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HAVFORSKNINGSINSTITUTTET
MILJØ - RESSURS - HAVBRUK

Nordnesparken 2 Postboks 1870 5024 Bergen
Tlf.: 55 23 85 00 Faks: 55 23 85 31

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OPTIMIZING NUTRIENT REDUCTION STRATEGIES IN THE MARINE ENVIRONMENT - A SIMPLIFIED EXAMPLE FROM THE NORTH SEA

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Forfatter(e):
Morten D. Skogen

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A coupled three dimensional physical, biological model (NORWECOM) has been used to study the effect of different reduction scenarios of nutrient inputs to the North Sea. Six different simulations where the nutrient loads from the Rhine and the German rivers have been varied, are performed.
Outside the Belgian and Dutch coast there is a linear relationship between the decreased inputs from the Rhine and primary production with little effects of reduced inputs in the German rivers. In the German Bight/Danish west coast effects are almost similar for reductions either in the Rhine or the German rivers. In the German Bight a summer oxygen minimum is also influence by a reduced input of nutrients, but the effects are relatively independent of which reduction scenario that have been chosen.

key words:
1. North Sea
2. Euthrophication
3. Nutrients reduction
4. Oxygen depletion
5. Primary production

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Prosjektleder

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Seksjonsleder

1 Introduction

There is an increasing concern about the ecological effects of increased anthropogenic nutrient inputs to the North Sea (Salomons *et al.*, 1988; Buchwald, 1990; Lancelot *et al.*, 1990; Charnock *et al.*, 1994; Sündermann, 1994). The primary production is affected by the changes in nutrient inputs, and in many areas this has caused severe problems. There seems e.g. to have been an increasing trend of harmful flagellate blooms in the coastal areas of the southern North Sea (Lancelot *et al.*, 1991). Probably the most extreme case was the *Chrysocromolina polylepis* bloom in the spring 1988 extending as far north as the Norwegian west coast (Dundas *et al.*, 1989; Maestrini & Graneli, 1991)

Related to the problems with algae, and environmental questions in general, there has been an increasing political interest in eutrophication issues, and at the *2nd. International conference on the protection of the North Sea* (London 1987), all countries around the North Sea agreed on reducing the input of nutrients by 50 % between 1985 and 1995 for those areas where nutrients cause, or are likely to cause, pollution. As a part of the Oslo and Paris Conventions for the prevention of marine pollution, there are also ongoing work to define ecological quality objectives in order to provide a clear statement on the desired state of the maritime area and its regions (OSPARCOM : ASMO 1995 Summary Record).

In the investigations of the ecological effects of reduced anthropogenic nutrient inputs, numerical models have shown an important tool (de Vries, 1992; Skogen *et al.*, 1995; Anon., 1997; Pätsch & Radach, 1997). In the present study a state-of-the-art ecological model, NORWECOM (Skogen, 1993; Skogen *et al.*, 1995), has been used to study the effects of different reduction strategies. The focus has been on reduced inputs of nitrate and phosphate from two different sources. The first source has been the German rivers Elbe, Ems and Weser, while the second source has been the Rhine, identified by the flows at Neue Waterweg (Maasluis), Nordzeekanal and Lake IJssel (Den Oever and Kornwerderzand). The focus has been on the year 1985, and a reference run has been compared with five different reduction scenarios.

2 The model design

The NORWegian ECOlogical Model system (NORWECOM) is a coupled 3-dimensional physical, chemical, biological model system applied to study primary production and dispersion of particles (fish larvae and pollution). The model is described in Skogen (1993). See also Aksnes *et al.* (1995); Skogen *et al.* (1995).

The hydrodynamics is simulated using the primitive equation, wind and density driven Bergen Ocean Model (BOM) (Berntsen *et al.*, 1996). The prognostic variables of BOM are three components of the velocity field, salinity, temperature, two turbulent variables (kinetic energy and macroscale) (Mellor & Yamada, 1982) and the water level. The forcing variables are six-hourly hindcast atmospheric pressure fields provided by the Norwegian Meteorological Institute (DNMI) (Eide *et al.*, 1985; Reistad & Iden, 1995), 6-hourly wind stress (translated from the pressure fields by assuming neutral air-sea stability), four tidal

