees as well as the Thames are taken into account in addition to the rivers entering the target area UK-C1.

Table 9. Ranges of reductions (in %) after linear optimization in relation to 2002 for each target area related to winter nutrient concentrations from the Delft3D-GEM model and the “hybrid” approaches. * The low reduction requirements for German rivers partly result from the application of assessment levels for coastal waters / estuaries that were at the high end of the range defined for these waters (see Table 3).

Country, where river enters the sea	River group	Rivers	DIN reduction level (%)	DIP reduction level (%)
France	RF1	Authie, Canche, Seine, Somme	0-85	85
Belgium	RBE	Scheldt	0-85	79-85
The Netherlands	RNL1	Meuse, Rhine, North-Sea Canal	44-85	85
The Netherlands	RNL2	Lake IJssel	0	0-45
Germany	RDE	Ems Weser Elbe	0-1*	0-58*
United Kingdom	UKR1 (partly)	Chelmer, Colne, Darent, Gipping, Medway, Stour at Harwich, Thames	42-85	85
	UKR2 (partly)	Humber, Wash, Tees	0-85	0-85

It should be pointed out that the results of the linear optimization as shown in Table 9 is one representation from a large number of possible realizations which could be achieved by imposing different constraints to the procedure (Annex 1). For example, for the results shown in Table 9, the optimization procedure assumes that the costs for obtaining a certain reduction percentage are the same for each river. As evident from Table 9 downstream countries benefit disproportionally from reductions in upstream countries. Little trust can be placed in the very low reduction requirements resulting for German rivers due to assessment levels applied for coastal waters that were too high. Furthermore, there were no target areas defined downstream of German national waters that receive nutrients from German rivers and could therefore trigger higher reduction requirements for Germany. Furthermore, it turned out that the optimization results based on the Delft3D-GEM model and the results based on the hybrid approaches were quite similar; the large ranges resulting in some areas are mostly due to extreme values in one of the “hybrid” approaches; if TBNT results would be available for each individual model, results would possibly become more similar which would result in smaller ranges. This result is also biased since nutrient export from German waters to downstream Danish and Norwegian waters is not considered because no model target areas were selected in the waters of these countries. The optimization procedure needs to be improved in the future to arrive at a more balanced share of reductions by all Contracting Parties.

3.1.3. Final definition of reduction targets

The final reduction targets that result under the assumption that all participating Contracting parties achieve their assessment levels for nutrient concentrations are shown in Table10. They are derived from Table 9 by using expert judgement (step E in Figure 9). Expert judgement is required since, for example, the German contribution resulting from the optimization method was zero for the N-scenario and also for most of the P-scenarios. Here the judgement was that for the German rivers the reduction should be closer to the model reduction levels presented in Table 8. Therefore a mean reduction level from the reference and the 85% reduction run as described in Table 7 (DIN) and Table 8 (DIP) was considered and merged with the information from the linear optimization procedure (Table 9) in order to define a reduction target, representing more balanced contributions from the Contracting Parties (Table 10). To achieve the assessment level values for the variables under consideration, an iterative approach would be preferable, including a number of reduction scenarios. However, this was not feasible since for budget reasons only one such run, based on the reduction levels as described in Table 10, could be carried out. Note that the DIN and DIP reduction in Table 10 are related to individual rivers for the national areas.

Table 10. Defined reductions (in %) in relation to 2002 for each country and the related rivers under the assumption that all participating Contracting Parties achieve their assessment levels for nutrient concentrations.

Country, where river enters the sea	River group	Rivers	DIN reduction level (%)	DIP reduction level (%)
France	RF1	Authie, Canche, Seine, Somme	55	50
Belgium	RBE	Scheldt	23	60
The Netherlands	RNL1	Meuse, Rhine, North-Sea Canal	55	60
The Netherlands	RNL2	Lake Ijssel	0	60
Germany	RDE	Ems Weser Elbe	20	35
United Kingdom	UKR1 (partly)	Chelmer, Colne, Darent, Gipping, Medway, Stour at Harwich, Thames	75	70
	UKR2 (partly)	Humber, Wash, Tees	75	70

3.1.4 Nutrient results from “distance to target” run

In Figures12 and 13 the final simulation results of the “distance to target” runs for nutrients by four of the ecosystem models are presented (step F of Figure 9). The runs represent the simulation in which all nutrient loads from the rivers have been reduced by the amounts described in Table 10 with the aim to move nutrient concentrations below their assessment levels. POLCOM-ERSEM could not provide a “distance to target” run. MUMM was able to contribute the 2002 reference run and the “distance to target” run, but no results for 85% nutrient reduction scenario. Therefore the green lines, representing the MIRO&CO-3D results, end with the simulated concentration related to the distance to target run for those target areas that are covered by the model domain.

Please note that since the prescribed reduction varied for the different target areas, the concentrations representing the reduction target were plotted at different positions on the x-axis, corresponding with the local reduction target. Therefore, seeming non-linearities in the model results in Figures12 and 13 in form of braking lines (e.g. for DIN in target area B-C1 and UK-C1 for the ECO-MARS3D model) do not necessarily originate from non-linear model behaviour, but may also result from the fact that the nutrient concentrations in most areas are affected by more than one river, while the value on the x-axis represents the percentage of nutrient reduction of the local rivers.

As one can see from the selected target areas in Figures12 and 13, the mean winter concentration for DIN and DIP for a number of target areas are still above the OSPAR assessment level in some of the presented model results. A schematic overview where concentrations are below (blue) or still above (red) the area specific OSPAR assessment levels for all model runs are provided in Table 11.

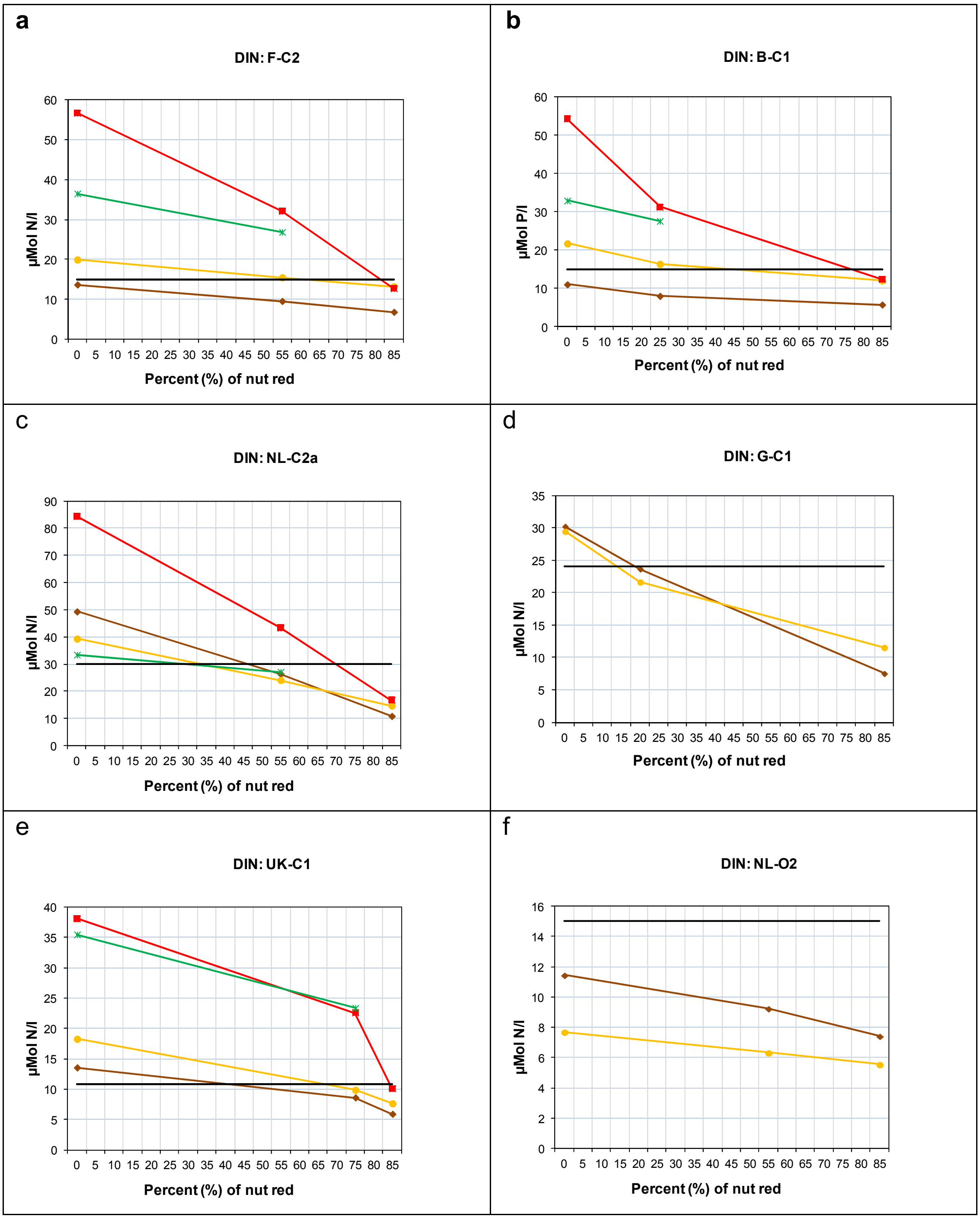


Figure 12. Winter means of DIN of reference run, distance to target run and 85% reduction run according to the models of ECOHAM (—◆—), Delft3D-GEM (—•—), ECO-MARS3D (—▪—), MIRO&CO-3D (—✳—) with the area-specific assessment levels (—).

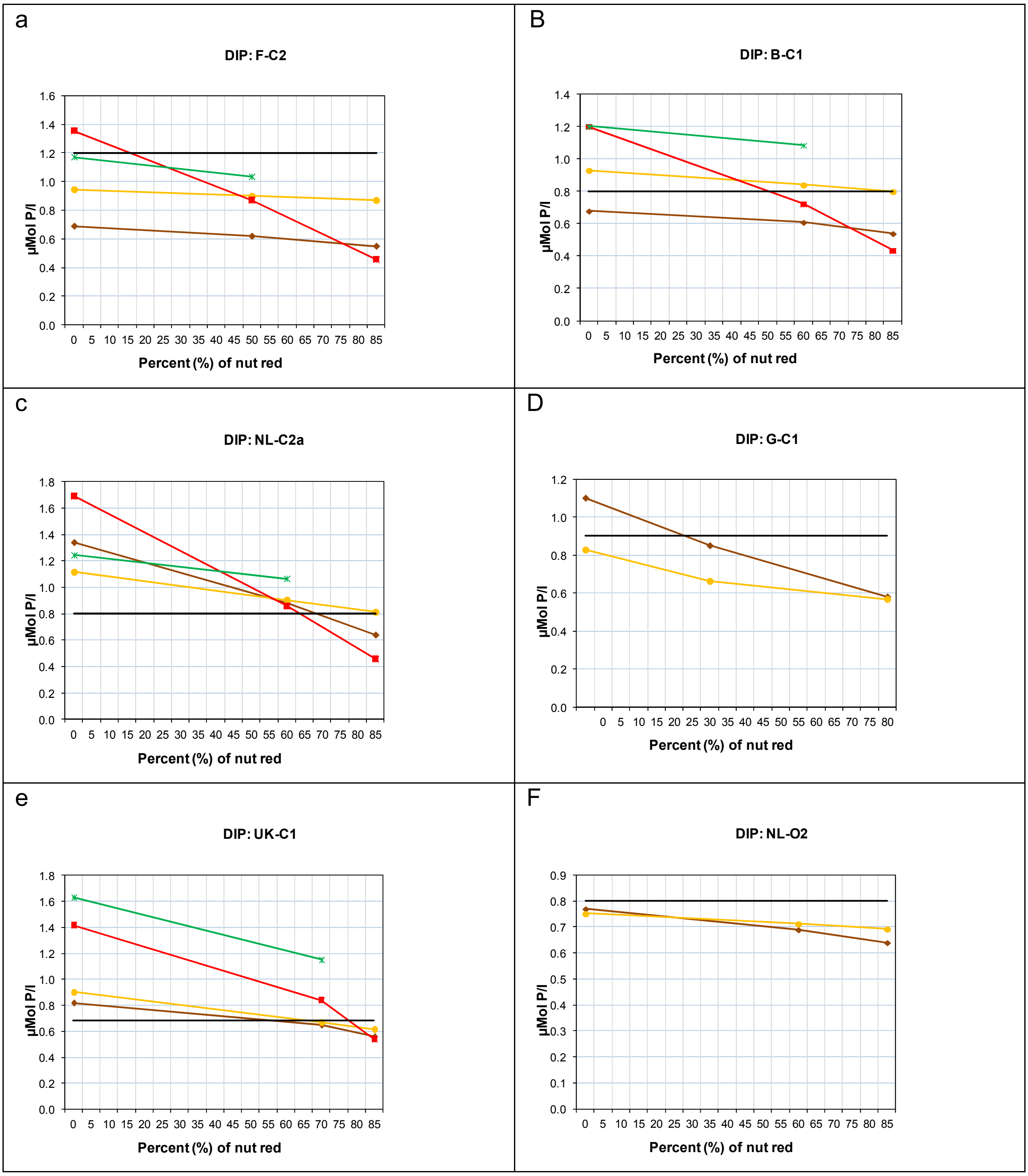


Figure 13. Winter means of DIP of reference run, distance to target run and 85% reduction run according to the models of ECOHAM (—◆—), Delft3D-GEM (—•—), ECO-MARS3D (—▪—), MIRO&CO-3D (—✳—) with the area-specific assessment levels (—).

Table 11. Summary of the results presented in Figures12 and 13. Red cells: nutrient enriched; blue cells; not enriched; white cells not applicable; the area GC1 and NLO2 are outside the model domains of Ifremer and MIRO&CO-3D. The simulations are indicated by: 1 = reference run, 2 = “distance to target” reduction run and 3 = 85% reduction run.

Target Area	var.	ECOHAM			Delft3D-GEM			ECO-MARS3D			MIRO&CO-3D			POLCOM-ERSEM		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
FC2	DIN	blue	blue	blue	red	red	blue	red	red	blue	red	red	white	red	grey	red
	DIP	blue	blue	blue	blue	blue	blue	red	blue	blue	blue	blue	white	blue	grey	blue
BC1	DIN	blue	blue	blue	red	red	blue	red	red	blue	red	red	white	red	grey	blue
	DIP	blue	blue	blue	red	red	blue	red	blue	blue	red	red	white	red	grey	blue
NLC2a	DIN	red	blue	blue	red	blue	blue	red	red	blue	red	blue	white	red	grey	blue
	DIP	red	red	blue	red	red	red	red	red	blue	red	red	white	red	grey	blue
NLO2	DIN	blue	blue	blue	blue	blue	blue	grey	grey	grey	grey	grey	white	blue	grey	blue
	DIP	blue	blue	blue	blue	blue	blue	grey	grey	grey	grey	grey	white	blue	grey	blue
GC1	DIN	red	blue	blue	red	blue	blue	grey	grey	grey	grey	grey	white	red	grey	blue
	DIP	red	blue	blue	blue	blue	blue	grey	grey	grey	grey	grey	white	red	grey	blue
UKC1	DIN	red	blue	blue	red	blue	blue	red	red	blue	red	red	white	red	grey	red
	DIP	red	blue	blue	red	blue	blue	red	red	blue	red	red	white	red	grey	red

3.2 Eutrophication effect parameters

We have been looking at nutrient enrichment in detail, but the determining criterion for eutrophication assessment according to the Common Procedure is the state of eutrophication effect parameters (see Table 12), which is represented in the ecosystem models by the chlorophyll concentration. The reason that we started with the nutrients is, that the chlorophyll concentration (in the context of the models one of the very few indicator variables for the state of the ecosystem) can only be changed by the reduction of riverine nutrients. This implies that due to the non-linearity of ecosystem processes we would require a number of reduction runs to iteratively achieve the target chlorophyll levels, but there was only resource to carry out one run. Therefore the best estimate for the “distance to target” run is used as presented in Table 10.

Out of the categories “direct effects” and “indirect effects”, as listed in Table 12, all models can give information about chlorophyll and some of them about the indicator species *Phaeocystis spec.* and oxygen deficiency. The status of these variables are an indication for the classification the OSPAR maritime areas. Areas with direct and/or indirect effects are problem areas, regardless of the nutrient concentrations, (Table 12, groups a and b), areas without direct and/or indirect effects are non-problem areas (Tab 12, groups c^1 and d) unless there is insufficient data on effect parameters. In the latter case, the area is classed as a potential problem area Tab 12, groups c^2). The Common Procedure acknowledges, nevertheless, that nutrient enrichment in one area without effects may contribute to direct and indirect effects elsewhere.

