

# **The Year 2006**

## **An Eutrophication Status Report of the North Sea, Skagerrak, Kattegat and the Baltic Sea**

### **A demonstration Project**

**Elin Almroth, Morten Skogen, Ian Sehested Hansen  
Tapani Stipa and Susa Niiranen**



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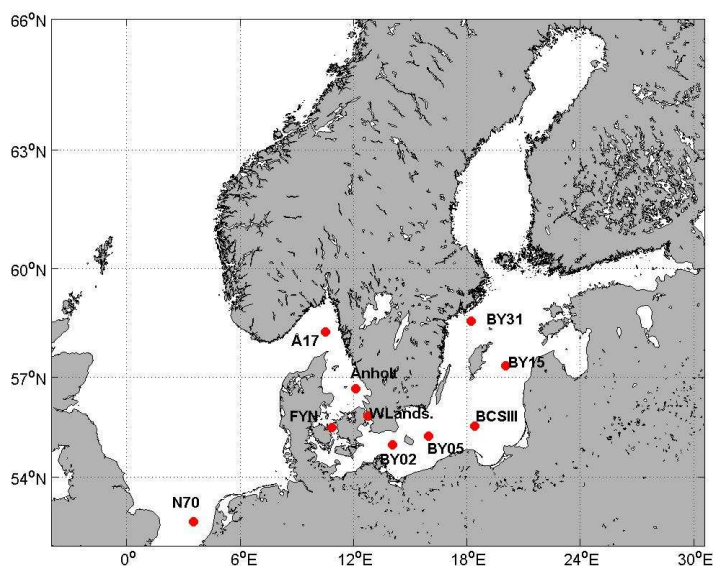


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# 1 Introduction

This is the third year joint status report for the North Sea, Skagerrak, Kattegat and the Baltic Sea area (Fig. 1) carried out by SMHI, IMR, DHI and FIMR as a part of the project BANSAL, supported by the Nordic Council of Ministers' Sea and Air Group. The aim of the demonstration project is to integrate marine observations and eutrophication model simulations in an annual eutrophication assessment of the Baltic and the North seas. The present report is mainly based on model estimates of some of the indicators suggested by the OSPAR Common Procedure (c.f. Appendix) for the identification of the eutrophication status of the maritime area (OSPAR, 2005). This report serve as a basis for the on-going discussions about the ecological quality indicators included in the assessment, and the way to merge results from different models and observations for the assessment.



*Fig. 1. A map of the North Sea and Baltic Sea area. Monitoring stations used for model validation are shown by red dots.*

Estimations of river discharges and model results are used to describe the degree of nutrient enrichment (Category I) defined by the riverine loadings of nitrogen and phosphorus, and winter surface concentrations and ratios of DIN and DIP. The direct effects of nutrient enrichment during the growing season (Category II) are described in terms of the mean and maximum chlorophyll-a concentrations and model estimations of primary production. The ratio between diatoms and flagellates is used as an indicator of region specific phytoplankton indicator species (Category II). The indirect effects of nutrient enrichment (Category III) are discussed in terms of oxygen depletion in bottom waters. Estimations of region specific background concentrations and threshold values are gathered from the literature (Helcom, 2006; OSPAR, 2005) and used for the model assessment.

The four model systems used for the joint assessment (Fig. 2) cover different parts of the North Sea, Skagerrak, Kattegat and the Baltic Sea area. Detailed descriptions of the models may be found on the web-sites presented below the figure.