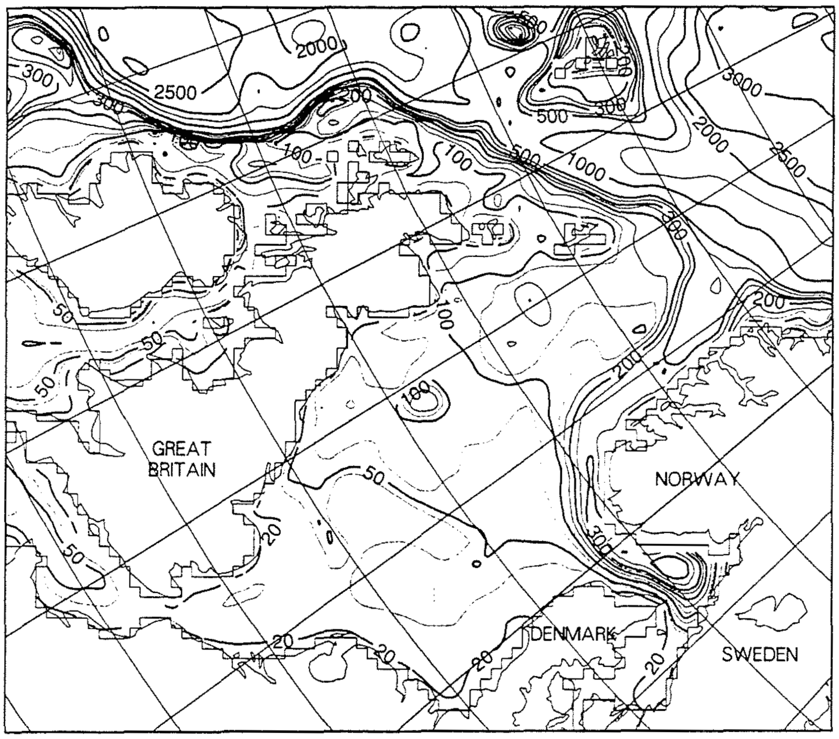

Figure 1: Bottom topography, North Sea 20 × 20 km for the NORWECOM model.

constituents and freshwater runoff. In the lack of data on the surface heat fluxes, a "relaxation towards climatology" method is used (Cox & Bryan, 1984). During calm wind conditions, the surface temperature field will adjust to the climatological values after about 10 days (Oey & Chen, 1992). The net evaporation precipitation flux is set to zero.

The biological model is coupled to the physical model through the subsurface light, waves, the hydrography and the horizontal and the vertical movement of the water masses. The prognostic variables are : inorganic nitrogen, phosphorous and silicate, two different types of phytoplankton (diatoms and flagellates), detritus (dead organic matter), light and turbidity. In the present run the biological model is extended with bottom processes (sedimentation and resuspension) and oxygen dynamics. Three additional prognostic variables are added : oxygen, silicate shells and suspended particulate matter. The extended version of the biological model is described in Søiland (*in prep*).

The incident irradiation is modeled using a formulation based on Skartveit & Olseth (1986, 1987). Data for global daily radiation from 1990 is taken from a station at Taastrup (Denmark) (Anon., 1991). Nutrients (inorganic nitrogen, phosphorous and silicate) are added to the system from the rivers and from the atmosphere (only inorganic nitrogen). Wavefields are taken from the operational model (SWADE) at DNMI.

Initial values for velocities, water elevation, temperature and salinity are taken from monthly climatologies (Martinsen *et al.*, 1992). Interpolation between monthly fields are also used at all open boundaries, except at the inflow from the Baltic where the volume

	Run 0	Run 1	Run 2	Run 3	Run 4	Run 5
Elbe+Ems+Weser	0	0	25	50	75	100
Rhine	0	100	75	50	25	0

Table 1: Reduction scenarios. All numbers are reduction in percentage of the nitrogen and phsophorous concentrations in the river water. Thus Run 0 with 0 percentage reduction for both German rivers and the Rhine, is the reference run

fluxes have been calculated (Stigebrandt, 1980) from the modeled water elevation in Kattegat and the climatological monthly mean freshwater runoff to the Baltic. To absorb inconsistences between the forced boundary conditions and the model results, a 7 gridcell "Flow Relaxation Scheme" (FRS) zone (Martinsen & Engedahl, 1987) is used around the open boundaries.