In the following, the influence of the reductions as proposed in Table 10 on selected eutrophication effect parameters is shown and discussed.

Table 12. Examples of the integration of categorised cause-effect related assessment parameters for an initial area classification (Source: OSPAR Common Procedure; OSPAR 2005) used in this exercise. Not all Contracting Parties follow the same classification procedure.

group	Category I Degree of nutrient enrichment Nutrient inputs Winter DIN and DIP Winter N/P ratio	Category II Direct effects Chlorophyll a Phytoplankton indicator species Macrophytes	Categories III and IV Indirect effects/other possible effects Oxygen deficiency Changes/kills in zoobenthos, fish kills Organic carbon/matter Algal toxins	Initial Classification
a	+	+	+	problem area
	+	+	-	problem area
	+	-	+	problem area
b	-	+	+	problem area[1]
	-	+	-	problem area[1]
	-	-	+	problem area[1]
c[1]	+	-	-	non-problem area[2]
c[2]	+	?	?	potential problem area
	+	?	-	potential problem area
	+	-	?	potential problem area
d	-	-	-	non-problem area

(+) = Increased trends, elevated levels, shifts or changes in the respective assessment parameters

(-) = Neither increased trends nor elevated levels nor shifts nor changes in the respective assessment parameters

? = Not enough data to perform an assessment or the data available is not fit for the purpose

Note: Categories I, II and/or III/IV are scored '+' in cases where one or more of its respective assessment parameters is showing an increased trend, elevated level, shift or change

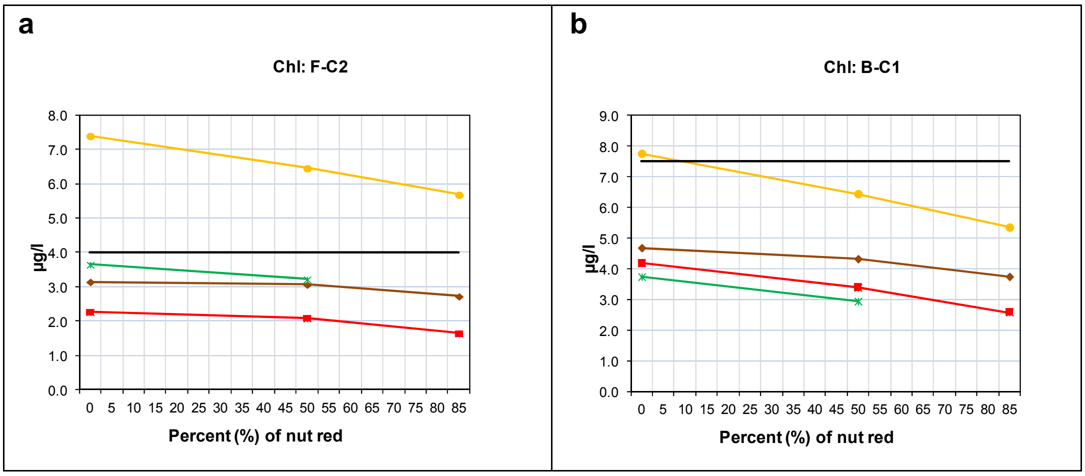
[1]For example, caused by transboundary transport of (toxic) algae and/or organic matter originating in adjacent/remote areas.

[2]The increased degree of nutrient enrichment in these areas may contribute to eutrophication problems elsewhere.

3.2.1 Phytoplankton

Results for chlorophyll-a (in the rest of the report also indicated as Chlorophyll or Chl) averaged over the growing season of the three runs by the various models are shown in Figure 14.

The results presented in Figure 14 are summarised in Table 13. Where available, results for the 90th percentile are also given in Table 13. As assessment level for the 90th percentile twice the value for the mean chlorophyll has been used.



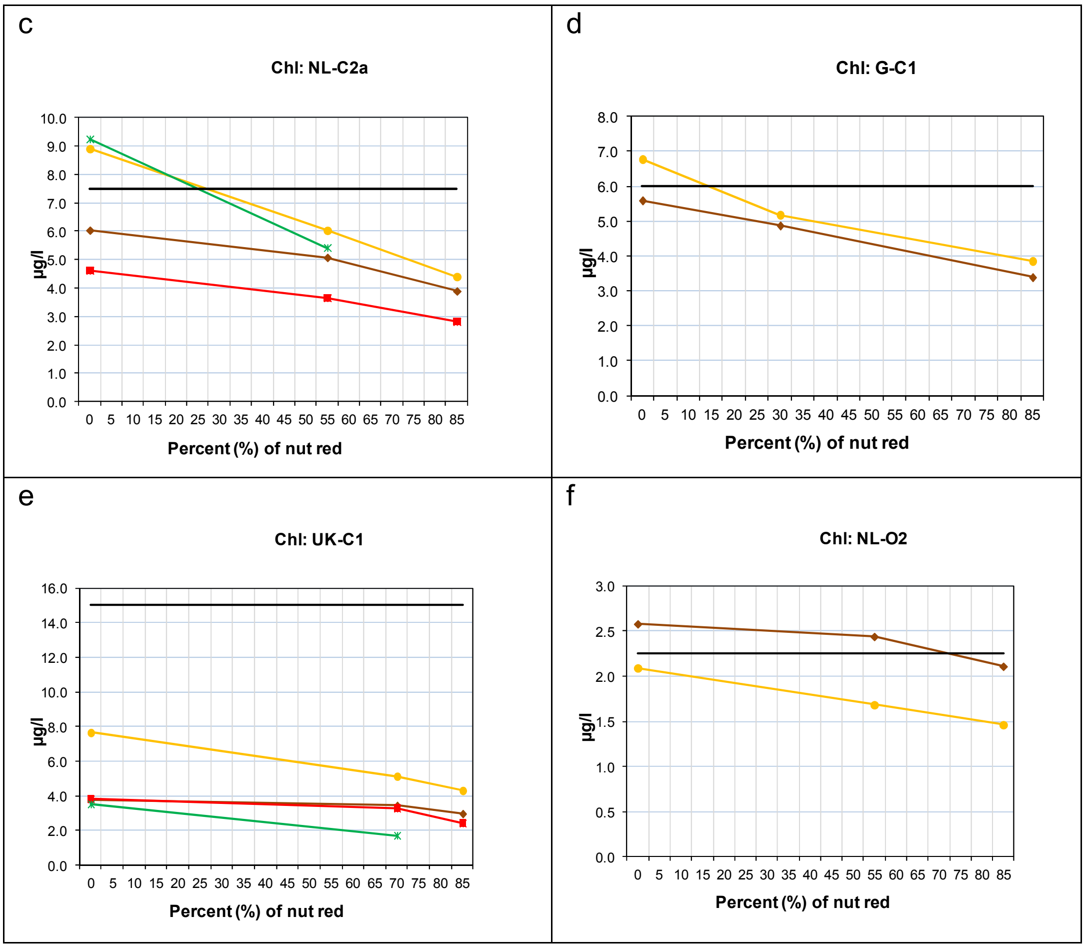


Figure 14. Growing season means of Chl of reference run, distance to target run and 85% reduction run according to the models of ECOHAM (—◆—), Delft3D-GEM (—•—), ECO-MARS3D (—▪—), MIRO&CO-3D (—✳—) with the area-specific assessment levels (—).

Table 13. Summary of the results for the mean Chlorophyll model results (C-m) (for all models, except POLCOM-ERSEM, also presented in Figure 14) together with the 90th percentiles (C-90), according to all participating models; “blue” is under assessment level and “red” is above. For the white cells no model results are available, because these areas are outside the model domain or the run is missing. 1 = 2002 reference run; 2 = target run; 3 = 85% reduction run.

Target area		ECOHAM			Delft3D-GEM			ECO-MARS3D			MIRO&CO-3D			POLCOM-ERSEM		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
FC2	C-m	blue	blue	blue	red	red	red	blue	blue	blue	blue	blue		blue		blue
FC2	C-90	blue	blue	blue	red	red	red	blue	blue	blue	red	blue		blue		blue
BC1	C-m	blue	blue	blue	red	blue	blue	blue	blue	blue	blue	blue		blue		blue
BC1	C-90	red	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue		blue		blue
NLC2a	C-m	blue	blue	blue	red	blue	blue	blue	blue	blue	red	blue		blue		blue
NLC2a	C-90	red	red	blue	blue	blue	blue	blue	blue	blue	red	blue		blue		blue
GC1	C-m	blue	blue	blue	red	blue	blue							blue		blue
GC1	C-90	blue	blue	blue	blue	blue	blue							blue		blue
UKC1	C-m	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue		blue		blue
UKC1	C-90	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue		blue		blue
NLO2	C-m	red	red	blue	blue	blue	blue							blue		blue
NLO2	C-90	red	blue	blue	blue	blue	blue							blue		blue

In the 2002 reference run (1), Chlorophyll in UKC1 was below the assessment level for all models. A factor that plays a role in this result is the Chlorophyll assessment level for this area, which is higher than that for the other areas. For GC1 and NLO2 only one model showed values below the assessment level. All other target areas showed Chlorophyll concentrations below the assessment level by more than one model.

In the target run (2) **Chlorophyll-mean (C-m)** and/or **Chlorophyll-90th-percentile (C-90)** was above assessment level in three target areas. This is the case in area FC2 according to Delft3D-GEM, and in NLO2 and NLC2a according to ECOHAM. In FC2 this can be due to continued nutrient enrichment, because Delft3D-GEM predicts in this area also DIN levels above assessment level (Tab 11). This is also the case in NLC2, where ECOHAM predicts nutrient enrichment by DIP. In NLO2, however the situation is different. Here ECOHAM does not predict nutrients concentrations above assessment level, while Chlorophyll exceeds the assessment level.

Table 14. The results for the mean Chlorophyll model results (C-m), according to all participating models as in Table 13. The numbers (in %) are the required reductions to reach the assessment level values per area; "blue" is under assessment level and "red" is above. For the white cells no model results are available, because these areas are outside the model domain or the run is missing. 1 = 2002 reference run; 3 = 85% reduction run.

Target area		**ECOHAM**		**Delft3D-GEM**		**ECO-MARS3D**		**MIRO&Co 3D**		**POLCOM-ERSEM**	
		1	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
FC2	C-m			46	30						
BC1	C-m			3							
NLC1	C-m			8							
NLC2a	C-m			16				19			
NLC2b	C-m										
NLC3	C-m										
GC1	C-m			11							
UKC1	C-m										
NLO2	C-m	13									
GO2	C-m			0							

In order to provide a first estimate of the reduction related to Chlorophyll concentration only, Table 14 provides the "distance to target" for growing season mean concentrations of Chlorophyll in 2002 from the reference run (1) and the 85% reduction run (3). Note that the nutrient reductions according to the Delft3D-GEM model are significantly larger than those of the other models. It is beyond the scope of this exercise to find the reason for this discrepancy.

Two of the participating institutes, Deltares and MUMM, delivered model results for *Phaeocystis* (see Table 15). *Phaeocystis* is one of the OSPAR indicator species. As assessment level for all countries 10^7 cells/l is used. The assumption is that 10^6 cells/l is the size of a normal bloom (Cadée *et al*., 2002 defined the Phaeocystis bloom as the period with more than 1000 cells cm^3 (~10^6 cells/l)), and 10^7 cells/l the size of an extreme bloom. Depending on the assumption of the carbon content per *Phaeocystis* cell this assessment level corresponds to a concentration of 0.15 to 0.3 mg C l^{-1} (based on Rousseau *et al*., 1990 and Jahnke, 1989).

Using the lowest value (this is the most strict value) MIRO&CO-3D calculated concentrations of *Phaeocystis* cells above assessment level in all target areas included in their model domain both for the reference and the target run, while Delft3D-GEM calculated concentrations of *Phaeocystis* cells under assessment level in the target areas FC2, NLO2 and GO2 in the reference run and for NLC1, NLC3, GC1 and UKC1 above assessment level in the target run. In the 85% reduction run *Phaeocystis* is above assessment level only in GC1, according to Delft3D-GEM. For the Delft3D-GEM results "distance to target" estimates are added in Table 15 for *Phaeocystis* values above assessment level.

Table 15. Summary of the results for the maximum concentrations for *Phaeocystis* cells at the peak of the bloom, according to all participating models; "blue" is under assessment level and "red" is above. For the white cells no model results are available, because these areas are outside the model domain or the run is missing. The numbers (in %) are the required reductions to reach the assessment level values per area. 1 = 2002 reference run; 2 = target run; 3 = 85% reduction run.

Target	Delft3D-GEM			MIRO&CO-3D		
	1	2	3	1	2	3
FC2				85	75	
BC1	21			81	72	
NLC1	25	21		83	71	
NLC2a	25			84	65	
NLC2b	32					
NLC3	32	12				
GC1	53	50	25			
UKC1	44	12		94	83	
NLO2						
GO2						

3.2.2. Oxygen

Results on the minimum oxygen concentration encountered are given by Delft3D-GEM and ECOHAM. Delft3D-GEM presented results for all designated target areas (Table 16) while ECOHAM presented results for the offshore station Terschelling135 that lies in target area NLO2.

Delft3D-GEM simulated only in the reference run (2002) in target area GO2 a bottom oxygen concentration of 5.9 mg/l that was below the assessment level of 6 mg/l (Table 15).

Table 16. Minimum values for bottom oxygen according to the Delft3D-GEM run.

Oxygen	year	bottom	
	2002	target	85% red
NLC1	6.1	6.4	6.6
NLC2a	6.3	6.7	7.1
NLC2b	6.5	7.2	7.4
NLC3	7.1	7.3	7.4
NLO2	6.4	6.6	6.8
GC1	7.1	7.3	7.6
GO2	5.9	6.3	6.5
UKC1	7.4	7.5	7.6
BC1	6.2	6.4	6.6
BO1	6.5	6.6	6.8
FC1	7.7	7.7	7.7
FC2	7.1	7.2	7.3

The minimum values for bottom oxygen concentration at Terschelling 135 according to ECOHAM (Figure 15) were 5.01, 5.46 and 6.05 mg/l for the reference, target, and 85% reduction run, respectively. The numbers of days that the oxygen concentration at the station Terschelling 135 is below assessment level was 60 days in the reference run and 46 days in the target run.

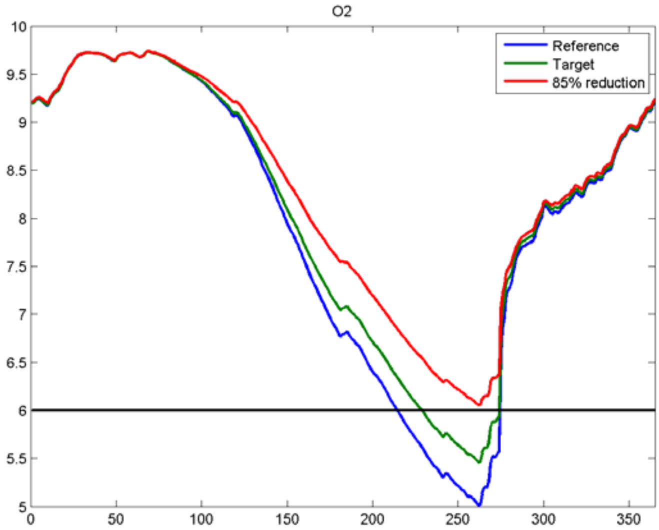


Figure 15. Bottom Oxygen Concentration at station Terschelling 135, in target area NLO2 according to the ECOHAM model. Blue: reference run (2002); green (target run); red 85% reduction run.

3.3 Summary of model results

In Table 17 the combined results for all ten target areas, of which the results of six are presented in the Figures12-14, have been summarised for the models ECOHAM, Delft3D-GEM, ECO-MARS3D, MIRO&CO-3D and POLCOM-ERSEM. The results of the 2002 reference run, the target run and the 85% reduction run are shown (step G of Figure 9).

The run with an 85% reduction in relation to 2002 of all river loads (DIN and DIP) still left nutrient enrichment according to the Delft3D-GEM model in three target areas for DIP (NLC2a, NLC2b, NLC3). Also, chlorophyll levels were above assessment level for FC2, indicating problem area status. *Phaeocystis* values were below the assessment level in this run, according to Delft3D-GEM, the only model with *Phaeocystis* in this run. According to the POLCOM-ERSEM model DIN concentrations in the 85% reduction run are still above assessment level in the areas FC2 and UKC1. In UKC1 also DIP is above assessment level in this run.