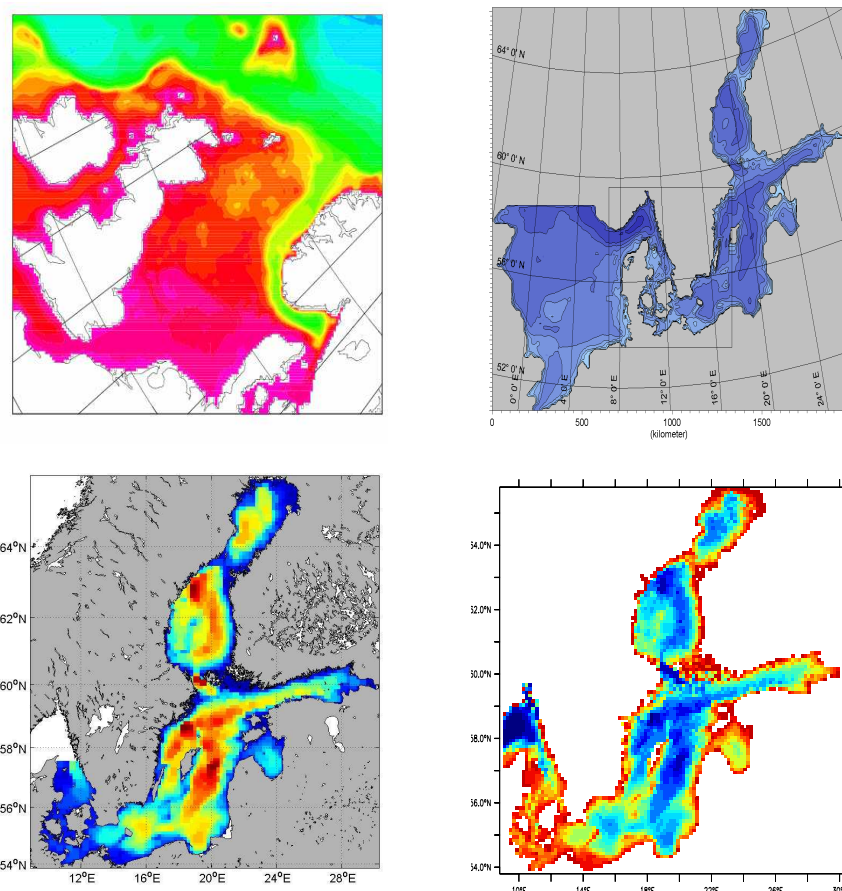


Fig. 2. Overview of model domains. The colors indicate depth ranges (not shown).

Top Left:	IMR – Norwecom model	( <a href="http://www.imr.no/~morten/norwecom">http://www.imr.no/~morten/norwecom</a> ).
TopRight:	DHI – Mike III model	( <a href="http://www.vandudsigten.dk/havmiljoe">http://www.vandudsigten.dk/havmiljoe</a> ).
Bottom Left:	SMHI – RcoScobi model	( <a href="http://www.smhi.se">http://www.smhi.se</a> )
Bottom Right:	FIMR- BalEco model	( <a href="http://www.fimr.fi">http://www.fimr.fi</a> )

In section 2 the key messages from this assessment will be presented. In section 3, each country gives a brief observations overview for 2006 and some references to other sources and reports that might be useful for the readers. The methods of the assessment are described in section 4. Statistical characteristics of model results and in-situ data are presented in section 5 and the model assessment of eutrophication status is done in section 6. Conclusions and comments to the assessment are presented in section 7.

## 2 Key messages

The report presents results obtained with a preliminary method of assessment in this demonstration project. The assessment results depend much on the threshold values used for the classification of eutrophication status.

The present assessment of the eutrophication status indicates that the entire southeastern part of the North Sea, the Kattegat, the Danish Straits, the Gulf of Finland and the Bay of Riga area as well as parts of the Arkona Basin, the Bornholm Basin and the Baltic Proper may be classified as problem areas. The Bothnian Bay and parts of the Baltic Proper, the Bornholm Basin and the Arkona Basin are classified as potential problem areas.

The elevated primary production seem to be the reason for the Gulf of Finland, Gulf of Riga, Danish Straits, Kattegat and at some of the river mouths being categorized as problem areas. In the North Sea, Bornholm Basin and the Baltic Proper the low bottom layer minimum oxygen concentration seem to be the reason.

## 3 Observations overview 2006

### 3.1 Sweden

The year 2006 was in general a warm year. However, the beginning of the year was cold, and the winter long, with low temperatures all the way through March. From June onwards the temperature was higher than normal for most of the time, with small exceptions in the fall. During this time period a majority of past temperature records were beaten and the average temperature was 1.8 °C above normal for the whole country (Karlström, 2007).