The nutrient fields are derived and extrapolated/ interpolated (Ottersen, 1991) from data (obtained from ICES) together with some small initial amounts of diatoms and flagellates ($2.75 mgNm^{-3}$). Very few (continuous) time series of nutrients are available from the inflow of Atlantic water. At the open boundaries (outside the North Sea) nutrient values from station M ($66\,°N, 2\,°E$) from 1992 (F. Rey, pers. comm., 1993) have been used and assumed valid everywhere in the inflow area. Nutrient data (monthly means) measured in the Baltic (ICES) are used for the water flowing into Kattegat.

Monthly data for freshwater runoff (or annual averaged data), including nutrient data, from main rivers are taken from Baliño (1993). In addition extra freshwater is added along the Norwegian and Swedish coast to fulfil requirements to estimated total freshwater runoff from these coastlines (Egenberg, 1993).

In the present study the model is used with a horizontal resolution of 20 × 20 km on an extended North Sea (see Figure 1). In the vertical 12 bottom following sigma layers are used. The model run starts December 15, 1984 and continues for 382 days (January 1, 1986), with a 15 minute time step.

3 Results

Six different runs with the model have been done. In the first one the river inputs are left unchanged, while in the 5 others the different reduction scenarios (see Table 1) for nitrate and phosphate from the Rhine and the German rivers have been investigated. For the reference run the annual loads from the rivers are (except for retention in the estuaries) 197 kT (kilotons) of nitrogen and 7.6 kT phosphorous from the German rivers, and 246 kT of nitrogen and 19.4 kT of phosphorous from the Rhine.

3.1 Primary production

In Figure 2 the annual depth integrated primary production ($gC/m^2/year$) for the reference run is shown. The production varies from less than $50gC/m^2/year$ to more than

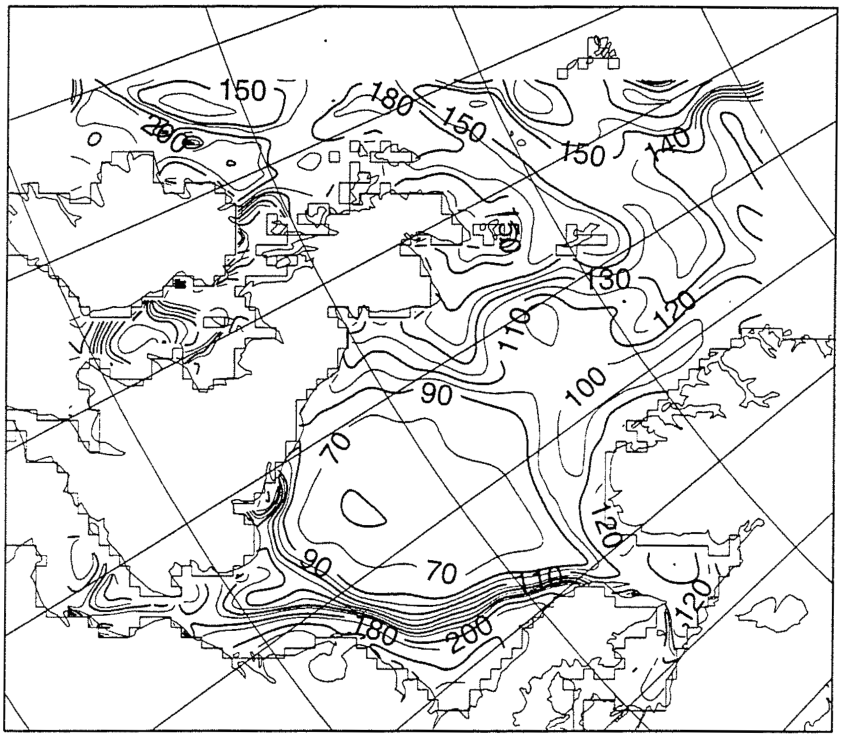

Figure 2: Annual production ($gC/m^2/year$) for the reference run

$350gC/m^2/year$. The highest numbers are found close to the main rivers along the continental coast in the southern North Sea, while the minimum is found in the central North Sea. The production is increasing northwards due to the inflow of nutrient rich Atlantic water.

The six different runs have first been compared with respect to the primary production within each ICES-box. In Table 2 all numbers ($gC/m^2/year$) for each individual box are given, together with the overall mean North Sea production. For locations of the different ICES-boxes see Figure 3.