The target scenario run with ECOHAM resulted in three areas (NL-C2a, NL-C2b, NL-O2) with chlorophyll levels above assessment level, indicating problem area status. Two areas showed nutrient enrichment, one for DIN (NL-C2a) and the other for DIP (NL-C2b). In the remaining areas there was no enrichment.

The Delft3D-GEM simulation for the target scenario resulted in three target areas with DIP above assessment level (NLC2a, NLC2b and NLC3), two with DIN + DIP above assessment level (BC1 and NLC1), and one with DIN + chlorophyll above assessment level (F-C2), the latter indicating problem area status.

The model domain of ECO-MARS3D contained six of the target areas, which were above assessment level for the target scenario for at least one of the variables, four areas due to DIN values above assessment level (FC2, BC1, NLC1 and NLC2b) and two with a DIP and DIN above assessment level (NLC2a, UKC1), indicating enrichment but non-problem area status.

The model domain of MIRO&CO-3D contained five of the target areas. All these areas had nutrient levels above assessment level according to the MIRO&CO-3D model (target run, 2), one area with only DIN above assessment level (FC2), two areas with only DIP above assessment level (NLC1 and NLC2a) and two with DIP and DIN above assessment level (BC1, UKC1), indicating enrichment and problem area status due to high concentrations of *Phaeocystis* in all areas.

Table 17. Summary of the results of the reference runs for 2002, the target run and the 85 reduction run, according to all participating models, as presented in the Figures12-14; “blue” is under the assessment level and “red” is above. For the white cells no model results are available, because these areas are outside the model domain. 1 = 2002 reference run; 2 = target run (cf. Table 10); 3 = 85% reduction run.

Target area		ECOHAM			Delft3D-GEM			ECO-MARS3D			MIRO&CO-3D			POLCOM-ERSEM		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
FC2	DIN															
	DIP															
	C-m															
	C-90															
	Phaeo															
BC1	DIN															
	DIP															
	C-m															
	C-90															
	Phaeo															
NLC1	DIN															
	DIP															
	C-m															
	C-90															
	Phaeo															
NLC2a	DIN															
	DIP															
	C-m															
	C-90															
	Phaeo															
NLC2b	DIN															
	DIP															
	C-m															
	C-90															
	Phaeo															
NLC3	DIN															
	DIP															
	C-m															
	C-90															
	Phaeo															
GC1	DIN															
	DIP															
	C-m															
	C-90															
	Phaeo															
UKC1	DIN															
	DIP															
	C-m															
	C-90															
	Phaeo															
NLO2	DIN															
	DIP															
	C-m															
	C-90															
	Phaeo															
GO2	DIN															
	DIP															
	C-m															
	C-90															
	Phaeo															

3.3.1 Distribution maps

Distribution maps for the nutrients DIN and DIP and for Chlorophyll, with

a) isolines for the concentrations in 2002 and

b) percent difference of the distance to target results compared to the 2002 hindcast run are presented in Annex 3.

The ECOHAM (Figure A3-1) and Delft3D-GEM (Figure A3-2) simulation results cover the whole North Sea both for the reference run and the distance to target reduction. In comparison the ECO-MARS3D distribution map covers the Atlantic area north of Spain up to the English Channel, while the focus of the MIRO&CO-3D model (Figure A3-4) is the Channel region. All the results presented by these models are related to the reference run and the distance to target reduction simulations. In contrast, the distribution maps from the POLCOM-ERSEM simulation (Figure A3-5) are related to the reference run and the 85% reduction run. Therefore the difference plots from POLCOM-ERSEM cannot be compared to the other model results.

For the distribution maps from Delft3D-GEM and ECOHAM one can clearly see the strong gradient in the nutrients DIN and DIP along the continental coast, while the area affected by higher Chlorophyll-a concentrations are spread over a wider area in the southern North Sea. The same is true for the graphs presenting the percent difference for the nutrient and Chlorophyll-a concentrations between the reference run and the distance to target. For both models local river mouth areas as well as wider parts of the southern North Sea show the impact associated with the distance to target reduction level applied on the river nutrient loads.

3.3.2 Interannual variability

In Annex 4 multi-annual results are presented for winter DIN, winter DIP and growing season chlorophyll for the reference run for all areas according to the models ECOHAM, Delft3D-GEM, MIRO&CO-3D and POLCOM-ERSEM. As can be expected, the nutrient concentration and the resulting summer Chlorophyll concentrations in the coastal areas reflect the variability in the river loads between the years 1997 to 2002 to a greater extent than offshore areas.

When looking for an explanation for the differences mainly in the winter nutrient concentrations from the different models in the hindcast run and the following scenarios, one conclusion can be drawn from the graphs representing the inter-annual variability within the models (Figures A4-1 to A4-4 in Annex 4) for the time period from 1997 to 2002. For each model, the concentration for DIN, DIP and Chlorophyll-a for the assessment year 2002 is within the range of the simulated concentrations for the period 1997-2002. This indicates that the models in themselves are consistent. Moreover the different models keep their individual level of winter nutrient concentrations. The strong differences in the nutrient concentrations between the models, as we find in the reference run (Figures12 and 13), are therefore not related to the assessment year 2002 but represent the characteristic of the individual model setup and its calibration. One improvement could be the use of a set of common boundary conditions. But this can also cause problems since the regional differences could not always be taken into account by the wider domain model providing the data, which results in inconsistencies within the individual model setup.

As mentioned above, an alternative and potentially more cost-effective solution could be to use the weighted ensemble mean (Almroth and Skogen, 2010), but since the weight applied in these methods is related to the cost function this is highly dependent on availability of a statistically relevant amount of validation data, and thus increases the problem of reliable data for model validation.

4. Discussion

The aim of the modelling work presented in this report is to estimate the nutrient reduction required in eutrophication problem areas through moving nutrient concentrations below their assessment levels. The state of eutrophication effects parameters, as the determining criterion for eutrophication assessment according to the Common Procedure, is represented in the ecosystem models by the Chlorophyll concentration. However, the Chlorophyll concentration can only be changed by nutrient levels in the marine waters via reductions of river nutrient loads. Therefore, the focus of this study is mostly on DIN and DIP, assuming that a reduction in these variables would also drive the direct and indirect eutrophication effect parameters below their assessment levels.

As the study shows, to achieve the goal for these nutrients to result in concentrations below their OSPAR assessment levels, a set of iterative model runs would have been necessary, which was not possible due to financial resource requirements. Due to the non-linearity of the ecosystem processes, it is even more difficult to predict the effects of reductions in river nutrient loads to Chlorophyll.

Two major steps had to be carried out by the models. The first step was to define the reduction target, and the second step was to carry out the reduction run. Despite funding problems each step was implemented by four of the five models (Table 4), providing a sufficient base for the assessment.

In contrast to hydrodynamical models which depend on a clear set of equations to describe the development of physical state variables, like the sea level, temperature or salinity, there is not a comparable set of equation to characterize the ecological state variables. The models have diverse representations of the ecological system, which can be seen in the differences of the state variables applied as well as in the miscellaneous process representation that define the development within the ecological state variables. All this leads to numerous representations of carbon and nutrient cycles within the ecological modeling community. For the question which “distance to target” reduction level should be achieved, it is essential to have a large number of ecosystem models with different response levels to at least have a hint of the complexity behind this question. But it should be pointed out, that the problem of the differences in the winter nutrient concentration within the model application needs to be addressed in the frame of the diverseness of the ecosystem representation within the different models.

Define “distance to target” reduction: The model-estimated reduction levels needed for the “distance to target” reductions were surprisingly high for a number of target areas (Table 10). This is especially true for DIP, in view of the fact that considerable and successful reduction efforts have been made since 1985. However one should consider that the reduction estimates were expressed in a relative manner, related to the river load of the reference year 2002 and therefore they cannot be compared directly to a 50% reduction in 1985. For example, a 50 % reduction with respect to 2002 is a smaller reduction in absolute terms than a 50% reduction with respect to 1985.

In addition, the assessment levels that should be met by this exercise are inconsistent. First, the missing gradient between coastal and offshore areas for DIP induces problems in the reduction runs. Second, there is a conceptual problem of strong differences in Chlorophyll-a assessment levels for neighbouring areas with about similar nutrient levels. This leads to the effect that in a number of areas the required DIP reduction to reach the Chlorophyll assessment level is smaller than the required reduction to reach the DIP assessment level itself.

Linear optimization: The results of the linear optimization were meant to “redistribute” the nutrient loads provided by the model calculations by taking into account the information of the transboundary nutrient transport (TBNT).

The results of the linear optimization are just one representation from a large number of possible realizations under the constraints to reach the target with no change at the boundaries (Atlantic). One drawback of the present realization is the fact that only the TBNT results from the Delft3D-GEM model could be used. It is however interesting to note that the “hybrid” approach by taking the reduction levels from different models combined with the TBNT information from the Delft3D-GEM model resulted in similar reduction distributions for the rivers. Therefore, an effort should be made to implement the information of more TBNT results into this linear interpolation scheme to be able to compare different results and to study the effect of the constraints for different realisations. The present settings for the linear optimization showed no need for any reduction for Germany. It should be pointed out that the rather low reduction requirements for the German rivers is dependent on the chosen constraints of the optimization routine, which in this particular case assumes that the costs for obtaining a certain reduction percentage is the same for each river. Also, this result should be interpreted in the context of the reduction for the river input upstream of the continental coastal current. Since countries further downstream were not represented by a target area (e.g. Denmark and Norway), the effect of nutrient exports from e.g. German waters is not sufficiently taken into account, resulting in zero reduction requirement for German rivers (Table 9).

Taking the TBNT information that the percentage contributions from the German national rivers (Elbe, Weser, Ems) to total nitrogen in the German maritime area is 28 %, the local reduction efforts without the reduction benefits upstream would need to be higher. The same is true for the Netherlands in relation to efforts in upstream countries like Belgium and France. It can be concluded, that countries with high contributions of nutrient transport in upstream areas will have problems facing in their local assessment levels without reduction efforts in upstream countries.

The transboundary transport results have shown that UK riverine nutrients only contribute marginally to the water bodies classified as problem areas along the continental coast. Thus, the reductions assigned to UK rivers in the present study are mostly associated with bringing nutrient concentrations in UKC1, which is not a problem area, below assessment level. Additional work is required to establish meaningful reductions levels in UK riverine nutrients in relation to resolving eutrophication in problem areas.

It still has to be checked whether the Delft3D-GEM model with the reduction percentages for DIN and DIP, calculated with the optimization procedure (without the adaptation based on expert judgement) really results in only areas without nutrient-enrichment. This is due to the fact that the optimization procedure has been carried out for DIN and DIP separately, without taking into account the interaction between the two nutrients.

Definition of the final reduction levels: The information from the first reduction runs and the linear optimization was combined and converted into one set of common reduction estimates per river (Table 10). This was done by means of interpolation and averaging, but also included a certain amount of expert judgement. To improve the method further consideration should be given to combine the effects of DIN and DIP into one approach and to make the method more objective. This includes an interactive approach between linear optimization and ecosystem model runs, which also involves the implementation of this combination in more models.

The last part of setting up the linear optimization method is related to the application of the so-called cost function. The cost function determines which of all possible solutions (combinations of nutrient reductions) should be considered as optimal. Ideally the coefficients of this cost function should be taken as the real costs in monetary units (i.e. Euros) which are necessary to reduce the loading from that particular source per unit of weight (i.e. tons of N or P). Determining these or alternative cost functions in a realistic way is very attractive but also quite challenging and beyond the scope of the present analysis.

One can conclude that the linear optimization method has proven to be a powerful tool to determine the required river load reductions in relation to the TBNT information, but the settings need to be further developed.

Distance to target reduction run: Despite the high reduction levels prescribed as “distance to target” reduction (Table 10), some indicators are still above the assessment levels in a number of areas in the scenario runs in all the models. Even for the 85% reduction scenario some of the assessment levels could not be reached from three out of the four model applications. In contrast, other indicators seem to be reduced beyond the level needed to achieve the assessment level. In order to overcome this deviation a number of iterative model approaches are needed, which was not feasible in this study. Furthermore, the estimated reductions include the model results from several models, they represent some “average” set of required reductions, which may not fit perfectly to each individual model.

While variables may behave non-linearly in reaction to river load reductions, in the interpolation exercise it was implicitly assumed as a first estimate that the models would behave linearly. This may be correct in case the reductions do not lead to a change in the limiting factors, but whenever limiting factors are changed (e.g. from DIP to DIN) this may lead to a non-linear model response. Since category II and III variables are less linearly related to the riverine inputs than DIN and DIP, their concentrations may deviate (even) more from their assessment level values than DIP and DIN. The reduction estimates are mainly based on DIN and DIP, deviations may occur if the assessment level values for category II and III variables are inconsistent with those for DIN and DIP.

In the ICG-EMO group the summer Chlorophyll concentration, calculated as mean concentration for the target area, has long been the representation for the standard assessment parameter for Chlorophyll in the previous reports. Since the use of the 90th percentile has been requested as additional information, the model runs were post-processed and the Chlorophyll a concentration was calculated as 90th percentile for the target areas. The assessment level values for the 90th percentile were set twice the assessment level values for the mean concentration. It turned out that the mean Chlorophyll assessment level is stricter than that for the 90th percentile for the Delft3D-GEM and MIRO&CO-3D model results.

In theory, 90th percentile (band of values) is expected to be a less stringent approach than using mean values (point value). It is not clear why the model results are so different between Delft3D-GEM, where the mean Chlorophyll a concentration for B-C1 is still above assessment level, while the 90th percentile is not and the opposite outcome from ECOHAM, also for B-C1, and MIRO&CO-3D for F-C2.

The reference year 2002: The year 2002 was selected as the main assessment year because of the use of the forcing data for this year in previous OSPAR workshops. To update the required forcing data, including model calibration and model validation, was not possible within the scope of this study. The fact that the year 2002 was a very wet year, implying high nutrient loads to the North Sea, a “distance to target” reduction estimate represents an upper limit of reduction needed. In other words, when considering the interannual variability in the river loads, one could also interpret the reduction levels associated with the 2002 river loads as a worst case scenario. Similar scenarios could then be performed on typically dry years, taking the present report as an important contribution for the other end of the spectrum of the interannual river load variability in terms of wet years.

5. Conclusions and further work

Both the definition of the “distance to target” reduction levels as well as the outcome of the final target scenarios are based on a substantial number of model contributions which include ecological processes and eutrophication effects. In addition, the use of the linear optimization method that takes into account the TBNT information is a powerful tool that should be further developed.

The defined reduction targets presented in this study are the best estimates based on the reference run for the year 2002 and the 85% reduction run. The application of the target reduction in the scenario runs from the different models showed that some indicators are still above assessment level in a number of areas. In contrast, in other areas the required reduction could be overestimated, resulting in concentrations much more below the assessment levels than necessary.

In conclusion, preliminary findings indicate that further reductions in nutrient releases are required by Contracting Parties bordering the North Sea to combat eutrophication in the Region. There is a need for a balanced approach to joint efforts of Contracting Parties to achieve good environment status in relation to eutrophication in the Region. This includes nutrient reductions by Contracting Parties whose waters are not affected by eutrophication effects (i.e. without “problem areas”).

For further work a number of conclusions can be drawn:

1. Model studies should be carried out for more recent years and for a time period rather than a single year, taking into account the interannual variability in the river loads and the characterization in terms of wet or dry year for the year of simulation.
2. The model results are strongly dependent on the choice of Contracting Parties assessment levels and the requirement to use those in the simulation. The 85% reduction run and the linear optimisation show inconsistencies
    - Within countries of national assessment levels for DIN, DIP and chlorophyll
    - Between countries of assessment levels

- Between assessment levels and ecosystem health conditions

There is a need for scientifically derived and more consistent assessment levels. Current model work can help improving consistency of assessment levels within and between countries.

3. The linear optimization method needs to be developed in closer cooperation with OSPAR national representatives in order to fulfil the needs in achieving management targets for the MSFD. This would partly replace the need for an iterative approach with multiple simulation runs in combination with re-adjusted river loads to find a set of minimum reduction estimates that would result in effect parameters below assessment levels. Such work should be aimed at current problem areas.
4. There is a need to further understand and reduce the differences between the models. However as this could result in a major effort per model.To overcome the importance of an individual model simulation, ensemble runs should be performed and the results combined by weighting the simulation results for the specific area by means of a cost function (Almroth & Skogen, 2010). However, one should point out that the quality of the outcome of this method is highly dependent on the quality of the validation data that build the basis for the cost function calculation.
5. Therefore one recommendation has to be that the ICG-EMO modelling community gets access to validation data in close cooperation with the OSPAR national representatives. This implies not only the availability of validation data but also help in the interpretation of the measured values. This would be the basis for the ICG-EMO modelling community first to examine how to improve the reliability of the models by validation and second test the significance of weighted ensembles runs for “distance to target” scenarios and assessment.