Only in box 4 (Belgian + Dutch coast) and box 5 (German Bight) the reduction of river nutrients gives any significant change. A 100 % reduction of nutrient from the Rhine decrease the production in box 4 with $15gC/m^2/year$ (8 %) and in box 5 with $22gC/m^2/year$ (10 %). For a similar reduction in German rivers, the numbers are $3gC/m^2/year$ (2 %) and $26gC/m^2/year$ (12 %) respectively. The change in production in Box 4 shows an almost linear change with respect to the reduced inputs of Rhine nutrients, while the changes in Box 5 seem to be more or less independent of the different reduction scenarios. Focusing on the monthly production, the results are comparable. The highest relative differences to the reference run is in June with 15 % in both box 4 and 5 from the Rhine, and July with 3 (box 4) and 19 (box 5) % reduction due to the German rivers.

For reference, an amount of 10 kT of phosphorous will (by using the models intercellular

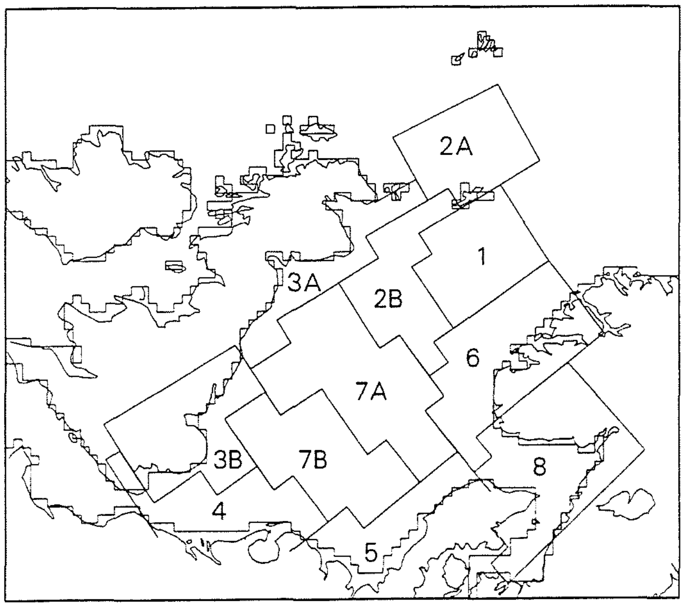

Figure 3: ICES-subareas

run/box	1	2a	2b	3a	3b	4	5	6	7a	7b	8	mean
run0	120	153	121	122	123	189	213	103	73	78	107	119
run1	120	153	121	122	123	174	191	102	73	77	104	116
run2	120	153	121	122	123	177	188	102	73	77	104	116
run3	120	153	121	122	123	181	187	102	73	77	104	116
run4	120	153	121	122	123	184	186	102	73	78	105	116
run5	120	153	121	122	123	186	187	102	73	78	105	117

Table 2: Production statistics ($gC/m^2/year$) for the six different runs for individual ICES-boxes

C:P ratio) give a production of 11 $gC/m^2/year$ if distributed equally over an area of $40000km^2$ (the size of box 4). However, recycling of nutrients is also an important aspect of the total production. The paper of Howarth *et al.* (1993) shows, from an analysis of the winter nutrient budget, that recycling of nutrients in the water column is a major supplier. Earlier model studies (Skogen *et al.*, 1995) agrees with this observation, in fact it seems that in some areas in the southern North Sea as much as 40 % of the total production has its origin in recycled nutrients.

For the other boxes only minor (if any) differences occur. In Skagerrak (box 8) both the Rhine and the German rivers contributes to $2-3gC/m^2/year$ of the total production, and for the North Sea as a whole the change is only 2-2.5 %. Reflecting the higher inputs of nutrients from the river systems, the effects from the Rhine reduction is slightly higher.

To get a better areal picture of what effects the different reduction scenarios have on

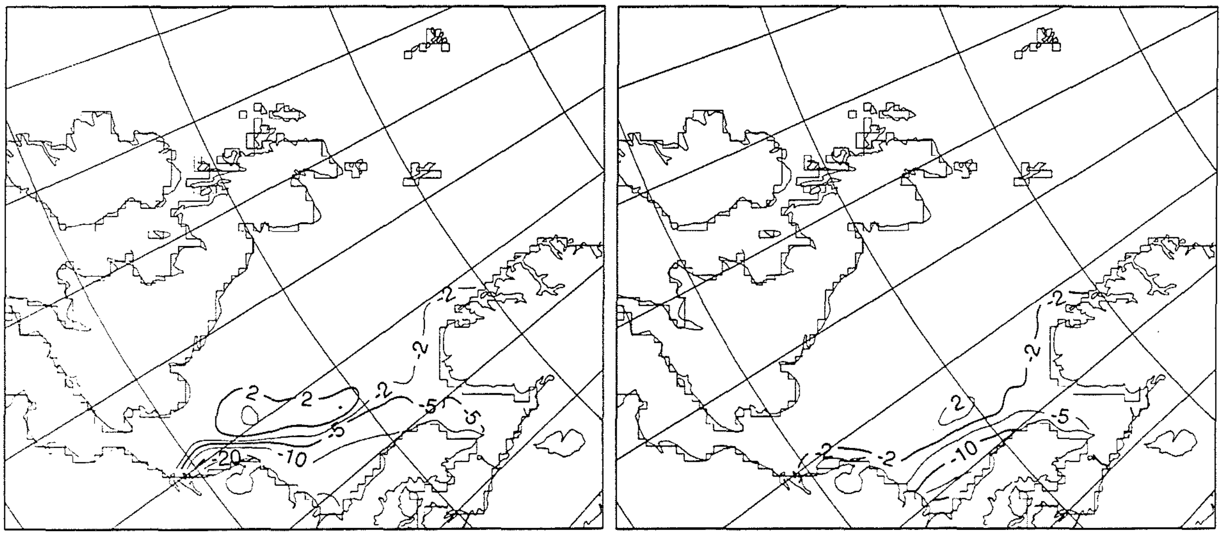

Figure 4: Reduction in flagellate production (%) for run1 (left) and run5 (right)

the primary production, two reduction plots are given in Figure 4. In the left panel the reduction in flagellate production for run1 (100 % reduction in Rhine nutrients) relative to the reference run are given, and in the right panel the corresponding figure for run5 (100 % reduction in German nutrients). For both Run1 and Run5 the maximum reduction close to the river outlets is almost 40 %. The figures confirm the results in Table 2. The Rhine reduction has the largest influence area, and gives significant changes both along the Belgian-Dutch coast and in the German Bight, while the German reduction only has small upstream effects. For both river systems, the limit of the 2 % reduction is as far north as the Hardangerfjord on the Norwegian west coast. It is also interesting to note an increased production (2-5 %) in the flagellate production in a large area south and east of the Doggerbank in Run1.

3.2 Diatoms vs. flagellates

Silicate is typically the first nutrient to become limiting in spring, causing the termination of the spring diatom bloom in the coastal waters (Gieskes & Kraay, 1975). The remaining nitrogen and phosphorus allow further growth of algae not requiring silicate. Reflecting high N/P ratio of the riverine nutrient input, phosphorus is typically the second nutrient to become limiting in coastal waters. This has clearly been demonstrated in data from the late 1980s (Lancelot *et al.*, 1989).

By reducing the inputs of nitrogen and phosphorous it is assumed that the reduction in primary production is in the flagellates, with a possible shift in production to diatoms. An opposite model experiment (Skogen *et al.*, 1997) with increase in silicate concentrations from Norwegian rivers (Glomma, Drammen and Numedalslågen), have shown how diatoms effectively utilize the extra silicate sources, and that the flagellate production furthermore

box/run	run0	run1	run2	run3	run4	run5
4	5.3	4.8	4.9	5.0	5.1	5.2
5	8.3	7.3	7.2	7.1	7.1	7.1

Table 3: Ratio flagellate/diatom production for ICES box 4+5 for the six different runs

is reduced.

In Table 3 the ratio flagellate to diatoms production (annual) is given for the two most effected boxes, Box 4 (Belgian/Dutch coast) and Box 5 (German Bight). The reference run shows that the production in these areas are dominated by flagellates, as the silicate consuming diatoms only contributes to 11-16 % of the annual production. This contribution is only to a small extent influenced by the different reduction scenarios. The small differences in the numbers in both boxes only reflects the change in flagellate production. The diatom production is unchanged ($30gC/m^2/year$ in box 4 and $23gC/m^2/year$ in box 5) in all runs.

3.3 Oxygen minimum

One of the main concerns related to eutrophication is oxygen depletion. High production, sink of dead organic matter and biochemical decomposition of organic matter, can locally give rise to low oxygen values in stagnant water. Modeled oxygen from the bottom layer has been stored from the reference run every 10 days. There is an oxygen minimum in the German Bight in the early summer, following the bottom of the Elbe-rinne into the deeper part of the bight. The largest extension of this oxygen minimum is found on July 1 with a minimum value of $4.56ml/l$ (see Figure 5). Ten days later the minimum area is smaller, and later on found further offshore probably due to advection. No new minimas is seen in this area during the fall of 1985.