6. Acknowledgements

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Annex 1 - Optimization procedure

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Finding the optimal reduction to meet all targets

Introduction

Traditionally mathematical models have been applied to investigate the impacts of river load reductions on the North Sea ecosystem. Normally this is done by imposing reduction factors on some or all of the discharges for one or several components (nutrients for example). This method works well if the environmental targets to be achieved are formulated with respect to the discharges e.g. a 50 percent reduction of all loads from all rivers relative to a reference case such as 1985. If, however, targets are defined based on the actual conditions within the ecosystem, it is neither obvious nor trivial to determine by how much the loading of each individual source (river) should be modified in order to reach the target at sea. We do know that the response tends to be less than proportional because:

1. The contribution of some sources of nutrients i.e. the Channel or the North Atlantic inflow, cannot easily be reduced by management measures,
2. The ecological system itself tends to adapt to new conditions which often means it gets more efficient in its usage of (scarce) resources.

By how much the actual response deviates from proportionality, cannot be predicted accurately. Instead this is usually assessed by running a model for different combinations of reduction scenarios until all targets are met. This, however, is a cumbersome method and moreover does not answer the question if the same or an even better response of the receiving water system might have been achieved by another combination of discharge reductions. In other words: after running the model many times we may find a solution satisfying all targets at sea, but the overall reductions might be unnecessarily large.

As an alternative to the traditional approach a new method is proposed here that gives us the minimum reduction of all discharges at which all the targets at sea are still met. This method consists of three steps:

Construction of a composition matrix relating the present concentrations at sea to the individual (nutrient) sources,

Application of an optimization technique (Linear Programming) to find the most effective reduction scenario,

Rerunning the model with some of the scenarios found under step 2 as an input.

The optimization step may be regarded as a meta-model with two major advantages:

- Every solution produced by this method is not only valid in the sense that all targets are met but it can be demonstrated that it is the most efficient way of achieving this,
- Simulations are completed in a fraction of a second so it is possible to assess many alternative assumptions in a very short period of time.

Step 1: Determining the composition matrix

Normally when applying eco-hydrodynamic models the river loads are known inputs and the concentrations of all state variables (Chlorophyll-a, PO4, NO3, etc.) are known outputs but we do not know to what extent each individual nutrient source contributes to the concentrations computed by the model. Using conservative tracers of the water masses gives additional information on the relative importance of various sources, but due to the non-linearities of eco-models, these numbers are only an approximation. To obtain more accurate numbers some of the North Sea models were extended with additional features to relate concentrations to loads. The most advanced method was introduced into the Deltares model, which was extended with a labeling technique to trace all nutrients from all groups of rivers throughout the entire model domain. These methods were previously employed within the OSPAR ICG-EMO modelling group for analyzing transboundary nutrients transport (TBNT) fluxes.

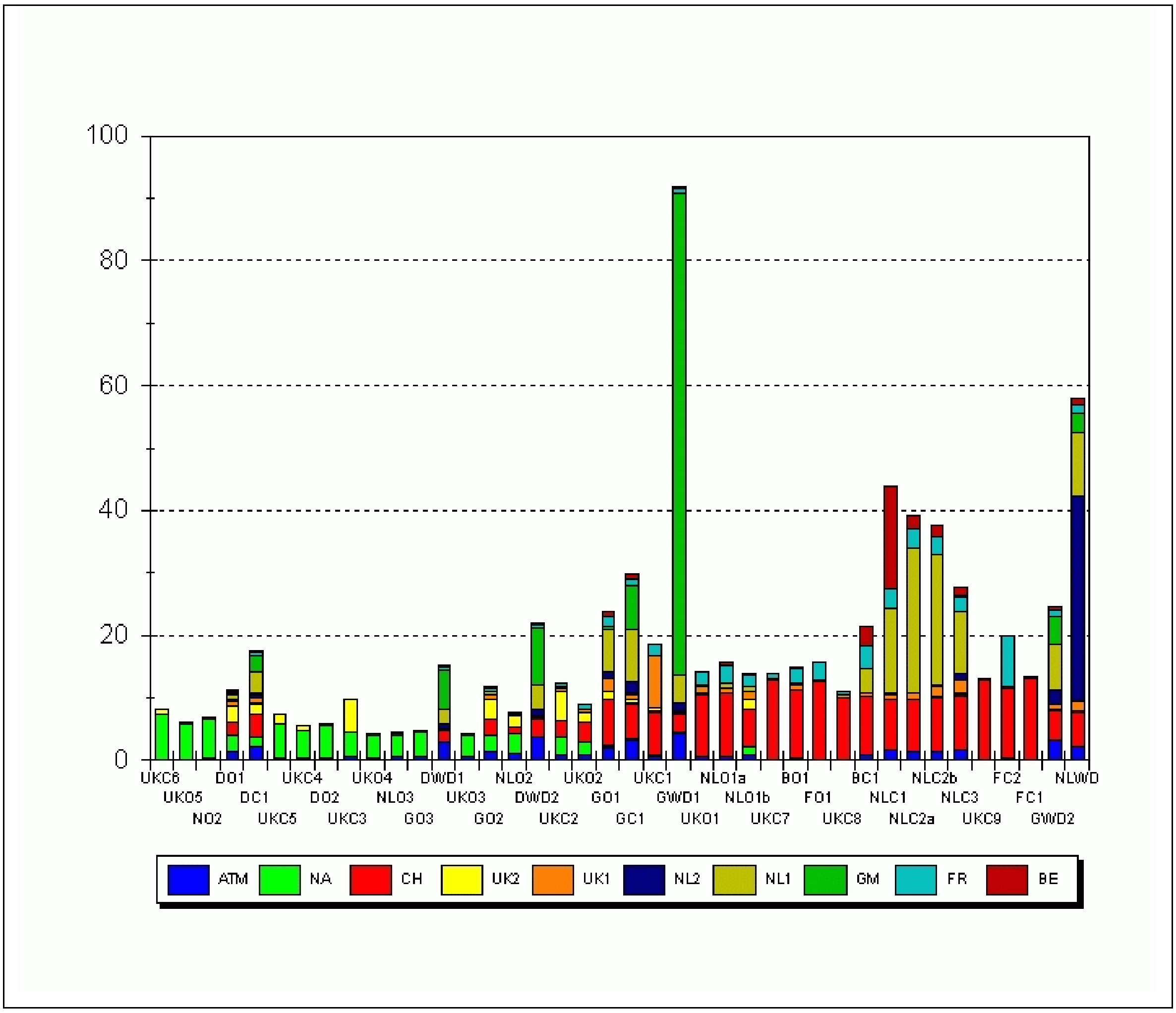
The result of this labeling is a composition matrix, the rows of which correspond to the areas and the columns to the river groups. Each coefficient in the matrix represents the contribution of a source (river group, boundary and atmosphere) to the local concentration. Taking the sum of all contributions per row gives exactly the total concentration in the area, which is the same number as computed by the traditional model without the labeling technique. As an alternative we can also normalize this matrix such that the sum per row equals 1.0. This enables us to transpose the composition matrix from one simulation or from one model to another. This composition matrix is determined for every output period of the model. For use in the optimization procedure, however, the composition matrix should be averaged over time to correspond to the period to which the targets apply.

An example of a composition matrix for the Deltares model for winter values of PO_4 is shown in Table A1-1. Because the composition matrix contains many numbers, it may be easier to assess graphically rather than as a table. As an example Figure A1-1 shows winter average results for DIN as computed for 2002 with the Deltares model. The upper panel shows the results for all areas, but because in one small area in the German part of the Wadden Sea (GWD1) the numbers are much higher than elsewhere, the middle panel shows the same composition matrix without this area. Finally the lower panel shows the normalized results, which makes it easier to compare the relative importance of the sources across areas. Notice that in many areas the contributions of the Atlantic or Channel boundaries are relatively large. This means that controllable sources only affect a limited number of areas, but as may be seen from the middle panel, the concentrations in these areas are the highest.

Area/River	BE	FR	GM	NL1	NL2	UK1	UK2	CH	NA	ATM	PO4
UKC6	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000288	0.000012	0.022190	0.000000	0.02249
UKO5	0.000000	0.000002	0.000004	0.000002	0.000000	0.000003	0.000025	0.000244	0.022566	0.000000	0.022846
NO2	0.000003	0.000017	0.000025	0.000024	0.000001	0.000030	0.000236	0.002374	0.020817	0.000000	0.023527
DO1	0.000085	0.000215	0.000263	0.000612	0.000043	0.000435	0.001901	0.017441	0.014486	0.000000	0.035481
DC1	0.000252	0.000558	0.001977	0.002379	0.000222	0.000635	0.001018	0.030624	0.008692	0.000000	0.046357
UKC5	0.000000	0.000001	0.000001	0.000001	0.000000	0.000001	0.000657	0.000046	0.023142	0.000000	0.023849
UKC4	0.000000	0.000002	0.000001	0.000001	0.000000	0.000002	0.000378	0.000060	0.022880	0.000000	0.023324
DO2	0.000002	0.000016	0.000014	0.000016	0.000001	0.000027	0.000242	0.002743	0.020642	0.000000	0.023703
UKC3	0.000000	0.000001	0.000001	0.000001	0.000000	0.000002	0.003233	0.000048	0.022592	0.000000	0.025878
UKO4	0.000001	0.000004	0.000001	0.000003	0.000000	0.000005	0.000084	0.000107	0.021042	0.000000	0.021247
NLO3	0.000001	0.000012	0.000001	0.000008	0.000001	0.000022	0.000416	0.000890	0.020350	0.000000	0.021701
GO3	0.000002	0.000013	0.000002	0.000010	0.000001	0.000023	0.000372	0.001708	0.020178	0.000000	0.022309
DWD1	0.000237	0.000467	0.001962	0.002312	0.000248	0.000378	0.000117	0.008755	0.000984	0.000000	0.01546
UKO3	0.000001	0.000005	0.000001	0.000003	0.000000	0.000006	0.000197	0.000127	0.021148	0.000000	0.021488
GO2	0.000059	0.000172	0.000008	0.000253	0.000013	0.000524	0.002121	0.013181	0.014801	0.000000	0.031132
NLO2	0.000020	0.000084	0.000000	0.000065	0.000002	0.000198	0.001332	0.003989	0.018964	0.000000	0.024654
DWD2	0.000334	0.000651	0.003289	0.003239	0.000345	0.000558	0.000216	0.013368	0.001074	0.000000	0.023074
UKC2	0.000011	0.000090	0.000000	0.000019	0.000000	0.000206	0.003137	0.007305	0.015703	0.000000	0.026471
UKO2	0.000038	0.000271	0.000000	0.000060	0.000000	0.000436	0.001268	0.010237	0.012667	0.000000	0.024977
GO1	0.000458	0.000858	0.000415	0.002850	0.000232	0.001867	0.001296	0.044914	0.002917	0.000000	0.055807
GC1	0.000571	0.001017	0.003236	0.005270	0.000587	0.001169	0.000514	0.039424	0.001860	0.000000	0.053648
UKC1	0.000089	0.000793	0.000000	0.000132	0.000000	0.007237	0.000615	0.019530	0.001030	0.000000	0.029426
GWD1	0.000413	0.000764	0.020616	0.004109	0.000474	0.000637	0.000188	0.013233	0.000616	0.000000	0.04105
UKO1	0.000126	0.001022	0.000000	0.000201	0.000000	0.001455	0.000088	0.024638	0.000210	0.000000	0.02774
NLO1a	0.000432	0.001254	0.000000	0.000852	0.000000	0.001217	0.000008	0.024627	0.000013	0.000000	0.028403
NLO1b	0.000168	0.000701	0.000000	0.000481	0.000010	0.001295	0.001498	0.019549	0.004623	0.000000	0.028325
UKC7	0.000002	0.000455	0.000000	0.000003	0.000000	0.000248	0.000001	0.027388	0.000001	0.000000	0.028098
BO1	0.000184	0.001055	0.000000	0.000360	0.000000	0.000990	0.000007	0.025638	0.000002	0.000000	0.028236
FO1	0.000006	0.001187	0.000000	0.000010	0.000000	0.000152	0.000001	0.026008	0.000001	0.000000	0.027365
UKC8	0.000000	0.000219	0.000000	0.000000	0.000000	0.000422	0.000000	0.022732	0.000000	0.000000	0.023373
BC1	0.001958	0.001340	0.000000	0.004015	0.000000	0.000665	0.000003	0.019743	0.000005	0.000000	0.027729
NLC1	0.006215	0.001217	0.000000	0.008665	0.000000	0.000982	0.000004	0.019279	0.000023	0.000000	0.036385
NLC2a	0.001144	0.001249	0.000000	0.011720	0.000000	0.001231	0.000005	0.023109	0.000027	0.000000	0.038485
NLC2b	0.000858	0.001238	0.000000	0.009147	0.000039	0.001896	0.000071	0.028759	0.000070	0.000000	0.042078
NLC3	0.000683	0.001126	0.000003	0.004097	0.000238	0.002140	0.000445	0.030589	0.000534	0.000000	0.039855
UKC9	0.000000	0.000054	0.000000	0.000000	0.000000	0.000071	0.000000	0.022430	0.000000	0.000000	0.022555
FC2	0.000004	0.003012	0.000000	0.000008	0.000000	0.000030	0.000000	0.023247	0.000000	0.000000	0.026301
FC1	0.000000	0.000105	0.000000	0.000000	0.000000	0.000000	0.000000	0.022364	0.000000	0.000000	0.022469
GWD2	0.000416	0.000762	0.002443	0.004235	0.000541	0.000744	0.000288	0.030153	0.001288	0.000000	0.04087
NLWD	0.000522	0.000667	0.000408	0.004005	0.005824	0.001097	0.000170	0.021453	0.000289	0.000000	0.034435

Table A1-1. Composition matrix Deltares model winter 2002 for PO_4 (mg/L).

- Yellow: Contributions > 20%



100
80
60
40
20
0
UKC6
UKO5
NO2
DO1
DC1
UKC5
UKC4
DO2
UKC3
UKO4
NLO3
GO3
DWD1
UKO3
GO2
NLO2
DWD2
UKC2
UKO2
GO1
GC1
UKC1
GWD1
UKO1
NLO1a
NLO1b
UKC7
BO1
FO1
UKC8
BC1
NLC1
NLC2a
NLC2b
NLC3
UKC9
FC2
FC1
GWD2
NLWD
ATM
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UK2
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NL1
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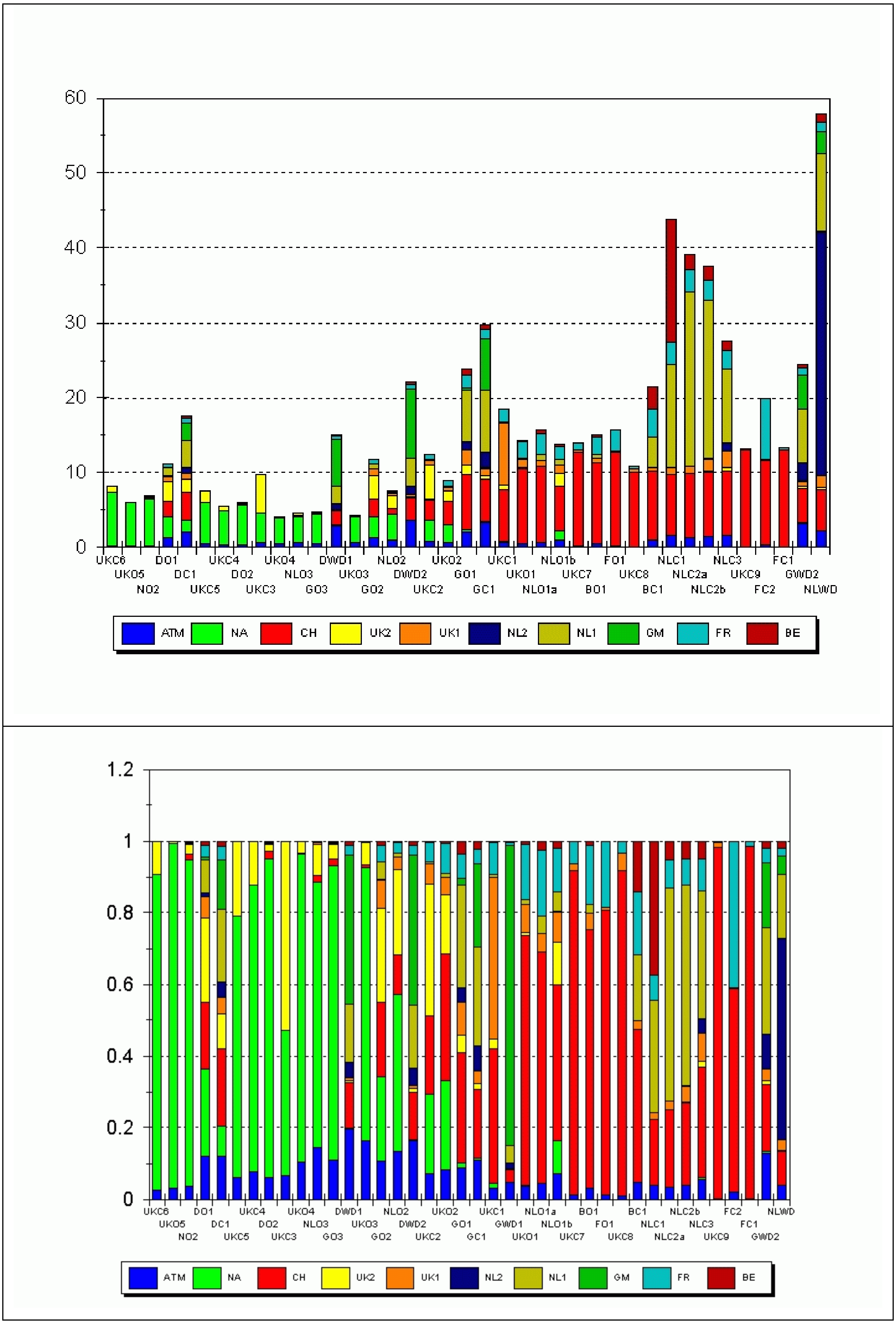

Figure A1-1. Composition matrix Deltares model winter 2002 for N (mol/L) (upper and middle panel) and normalized (lower panel).