The sensitivity of this oxygen minimum with respect to the different reduction scenarios, has been investigated. The minimum value for the different runs are given in Table 4. There is a slight increase in the oxygen values, but the minimas reflects the relationship between the different reduction scenarios and the change in primary production in the German Bight (Box 5). The changes are almost equal in all scenarios, with a slightly higher dependence to the inputs from the German rivers. At present the oxygen consumption algorithm in the model has not been properly validated, therefore the absolute values should be treated with care. However, relative changes between the different simulations may still be realistic.

In addition to look at the minimum value, we have also looked at the areal extent with significant reduced oxygen in the German Bight. We have chosen to focus on the size of the area with values below $5ml/l$ on the same date (July 1). The results are given in Figure 5. Also for this experiment, the results are almost independent of which reduction strategies that were chosen. However, compared to the reference run the area with oxygen values below $5ml/l$, is reduced with at least 40 %.

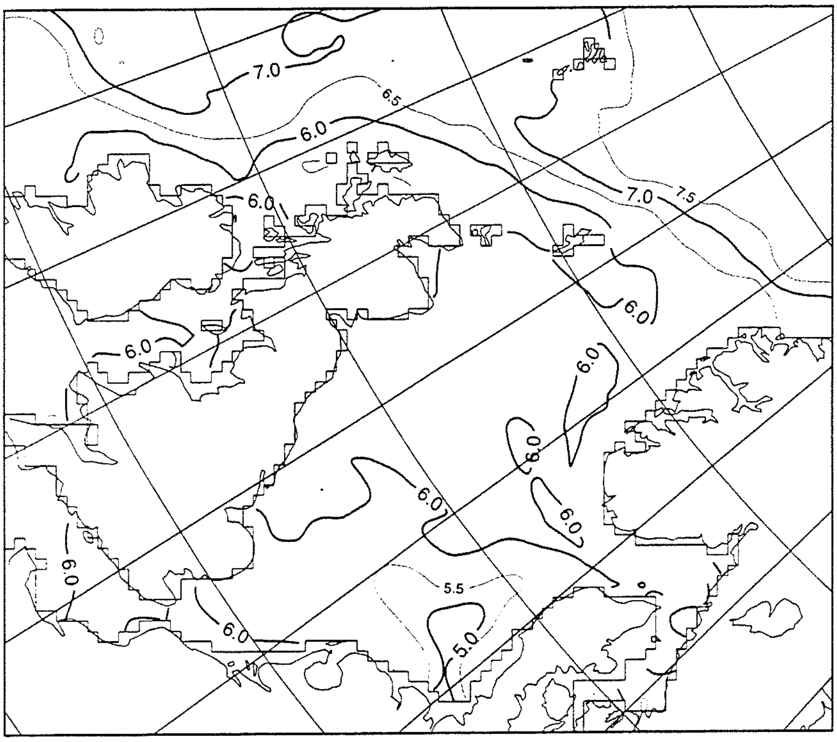

Figure 5: Oxygen (ml/l) in the bottom layer (2.5 % of totak depth above bottom) at July 1 in the reference run

	run0	run1	run2	run3	run4	run5
Oxygen minimum	4.56	4.74	4.77	4.78	4.78	4.77
Area($O_2 \leq 5.ml/l$)	10.0	6.0	5.6	6.0	6.0	6.0

Table 4: Oxygen minimum (ml/l) in the German Bight on July 1, and area ($1000km^2$) with oxygen concentration less 5.0 ml/l

4 Conclusion

With the use of the ecological model NORWECOM, the effect of five different reduction scenarios for river nutrient inputs to the southern North Sea have been investigated. The main concerns have been the changes in primary production and bottom oxygen minimum.

Focusing on the primary production in ICES-box 4 (Belgian-Dutch coast) and 5 (German Bight), the decrease in production in box 4 is almost linear to the changes in inputs of nutrients from the Rhine. For box 5, the effect seems to a less extent to be dependent on which reduction scenario that was implemented. The species composition (diatoms vs. flagellates) behaves similar, since the model did not indicate any change in diatom production for any of the reduction strategies. On box scale the decrease in the annual primary production are moderate (10 %), but close to the river outlets the model indicates a 40 %

reduction.

The model gives an area with low oxygen values in the early summer in the German Bight. The oxygen concentration increases as the input of nutrients (and thereby primary production) is reduced. But also for this parameter, the German Bight seems to be equally affected by both river systems, the Rhine and the German rivers. Compared to the reference run the area with oxygen below $5ml/l$ decreases with at least 40 % in all runs.

One should note that these results are the reductions during the first year. Since the initial fields were identical, the possible integrated effect of the different reduction scenarios may increase through successive years. To get the best picture of the different reduction strategies, it would be necessary to run the model for a longer period. Skogen & Moll (1998) showed that the interannual variability in production even in the coastal zone in the southern North Sea, was higher due to changes in circulation between the years, than the total contribution from the rivers. In the same study, 1985 was shown to have a low inflow of Atlantic water to the North Sea, thus the reduction in river inputs was assumed to play a more important role compared to a year with high Atlantic inflow. Therefore winds and rivers inputs from 1985 was chosen for the present study, even if the freshwater runoff to the North Sea was low this year (Baliño, 1993). Therefore, further studies including different years, reduction scenarios and parameters should be performed before any conclusions about cost effectiveness for reduction of anthropogenic nutrient inputs can be done.

References

AKSNES, D.L., ULVESTAD, K.B., BALIÑO, B., BERNTSEN, J., EGGE, J., & SVENDSEN, E. 1995. Ecological modelling in coastal waters : Towards predictive Physical-Chemical-Biological simulation models. *Ophelia*, **41**, 5–36.

ANON. 1991. *Solar radiation and radiation balance data, 1990.* The world radiation data centre, St. Petersburg, Russia.

ANON. 1997. *Report on ASMO modelling workshop on eutrophication issues.*

BALIÑO, BEATRIZ M. 1993. *Nutrient inputs to the North Sea, Skagerrak and Kattegat. River concentrations and loads from 1980- to 1990.* Tech. rept. HOV-senteret, Høyteknologisenteret, Bergen, Norway.

BERNTSEN, J., SKOGEN, M.D., & ESPELID, T. 1996. *Description of a σ-coordinate ocean model.* Tech. rept. Fisken og Havet, 12. Havforskningsinstituttet, Pb.1870, N-5024 Bergen, Norway.

BUCHWALD, K. 1990. *Nordsee - Ein Lebensraum ohne Zukunft.* Göttingen:Verlag die Werkstatt GmbH.

CHARNOCK, H., DYER, K.R.AND HUTHNANCE, J.M., LISS, P.S., SIMPSON, J.H., & TETT, P.B. 1994. *Understanding the North Sea system.* London: Chapman & Hall.

COX, MICHAEL D., & BRYAN, KIRK. 1984. A Numerical Model of the Ventilated Thermocline. *J. of Physical Oceanography*, **14**, 674–687.

DE VRIES, I. (ed). 1992. *Report of the NSTF Modelling Workshop.* Rijkswaterstaat, Tidal Waters Division, The Hague. Report DGW-92.045.

DUNDAS, I, JOHANNESSEN, O.M., BERGE, G., & HEIMDAL, B. 1989. Toxic Algal Bloom in scandinavian waters, May-June 1988. *Oceanography*, **2**(1).

EGENBERG, BJØRN. 1993. *The relationship between hydrographical variability in coastal water and meteorological and hydrological parameters.* M.Phil. thesis, Geophysical Institute. University of Bergen, Norway. In Norwegian.

EIDE, L.I., REISTAD, M., & GUDDAL, J. 1985. *Database av beregnede vind og bølgeparametre for Nordsjøen, Norskehavet og Barentshavet.* DNMI, Oslo, Norway. In Norwegian.

GIESKES, W.W.C., & KRAAY, K.W. 1975. The phytoplankton spring bloom in Dutch coastal waters of the North Sea. *Neth. J. of Sea Res.*, **9**, 166–196.

HOWARTH, M.J, DYER, K.R., JOINT, I.R., HYDES, D.J., PURDIE, D.A., EDMUNDS, H., JONES, J.E., LOWRY, R.K., MOFFAT, T.J., POMROY, A.J., & PROCTOR, R. 1993. Seasonal cycles and their spatial variability. *Phil. Trans. Roy. Soc. A*, **343**, 383–403.

LANCELOT, C., BILLEN, G., & V., ROUSSEAU. 1989. *Joint EEC project on the dynamics of Phaeocystis blooms in nutrient enriched coastal zones, First Annual Progress Report.* University of Brussels.