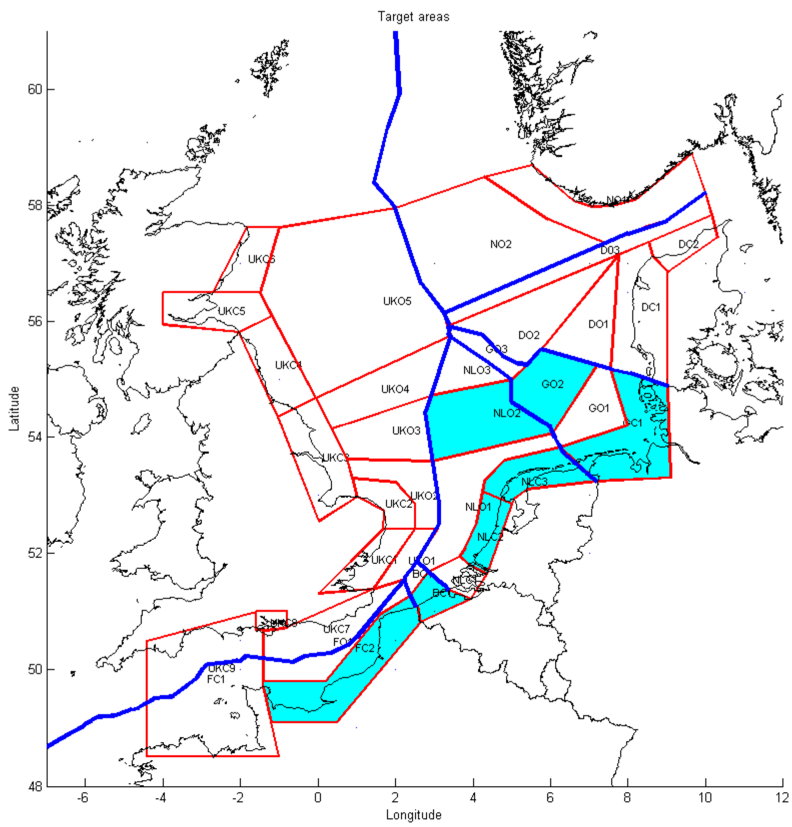

Figure A1-2. Location of OSPAR target areas.

Step 2: Finding the optimal solution

The composition matrix already gives a lot of information on the contribution of each individual source in each area. For instance if in a specific area the contribution of the Channel is 60% we know without performing any further computation that a target value, which is 50% of the present value, cannot be achieved because the amount coming from the Atlantic through the Channel cannot be reduced and therefore remains the same. We also know that the residual flows along the continental coast are from South-West to North-East. Hence a reduction in loads from the French rivers will have an effect in many areas along the continent, while the impact of a reduction of the Elbe will not help in achieving a reduction target for Belgium waters. So intuitively it is clear that reductions of nutrient loads from rivers, which contribute significantly to the concentrations in many areas, will be more effective than similar reductions of rivers that affect only a small number of areas. But is there a formal way to find the best possible reduction strategy?

To deal with this category of problems, a general mathematical technique called Linear Programming was developed during World War Two and formalized in the next decades (Danzig, 1963).

A linear programming problem requires that a linear function:

$$H = c_1x_1 + ... + c_nx_n$$

be minimized subject to a set of linear constraints of the form:

$$a_{11}x_1 + ... + a_{1m}x_1 \geq b_1$$

$$a_{21}x_2 + ... + a_{2m}x_2 \geq b_2$$

$$a_{n1}x_n + ... + a_{nm}x_n \geq b_n$$

As a further requirement:

$x_i \geq 0$

for every value of i, where i = 1,...., n. Notice that the linear constraints may also take the form of an exact equality = or a ≤ condition. These various forms of constraints may also be combined in a single optimization problem. This makes it possible to constrain a variable at a non-zero, positive value. Also notice that the same mathematical technique can be applied to the inverse class of problems where a linear function is maximized given a limited set of resources. In economical terms one may think of these two types of goal functions as either minimizing costs or maximizing profits.

More specifically in the present context the goal is *to find the minimum possible reduction (x) of all river loads satisfying the reduction targets in all areas*.

In order to achieve this we consider two different types of constraints (the rows denoted by $a_{11}x_1$ to $a_{n1}x_n$ in the set of equations). The first set of constraints is the composition matrix which we have already discussed, the second puts a limit on the fraction by which the loadings from the rivers can be reduced and optionally allows us to require a minimum reduction level for the rivers. The composition matrix expresses the relationship between the concentrations in each area and the various sources. At this stage we make the important assumption that *the composition matrix remains the same* when some or all of the sources of nutrients are reduced. Because as we have already explained biological components do not react linearly to changes, this assumption is never fully met, but under many conditions it proves to be a sufficiently accurate approximation. This may seem counter intuitive but can be explained as follows.

The hydrodynamic conditions are independent from the nutrient loads and hence the distribution of water masses remains the same regardless whether or not nutrient loads from rivers are changed. Since the concentrations across the boundaries are assumed to remain the same and since the water masses from the boundaries typically enter the coastal waters via areas where the contribution of rivers is very small, the amount of nutrients originating from the boundaries is likely to remain almost constant when river loads are reduced. As a result the rate of change in nutrient availability encountered by the phytoplankton is (much) smaller than the rate of change in nutrient loads, which makes it more likely that the overall response can be approximated by a linear function.

Another aspect to take into account is that the optimization scheme is applied to compare different reduction strategies that all should result in (almost) the same local concentrations. In other words: no matter if river A or B is reduced, the resulting concentration of an area will (almost) be the same: equal or less than the target. This means that any deviation from a linear response in an area will be (almost) the same for each different scenario and hence cancels out when comparing them.

The validity of the above assumption should, however, be checked by running the full eco-hydrodynamic model for the most promising solutions, which will also reveal any other shortcomings of the optimization approximation

The right hand sides of the original composition matrix contain the (total) concentrations (i.e. DIN, DIP) in an area. During the application of the optimization these are replaced by *the amount by which the state variable (nutrient) has to be reduced in order to meet the target for the area*. Notice that we adopt a value of 0.0 if at present the concentration within the area already complies with the target: no further reduction is required.

The second part of the set of constraints contains information on the maximum (and optionally minimum) reduction of each individual source i.e. river group. We express this as a fraction that should be between 0 (or some positive number) and some chosen value which is ≤ 1.0. This number must be specified for each source considered during the optimization and thus can be different for each of them. For the Channel, the North Atlantic and the atmospheric deposition, we take 0.0 as the default reduction. So basically we assume that these sources cannot be reduced at all. For the river sources, a theoretical value of 1.0 could be adopted, but this implies that the total load from a group of rivers could be reduced to 0.0, which is an unrealistic assumption. Typically we assume that the maximum possible reduction factor is 0.85 or less.

Each row contains a coefficient value of 1.0 for the river group whose reduction we want to delimit and 0.0 for all other river groups. For each river group one constraint is defined.

The last part of setting up the optimization is to define the goal: the so-called cost function. This can be considered as a weight function for each individual source. It can be interpreted as the cost per unit of reducing a nutrient per source (river). As our default we have adopted a value of 1.0 for each river. Basically this means that the cost of obtaining a certain reduction *percentage* is the same for each river. As a consequence the optimization algorithm has a preference for reducing rivers with the highest loads. As an alternative one might argue that for each river the costs of reducing the loads by a certain *absolute* amount should be the same. It is important to keep in mind though that the cost function determines which of all possible solutions (combinations of nutrient reductions) should be considered as optimal; meeting all the targets is a prerequisite that will *always* be met, regardless what cost function is adopted. So adopting a different cost function usually does not result in a completely different optimal reduction strategy. Determining alternative cost functions in a realistic way is very attractive but also quite an exercise, however, which goes beyond the scope of the present analysis.

While running the optimization procedure as described in the previous paragraphs, we noted that occasionally there was no feasible solution: not all the targets could be met. In these cases the optimization procedure conveniently reports which constraint is invalid hence in which area the problem occurs. We noted that these infeasibilities typically occurred when the reductions to be achieved exceeded the actual contributions of controllable sources, which of course is not possible. To understand why this could happen one should take into account that the targets for the areas were determined based on expert knowledge and statistical techniques, not by deterministic models which have a higher level of internal consistency.

For practical reasons we therefore perform a check on the feasibility of the system at the moment when the reductions of the concentrations per area are calculated. This is done by checking the contributions of all sources using the composition matrix and multiplying them by the same factor that we adopt for the maximum possible reduction of a river group so typically 0.85. In other words: the highest possible reduction that we specify as a constraint for the optimization is equal to 0.85 times the sum of the concentrations of all rivers for each area. If the formal target is below this number, we raise its value in such a way that a feasible solution exists. Formally this means that the original target should be considered as unrealistic.

Example case for P scenarios

Some of the results from the optimization scheme may at first look somewhat trivial because particularly for phosphorus many rivers have to be reduced with the maximum possible fraction (0.85). This can easily be explained, however. For many of the areas the targets set for P are well below the present concentrations. As a considerable reduction in loads has already been achieved since the early 1990s, the contribution of controllable sources as depicted by the composition matrix has decreased in favour of the contribution by the non-controllable boundaries. So any further reductions of the concentrations at sea require rather drastic load reductions.

The results of such a default case are summarised as follows:

River	Reduction
BE	0.85
FR	0.85
GM	0.00
NL1	0.85
NL2	0.30
UK1	0.85
UK2	0.85

So the maximum reduction is necessary for BE, FR, NL1, UK1 and UK2. The most critical area where the target is just met is NLC3. In all other areas the new concentration is below the target for that area. It should however be noted that for various areas the targets were adjusted down to 0.85 times the sum of the contribution of all rivers in order to make the solution feasible because otherwise the targets could not be met.

Obviously the required reductions are high and one might wonder what would happen if we drop some constraints particularly the ones for the Dutch areas. So an alternative, hypothetical optimization was performed in which the targets for the areas along the Dutch and Belgium coast are no longer included. The result is as follows:

BE	0.72
FR	0.85
GM	0.00
NL1	0.85
NL2	0.00
UK1	0.85
UK2	0.00

Under these conditions the maximum reduction is still necessary for FR, NL1, and UK1. The necessary reduction for BE is still large, but the required reductions for NL2 and UK2 are now 0. So why is such a large reduction of the NL1 (and FR and BE) rivers still necessary although we did not impose any reductions for the Dutch and Belgium coastal waters in this example case? The answer can be found by looking at the areas where the targets are now just met: UKC6 and *BO1*. BO1 is a non-coastal area where the Channel is the major source of P and although the required reduction for this area is relatively small, it can only be achieved by a significant reduction of all rivers that contribute to the nutrients in this area, including NL1. So this is an example where meeting a target in a small offshore area puts a heavy burden on the nutrient reductions of several rivers (FR, BE and NL1). We may conclude that in this example meeting the target for BO1 is even more demanding than meeting the target for the Dutch coastal zone areas. Also notice that a reduction of UK2, which was maximal (0.85) in the original case, now has dropped to 0. This is because we have dropped the target for area NL3 in this example, which in the original case required the 0.85 reduction of UK2. So the reduction of UK2 in the default case was not necessary for meeting the UK targets but for meeting the Dutch NLC3 target.

Example case for N scenarios

For meeting nitrogen targets, the results of a default case are summarised as follows:

BE	0.74
FR	0.18
GM	0.00
NL1	0.73
NL2	0.00
UK1	0.61
UK2	0.00

The most critical areas just meeting the target in this case are UKC1, BC1, NLC1 and FC2. Notice that the target for GC1 is met (even exceeded) without any reduction of the German rivers. Also notice that unlike for P, reductions for all rivers are below the maximum value of 85 percent.

Like in the P scenarios above, a hypothetical optimization was performed in which the nitrogen targets for the Dutch and Belgium coastal areas were removed. The result is as follows:

BE	0.00
FR	0.00
GM	0.00
NL1	0.39
NL2	0.00
UK1	0.65
UK2	0.00

In order to reach the targets in the remaining (mainly German) areas, the nitrogen load of river NL1 should be reduced by 39 percent, which contrast with the 73 percent reduction from the previous example, which was required to satisfy the targets for Dutch coastal waters. Targets are just met in two areas: GC1 and UKC1. As explained above, the optimization procedure favours a reduction of NL1 over local German rivers because of its larger nitrogen load. When increasing the costs of reducing the load of NL1 from 1.0 to an (arbitrary) value of 1.25, results show that the remaining targets can also be met by reducing the German river loads with 46 percent:

BE	0.00
FR	0.00
GM	0.46
NL1	0.00
NL2	0.00
UK1	0.66
UK2	0.00

As in the previous case targets are just met in GC1 and UKC1. From the point of view of meeting the targets both results are just as good. However, a reduction of NL1 as in the previous example in addition results in a reduction of DIN along the Dutch coast which is not the case when the target for GC1 is achieved by a reduction of the German rivers.

Concluding remark

These are only some out of many possible examples demonstrating the power of the optimization technique in unravelling the relations between targets and sources. Many other examples can be worked out.

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Annex 2 - Model descriptions

MUMM-ULB — MIRO&CO-3D [BE model] The MIRO&CO-3D (in workshop terms BE) model has been developed by coupling the 3D COHERENS hydrodynamical model described in Lacroix *et al*. (2004) based on the COHERENS model (Luyten *et al*., 1999) with the biogeochemical MIRO model (Lancelot *et al*., 2005) to simulate the transport and dynamics of inorganic and organic nutrients, phyto-, bacterio- and zooplankton biomass (Lacroix *et al*., 2007a). The biogeochemical MIRO model simulates carbon, nitrogen, phosphorus and silicon cycling and includes thirty-two state variables and twenty-eight processes linking them, selected as relevant from knowledge of the structure and functioning of *Phaeocystis*-dominated ecosystems. The description of the MIRO model structure, state variables, processes and conservation equations is detailed in Lancelot *et al*. (2005; Appendices available at www.int-res.com/journals/ suppl/appendix_lancelot.pdf).

The MIRO&CO-3D model has been set up for the region between 48.5°N–4°W and 52.5°N–5.0°E using a 109 by 97 horizontal grid with a resolution of 5′ longitude (approx. 5.6 km) by 2.5′ latitude (approx. 4.6 km) and with 5 vertical sigma-coordinate layers. It has been run to simulate the annual cycle of carbon, inorganic and organic nutrients (NH4, NO3, PO4, and SiO2), phytoplankton (diatoms, nanoflagellates, and *Phaeocystis*), bacteria and zooplankton (microzooplankton and copepods) in the southern North Sea and the Channel under realistic forcing. The consideration of different forms (3–4) for each phytoplankton species allows to account for variable C:Chl ratio.