LANCELOT, C., BILLEN, G., & BARTH, H. 1990. *Eutrophication and algal blooms in North Sea coastal zones, the Baltic and adjacent areas: Prediction and assessment of preventive actions.* Tech. rept. Water pollution research report 12. Commision of the European Communities.

LANCELOT, C., BILLEN, G., & BARTH, H. 1991. The dynamics of Phaeocystis blooms in nutrients enriched coastal zones. *Water Pollution Research Reports*, **23**, 1–106.

MAESTRINI, S.E., & GRANELI, E. 1991. Environmental Conditions and Ecophysiological mechanisms which led to the 1988 Chrysochromulina polylepis bloom and hypothesis. *Oceanologica Acta*, **14**(4).

MARTINSEN, E.A., & ENGEDAHL, H. 1987. Implementation and testing of a lateral boundary scheme as an open boundary condition in a barotropic ocean model. *Coastal Engineering*, **11**, 603–627.

MARTINSEN, EIVIND A., ENGEDAHL, HARALD, OTTERSEN, GEIR, ÅDLANDSVIK, BJØRN, LOENG, HARALD, & BALIÑO, BEATRIZ. 1992. *MetOcean MOdeling Project, Climatological and hydrographical data for hindcast of ocean currents.* Tech. rept. 100. The Norwegian Meteorological Institute, Oslo, Norway.

MELLOR, G.L., & YAMADA, T. 1982. Development of a turbulence closure model for geophysical fluid problems. *Rev. Geophys. Space Phys.*, **20**, 851–875.

OEY, LIE-YAUW, & CHEN, PING. 1992. A model simulation of circulation in the Northeast Atlantic Shelves and Seas. *Journal of Geophysical research*, **97**(C12), 20087–20115.

OTTERSEN, GEIR. 1991. *MODgrid, a Model Oriented Data grider.* Tech. rept. 6/1991. Institute of Marine Research, Bergen, Norway.

PÄTSCH, J., & RADACH, G. 1997. *Long-term simulation of the eutrophication of the North Sea: Temporal development of nutrients, chlorophyll and primary production in comparison to observations.* in print, Journal of Sea Research.

REISTAD, M., & IDEN, K.A. 1995. *Updating, correction and evaluation of a hindcast data base of air pressure, winds and waves for the North Sea, Norwegian Sea and the Barents Sea.* Tech. rept. 9. Det Norske Meteorologiske Institutt, Oslo, Norway.

SALOMONS, W., BAYNE, B.L., DUURSMA, E.K., & FÖRSTNER, U. 1988. *Pollution of the North Sea- an assessment.* Berlin: Springer Verlag.

SKARTVEIT, ARVID, & OLSETH, JAN ASLE. 1986. Modelling slope irradiance at high lattitudes. *Solar Energy*, **36**(4), 333–344.

SKARTVEIT, ARVID, & OLSETH, JAN ASLE. 1987. A model for the diffuse fraction of hourly global radiation. *Solar Energy*, **37**, 271–274.

SKOGEN, MORTEN D. 1993. *A User's guide to NORWECOM, the NORWegian ECOlogical Model system.* Tech. rept. 6. Institute of Marine Research, Division of Marine Environment, Pb.1870, N-5024 Bergen.

SKOGEN, MORTEN D., & MOLL, ANDREAS. 1998. *Natural variability of the North Sea primary production.* In prep.

SKOGEN, MORTEN D., SVENDSEN, EINAR, BERNTSEN, JARLE, AKSNES, DAG, & ULVESTAD, KÅRE B. 1995. Modelling the primary production in the North Sea using a coupled 3 dimensional Physical Chemical Biological Ocean model. *Estuarine, Coastal and Shelf Science*, **41**, 545–565.

SKOGEN, MORTEN D., AURE, JAN, DANIELSSEN, DIDRIK, & SVENDSEN, EINAR. 1997. *Natural fertilization of the marine environment. Modeling of the Glomma flood 1995.* Submitted.

STIGEBRANDT, ANDERS. 1980. Barotropic and baroclinic response of a semi-enclosed basin to barotropic forcing of the sea. *In:* FREELAND, H.J., FARMER, D.M., & LEVINGS, C.D. (eds), *Proceeding of the NATO Conference on Fjord Oceanography.* Plenum Press, New York.

SÜNDERMANN, J. 1994. *Circulation and contaminant fluxes in the North Sea.* Berlin: Springer Verlag.