Benthic organic matter degradation and nutrient (N, P, and Si) recycling were calculated by algorithms developed by Billen *et al*. (1989). These algorithms, by solving steady-state diagenetic equations expressing the mass balance of organic C, oxygen and inorganic forms of N and P in the sedimentary column, calculate the fluxes of NO3, NH4 and PO4 across the sediment–water interface resulting from a given sedimentation flux of POM. The processes included are: organic matter degradation, associated NH4 and PO4 release, O2 consumption, nitrification and denitrification, PO4 and NH4 adsorption onto organic material, mixing in the interstitial and solid phases, and accretion of the sedimentary column by inorganic matter sedimentation. First-order kinetics describes biogenic silica dissolution and release of dissolved Si to the water column.

The PAR attenuation coefficient is modelled as function of: (i) non-algae particle concentration, (ii) chlorophyll-a concentration computed by the model, (iii) coloured dissolved organic matter (CDOM) absorption at 443 nm estimated from salinity computed by the model and (iv) depth. The non-algae particle concentration is estimated from total Suspended Particulate Matter (SPM) minus a fraction (function of the simulated chlorophyll-a concentration) representing the algae contribution. A SPM daily climatology has been built from 2003-2006 MODIS-Aqua images. The remotely sensed SPM data used is based on the BELCOLOUR archive of MODIS-Aqua imagery for the period 2003-2006 inclusive. The DINEOF univariate methodology has been applied to the MODIS-Aqua SPM images to reconstruct daily time series for the English Channel and the SNS (Sirjacobs *et al*., 2011). The complete data set has then been regridded on the MIRO&CO-3D model grid. For this application, open boundary conditions for nutrients and phytoplankton from the ECOHAM model were used. Atmospheric deposition was not included. A spin-up period of 2 years was sufficient to reach a stable repeating cycle of the pelagic variables.

Ifremer — ECO_MARS3D [FR model] MARS3D is a three-dimensional circulation model developed at Ifremer by Lazure and Dumas (2008), which uses a finite-difference scheme to solve the primitive Navier–Stokes equations under both hydrostatic and Boussinesq assumptions. The model domain in this study extends from the Galicia coast of Spain (43.17°N, 8.13°W) to the north of the river Rhine lume (52.75°N, 5.0°E). The grid is in spherical coordinates, with regular 16 km square meshes. The water column is divided into 30 sigma layers. The biogeochemical model is an extension of the NPZD model type but excludes variations of intracellular nutrient content. The biogeochemical cycles of carbon, nitrogen (with nitrate and ammonium treated separately), silicon and phosphorus are modelled, together with three bulk phytoplankton classes (diatoms, dinoflagellates, and nanoflagellates) and two bulk zooplankton groups (micro- and mesozooplankton). Oxygen concentration, as a critical indicator of the eutrophication level, is also modelled. The specific module for *Phaeocystis* was not used in this particular exercise. Erosion and deposition processes of organic and inorganic matter occur in the bottom layer of the water column. Remineralisation processes occur in the settled and the suspended detrital material. As swell forcing is not yet incorporated in the erosion module of ECO_MARS3D, the predicted SPM is too low in some areas of the domain. This leads to time shifts in the growth of autotrophs. Thus the SPM distribution used in the assessment of the light extinction has been prescribed as monthly composites of the sea surface mineral SPM, constructed from SeaWiFS-derived data and then interpolated to daily values to force the model. In regions of freshwater influence, especially near the coasts and inside estuaries, the satellite forcing is not accurate, or unavailable; in these ROFIs, satellite-derived SPM is replaced by SPM computed in the model by transport and sedimentation of the riverine SPM inputs. Full details about the model implementation and its validation in the English Channel area are given in Vanhoutte-Brunier *et al*. (2009).

UHAM — ECOHAM4 [DE model]. The coupled physical–biogeochemical or ecosystem model ECOHAM4 relies on the previous ECOHAM3 model which was used to calculate nitrogen and carbon budgets in relation to NAO conditions (Pätsch and Kühn, 2008; Kühn *et al*., 2010). The ECOHAM version which is used for the nutrient reduction simulations in this paper is an extension of this version with the focus on eutrophication applications. Therefore the nutrient cycles for phosphorus and silicon are included in this new model version (Lorkowski *et al*., 2012). Special attention is given on the representation of the seasonal oxygen dynamic (Müller, 2008). The physical part is based on the hydrodynamic model HAMSOM (Pohlmann, 1996). The biogeochemical part represents the pelagic and benthic cycles of carbon, nitrogen, phosphorus, silicon and oxygen. The state variables included are: the functional phytoplankton-group diatoms and flagellates, micro- and mesozooplankton, slowly and fast sinking detritus, labile and semi-labile dissolved organic matter and bacteria, dissolved inorganic carbon (DIC) and alkalinity as well as the nutrients and oxygen as mentioned above. Additionally, a module for the equilibrium chemistry of the carbonate system is implemented, so that the model is able to calculate the air–sea flux of CO_2. For phytoplankton, zooplankton and bacteria fixed, but different C:N:P ratios were prescribed. The C:N:P ratios of detritus and labile DOM can evolve freely. The benthic remineralisation processes are parameterized in a simple way: the sediment is represented by a horizontal layer (without vertical extension) where the sedimenting material is collected and remineralised, using different remineralisation rates for organic carbon, nitrogen, phosphorus and silicon (opal). The coupled benthic nitrification/denitrification is bound to the oxygen consumption due to carbon remineralisation.

The model area comprises the whole North Sea and large parts of the Northwest-European Shelf (47° 14’ – 63° 15’ N, 15° 15’ W – 13° 15’ E). The horizontal resolution is about 20 km (λ = ⅓° φ=0.2°), with 24 z-coordinate layers in the vertical (5 - 10 m thickness in the upper 50 m, below increasing). In shallow areas, phytoplankton growth is limited due to self-shading and light attenuation by silt. To include the latter effect, daily silt data from Lenhart *et al*. (1997) were interpolated to the grid and prescribed at each grid point. River loads, atmospheric nitrogen deposition and boundary conditions are those supplied for all participants.

Deltares — Delft3D-GEM [NL model] The Generic Ecological Model (GEM) for the Southern North Sea is an application based on the Delft3D integrated modeling system of Deltares (formerly, WL | Delft Hydraulics). It calculates the advective and dispersive transport of substances, biogeochemical processes and loads, accumulates fluxes and computes resulting concentrations for each time step. Hydrodynamic transports underlying GEM are calculated using Delft3D-FLOW, which calculates non-steady flow and transport phenomena that result from tidal and meteorological forcing. The GEM model has a curvilinear boundary fitted grid.

The GEM model simulates the nutrient cycles of carbon, nitrogen, phosphorus, silicon and dissolved oxygen. As dissolved inorganic nutrients, the following state variables are included in the model: nitrate (NO3, representing the sum of nitrite and nitrate), ammonium (NH4), phosphate (PO4) and dissolved silicate (SiO4). Four functional phytoplankton groups are simulated: diatoms, flagellates, dinoflagellates and *Phaeocystis*, with three phenotypes each to account for adaptation to environmental conditions by phytoplankton (different types under different conditions of resource limitation). Transport, transformation and recycling of nutrients are modelled explicitly. Grazing of algae by benthic suspension feeders and zooplankton is parameterized by phenotype-dependent loss rates. Sedimentation of algae and organic matter and extinction of light by particulate matter, algae and humic substance are modelled explicitly.

The GEM configuration includes the parameter settings that were calibrated for the North Sea and that have proven to be applicable for a range of other coastal ecosystems as well (Blauw *et al*., 2009). This paper also includes a detailed description of the model equations. Application specific to the North Sea have been described by Los and Bokhorst (1997) and De Vries *et al*. (1998). Los *et al*. (2008) present the setup and results of the model application for the 2007 OSPAR workshop in detail, whereas Los and Blaas (2010) discuss the evolution towards Delft3D-GEM over the past 15 years in terms of biogeochemical model skill.

For the present study, boundary conditions for temperature, salinity and nutrient were derived from measurements (Laane *et al*., 1993). At the surface, the Delft3D Flow hydrodynamic simulation that underlies the transport model was forced by the ECMWF data in addition to Dutch Met Office (KNMI) observation time series of light vessel Goeree off the southern coast of Holland. The spatial variation of the SPM concentrations are taken from an application of the Delft3D-SPM model, which is applied on the same grid as GEM. The temporal variations are described by a cosine function with relative high values in winter and low values in summer, the amplitude of which has been empirically derived. Short-term variations in SPM concentrations are included by a wind-dependent multiplication factor.

NOC — POLCOMS-ERSEM [UK-pol model] The coupled hydrodynamic-ecosystem model POLCOMS-ERSEM was set up for the Atlantic Margin region of the NE Atlantic, extending from 20°W to 13°E and from 40°N to 65°N. The physics model, the Proudman Oceanographic Laboratory Coastal Ocean Modelling System (POLCOMS), is a three-dimensional baroclinic B-grid model (Holt and James, 2001; Proctor and James, 1996) solving for hydrodynamics, temperature and salinity. Tides are included by using open boundary conditions of 15 tidal constituents and by adding in the equilibrium tide. Large-scale non-tidal dynamics are accounted for by including barotropic currents, elevation, temperature and salinity boundary data, taken from a 1° global implementation of the Nucleus for European Modelling of the Ocean (NEMO, 5-day means; Smith and Haines, 2009). ECMWF operational analysis data of mean sea-level pressure, wind speed and direction, air temperature, relative humidity and cloud cover are used as surface forcing. Surface fluxes are derived from COARE3 bulk formulae (Fairall *et al*., 2003).

The European Regional Seas Ecosystem Model (ERSEM) calculates carbon, nitrogen, phosphorus, and silicon cycling in a coupled pelagic–benthic system using 50 pelagic and 34 benthic state variables. Eight plankton functional types are represented including phytoplankton, zooplankton and bacteria. The coupling between the POLCOMS and ERSEM models is described by Allen *et al*. (2001), while the version of ERSEM used here is essentially that applied by Blackford *et al*. (2004). Boundary data for silicate, nitrate and phosphate are derived from monthly mean fields from the World Ocean Atlas (Garcia *et al*., 2006). Details of running POLCOMS-ERSEM on the Atlantic Margin domain are given by Wakelin *et al*. (2012).

To represent the suspended particulate matter (SPM) and coloured dissolved organic matter (CDOM), a simple interpolation-based assimilation of observations is used. An Inherent Optical Property (IOP) variable is introduced and relaxed to observations (8-day composites of non-biotic absorption from SeaWiFS) on a seven-day time-scale. This removes uncertainties in trying to model SPM and CDOM due to the many unknowns (settling velocities, sea bed dynamics, sources/sinks, chemistry etc.).

The Atlantic Margin implementation of POLCOMS-ERSEM uses a spherical polar grid of resolution 1/9° latitude by 1/6° longitude (~12 km) with 42 sigma-coordinate levels in the vertical. Both the reference and the distance to target simulations run from 1994 to 2002, with the first three years treated as spin up.

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Annex 3 - Distribution maps

UHAM

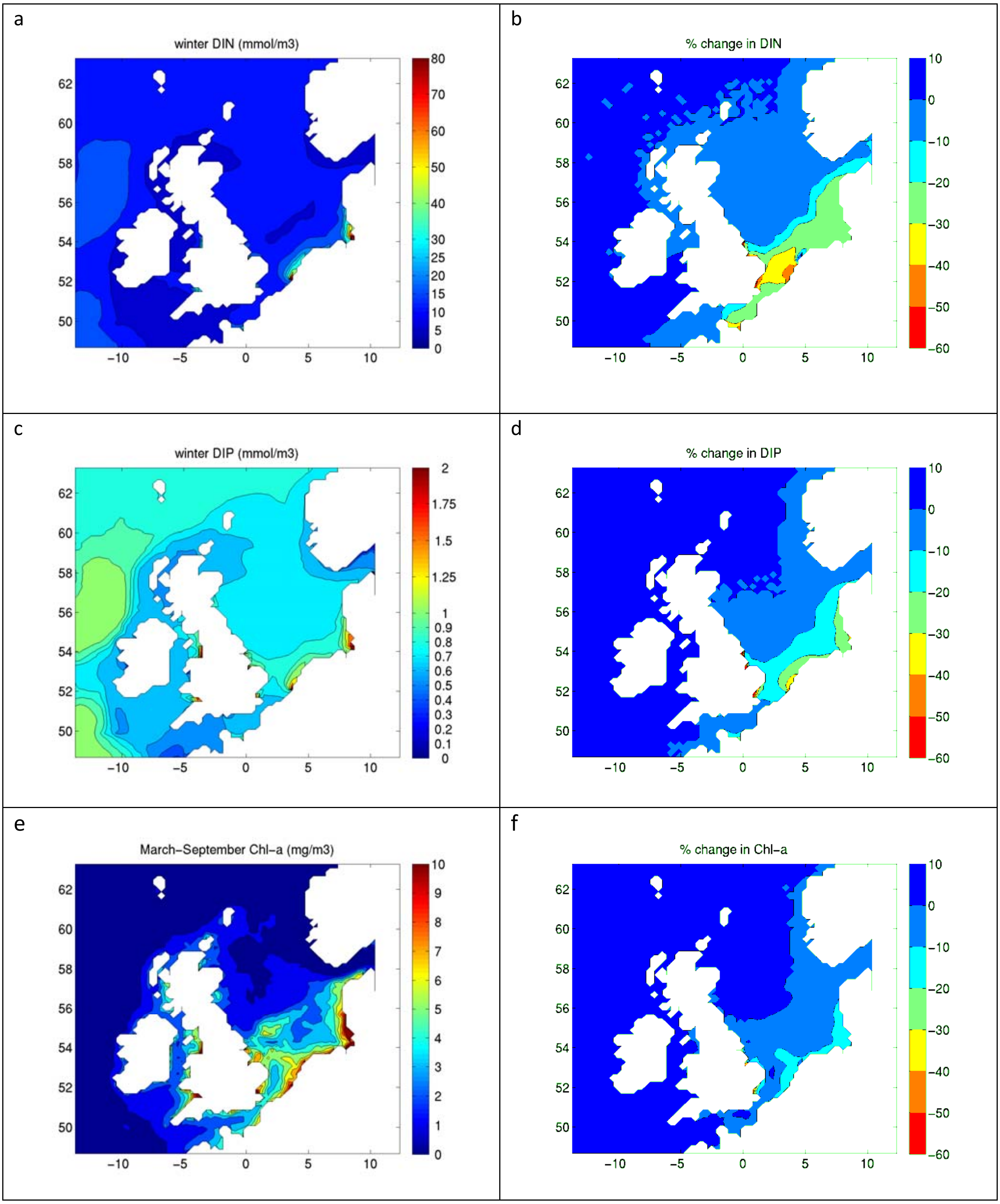
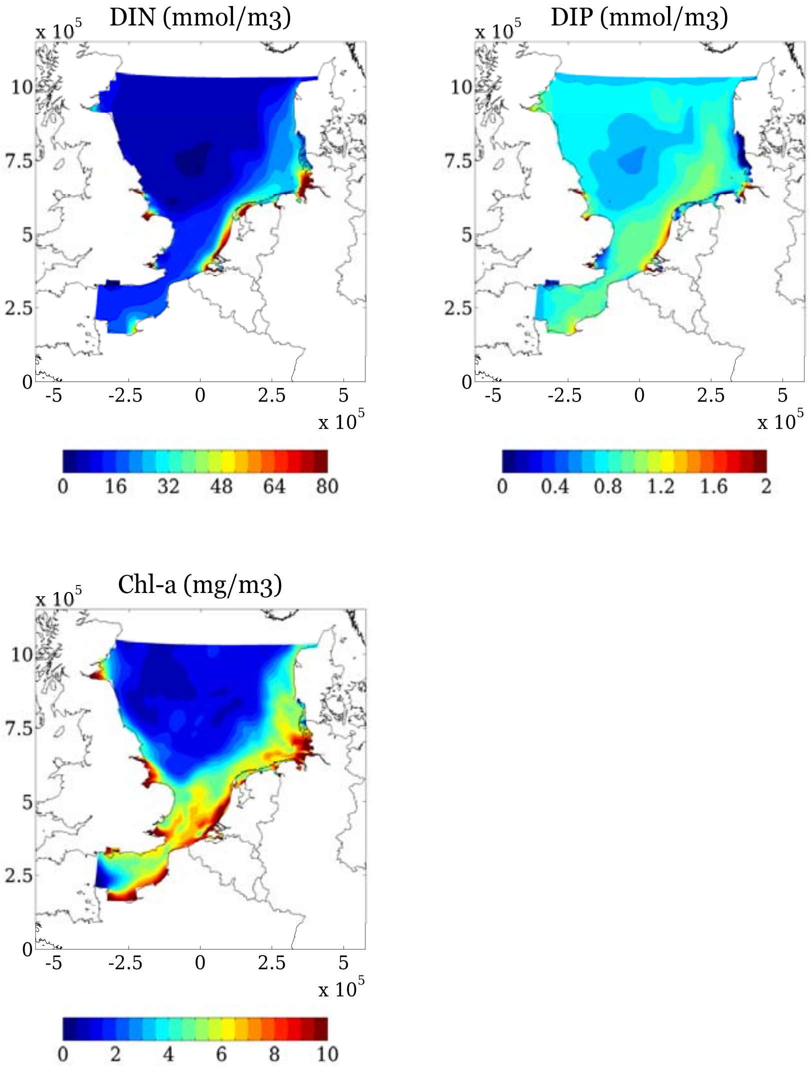


Figure A3-1 Results of the UHAM model, showing in the left column : winter DIN, winter DIP and growing season Chl in the reference run 2002. And in the right column for the same variables the difference in % between the results of the 2002 run and the distance to target run.

Deltares


DIN (mmol/m3)
x 10^5
10
7.5
5
2.5
0
-5
-2.5
0
2.5
5
x 10^5
0 16 32 48 64 80
DIP (mmol/m3)
x 10^5
10
7.5
5
2.5
0
-5
-2.5
0
2.5
5
x 10^5
0 0.4 0.8 1.2 1.6 2
Chl-a (mg/m3)
x 10^5
10
7.5
5
2.5
0
-5
-2.5
0
2.5
5
x 10^5
0 2 4 6 8 10

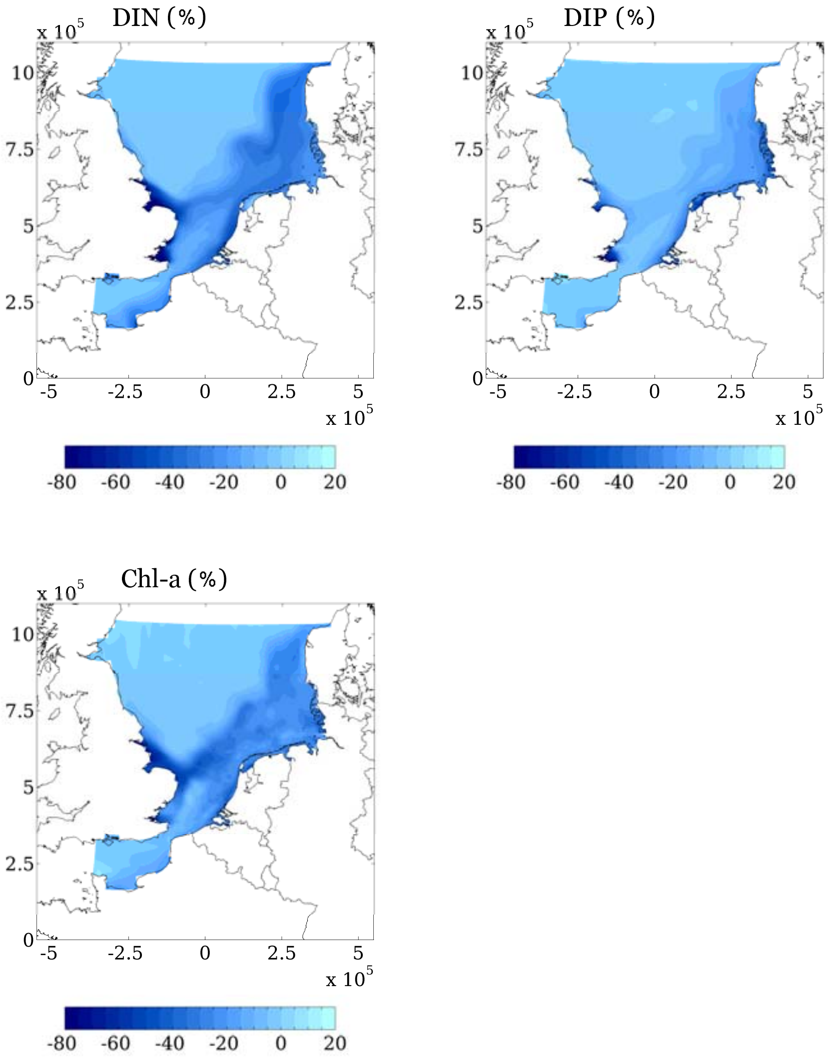


Figure A3-2. Results of the Deltares model, showing in the left column: winter DIN, winter DIP and growing season Chl in the reference run 2002. And in the right column for the same variables the difference in % between the results of the 2002 run and the distance to target run.

Ifremer

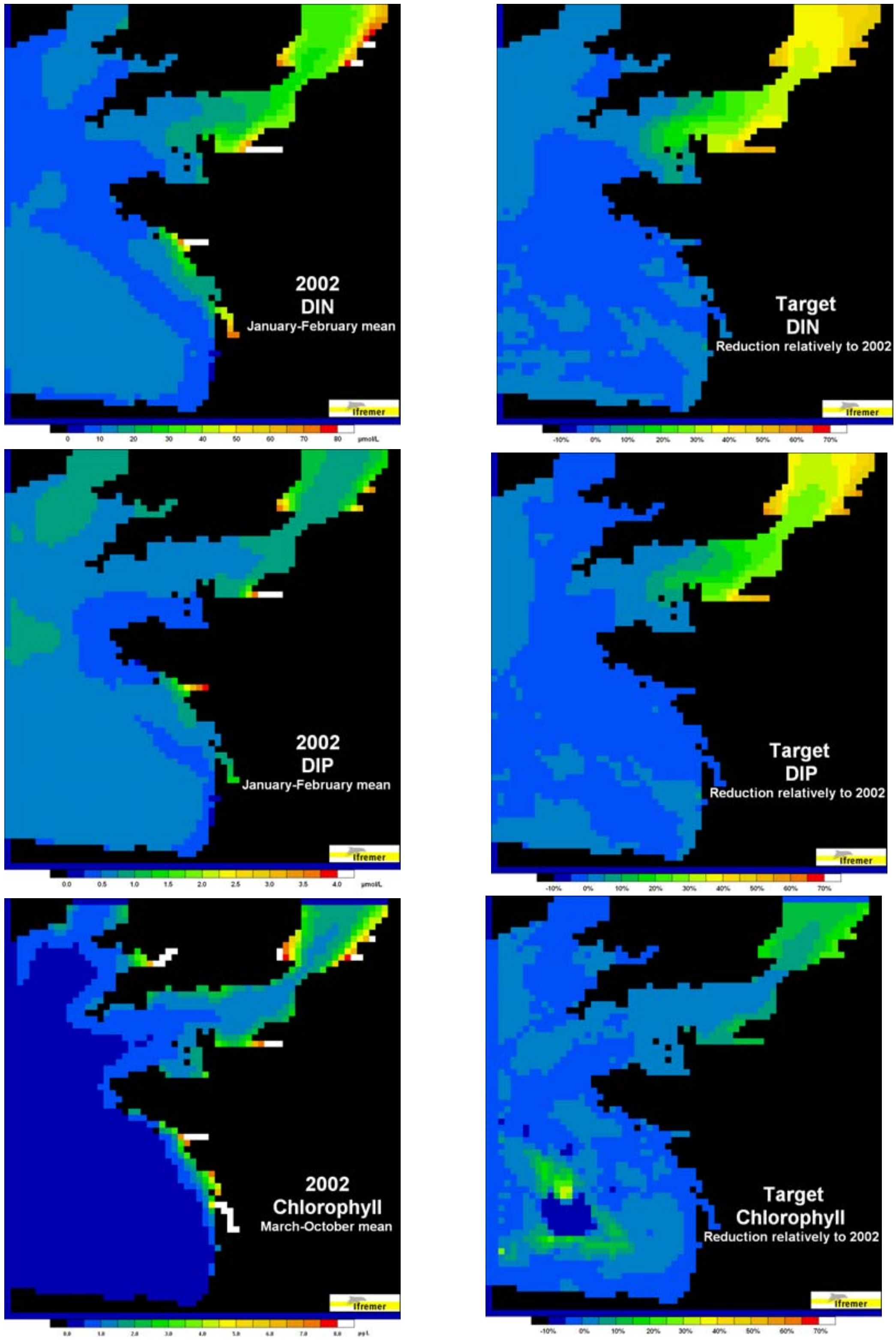
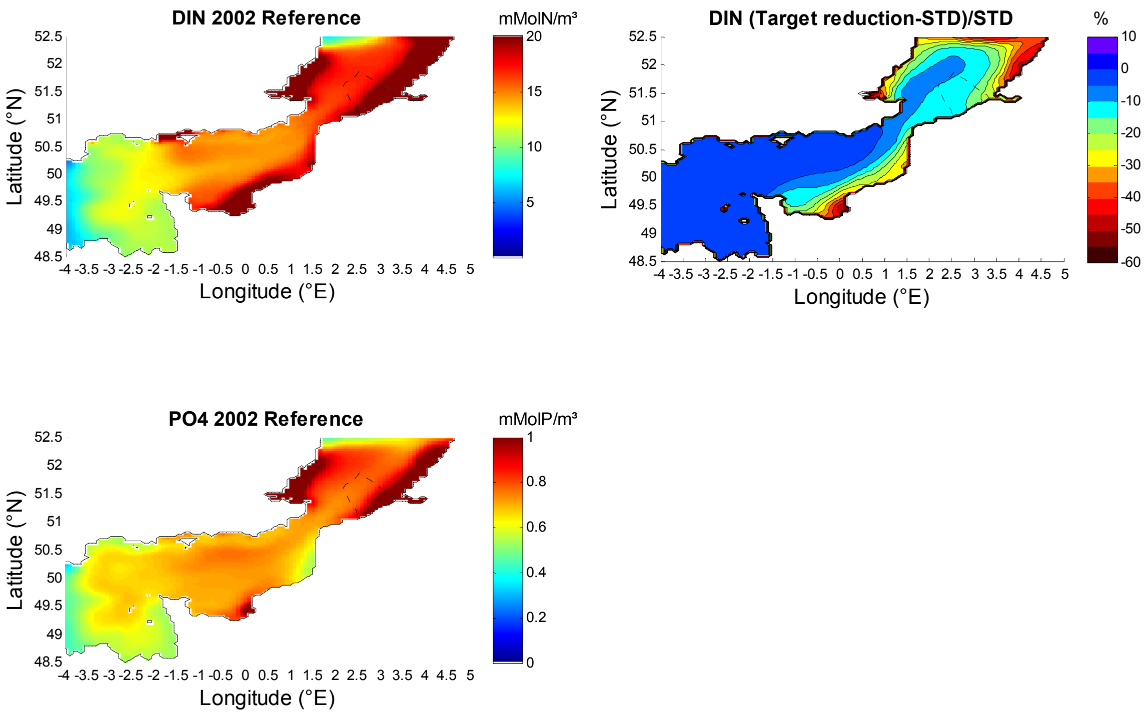
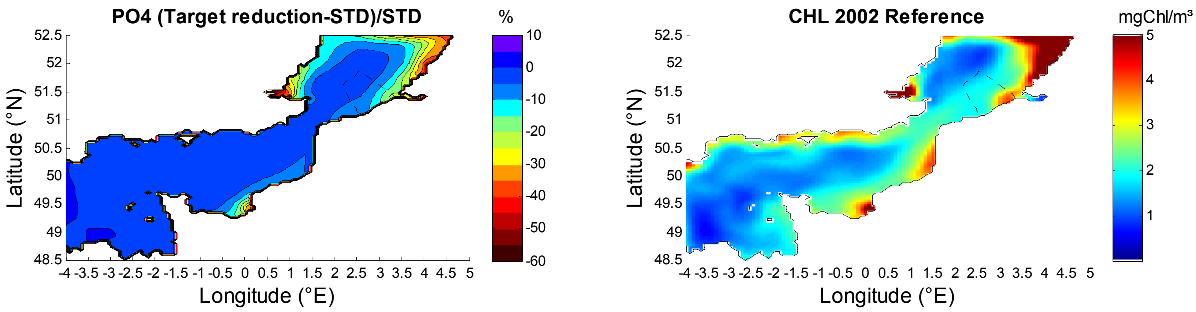


Figure A3-3. Results of the Ifremer model, showing in the left column : winter DIN, winter DIP and growing season Chl in the reference run 2002. And in the right column for the same variables the difference in % between the results of the 2002 run and the distance to target run.

MUMM





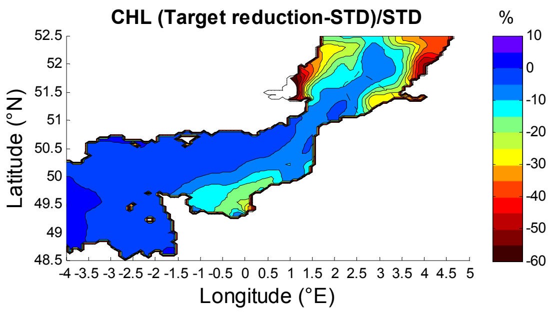


Figure A3-4. Distribution maps showing at the right side results from the reference run 2002 and at the left side the difference in % between the results of the 2002 run and the target reduction run. From top to bottom: winter DIN, winter DIP and growing season Chl (MUMM results).

NOC

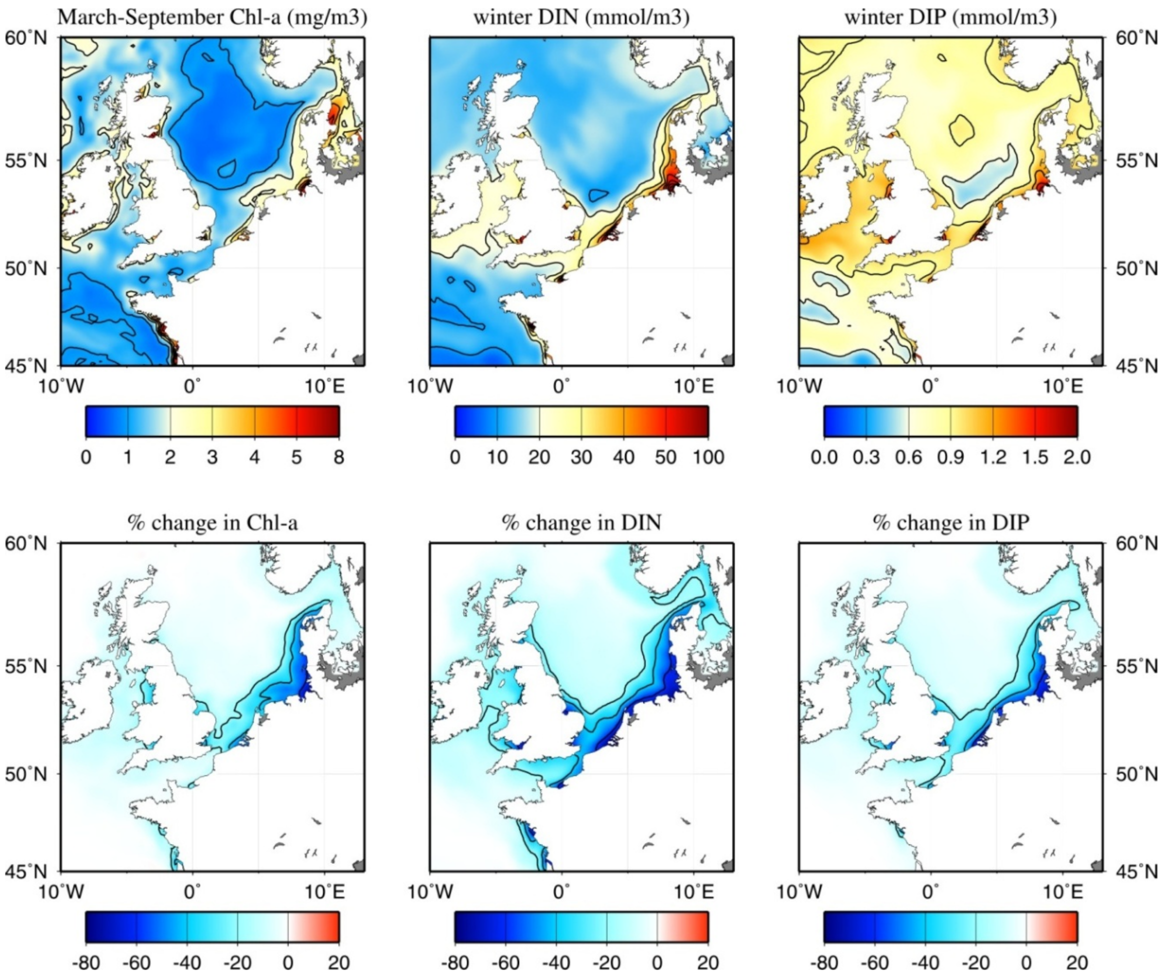


Figure A3-5 Results of the NOC model, showing in the upper row : winter DIN, winter DIP and growing season Chl in the reference run 2002. And in the lower row for the same variables the difference in % between the results of the 2002 run and the 85% reduction run.

Annex 4 - Interannual variability

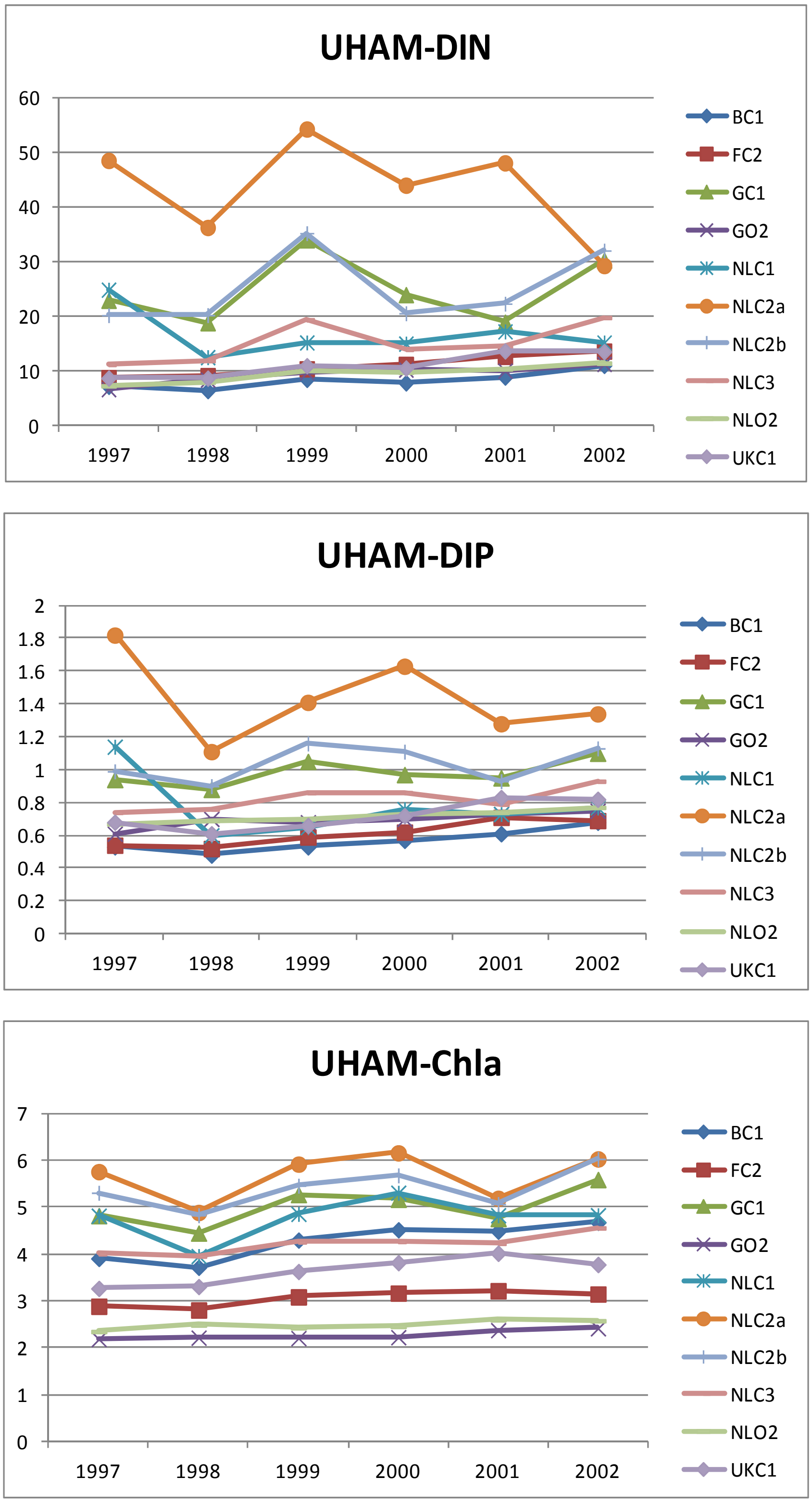


Figure A4-1 Results of the UHAM model for the hindcast 1997 to 2002. The variables winter DIN (umol N/l), winter DIP (µmol P/l), and chlorophyll (µg/l) are shown.

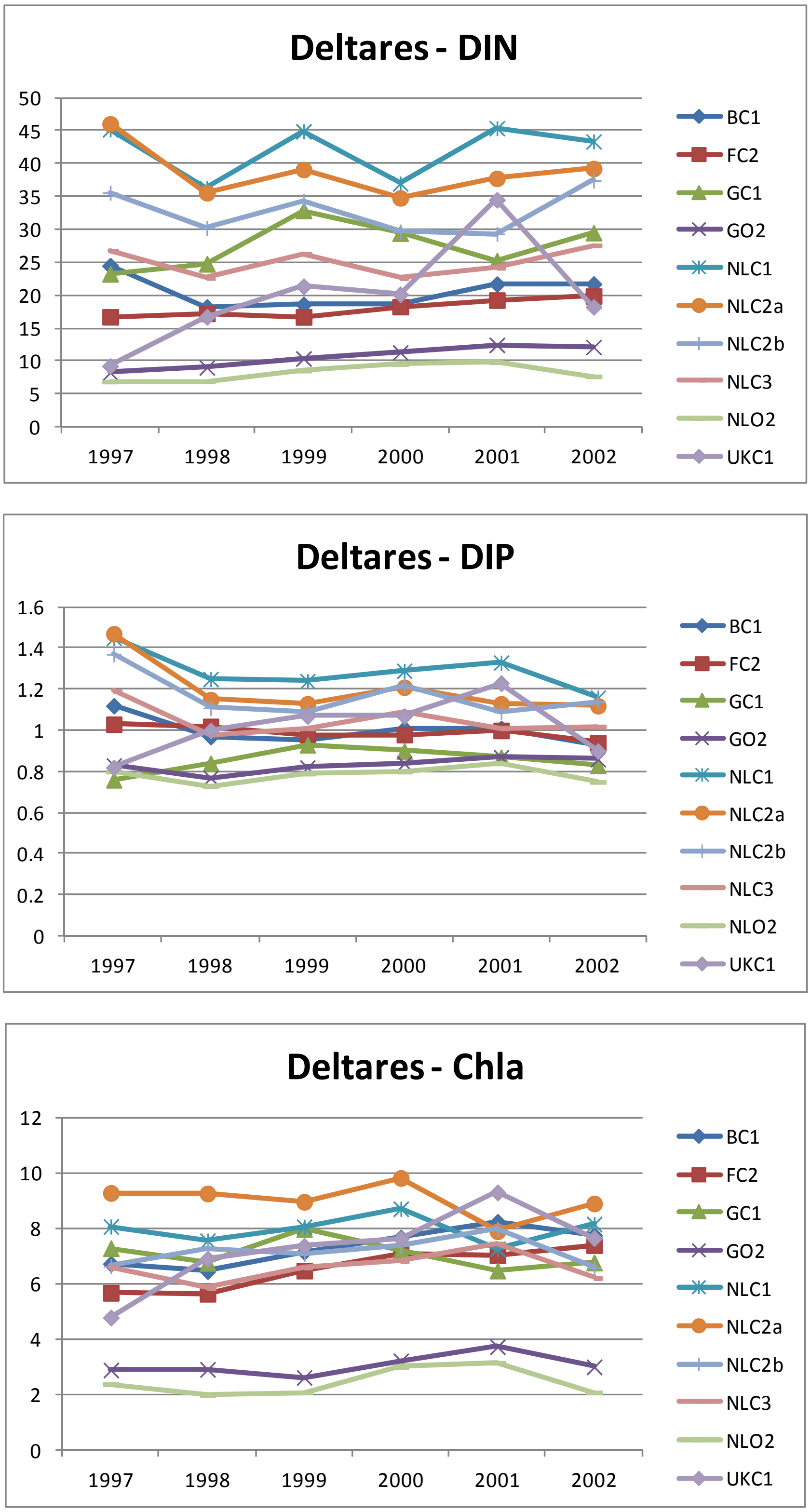


Figure A4-2. Results of the UHAM model for the hindcast 1997 to 2002. The variables winter DIN (umol N/l), winter DIP (µmol P/l), and chlorophyll (µg/l) are shown.

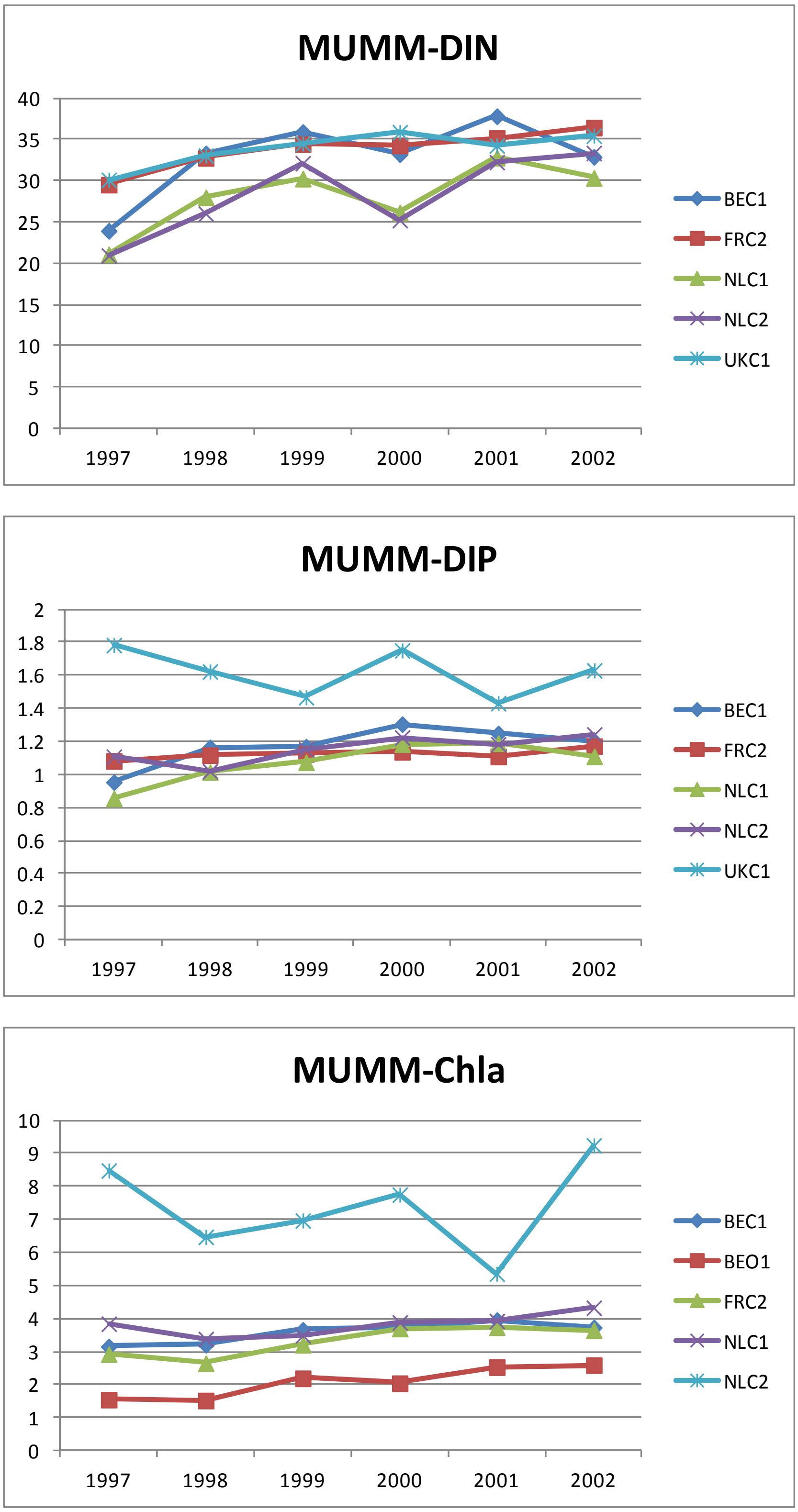


Figure A4-3. Results of the UHAM model for the hindcast 1997 to 2002. The variables winter DIN (umol N/l), winter DIP (µmol P/l), and chlorophyll (µg/l) are shown.

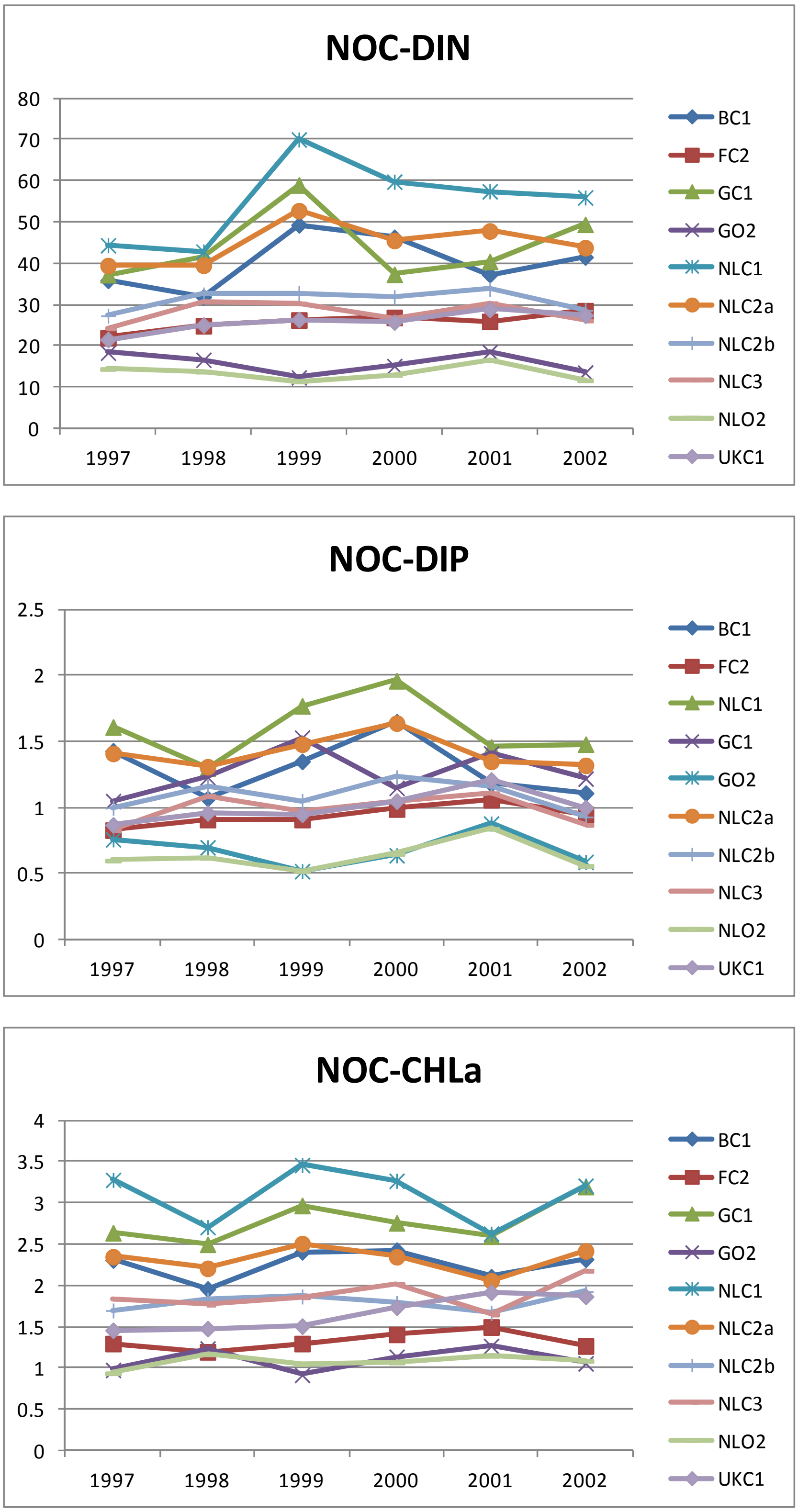


Figure A4-4. Results of the UHAM model for the hindcast 1997 to 2002. The variables winter DIN (umol N/l), winter DIP (µmol P/l), and chlorophyll (µg/l) are shown.

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