In Northern Sweden the runoff to the Bothnian Bay and Bothnian Sea during the winter was above normal. The springtime runoff was relatively moderate but in the summer the runoff was very low compared to average runoff from the period 1961-1990 (Fig. 3). In the southern Sweden the long and cold winter was a reason for the lower runoff to the Baltic Proper and to the Skagerrak and Kattegat in the beginning of the year. However, in the Baltic Proper the spring flood was as much as 30 % higher than the long time average (1961-1990). In the west of Sweden the runoff stayed high during the summer months. In November and December the precipitation was 15 % higher than normal in the whole Sweden, and consequently the runoff increased above the long time average, as can be seen in Fig. 3 (Jutman et al., 2007; Karlström, 2007).

A large bloom of cyanobacteria was observed in the Baltic Proper in the beginning of July. The bloom maximum was detected in the middle of July and was mainly observed in the southern parts of the Baltic. The bloom consisted mainly of *Nodularia spumigena* (Fig. 4), but also *Aphanizomenon* sp. and *Anabaena* spp. were present. The algae were also transported by currents to the Kattegat and could even be traced as far out as the Skagerrak. On the west coast, the spring bloom of silica containing algae was followed by a bloom of the harmful algae *Verrucophora farcimen* (previous name *Chattonella*). However, no toxic effects were observed in Swedish waters, but on the Danish east coast a fish in a fish farm got killed. Observations of some toxic producing algae as the dinoflagellate *Dinophysis* occurred, and the threshold for harvest mussels were exceeded at some places. Also the toxic producing algae *Alexandrium* spp. occurred in low concentrations, but no threshold value was exceeded.

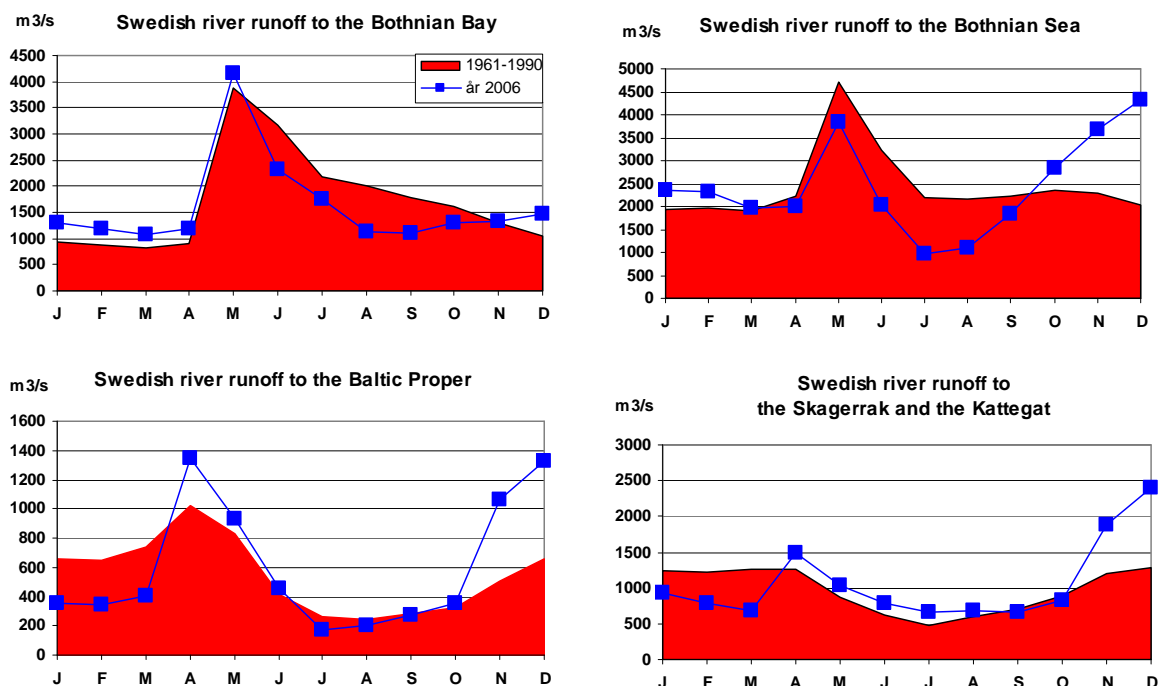


Fig. 3 Measured river runoff 2006 compared to long time average (Karlström, 2007).



Fig. 4. *Aphanizomenon* sp. to the left and *Nodularia spumigena* to the right. Photo: Ann-Turi Skjevik, SMHI.

The annual oceanographic report summarizing hydrographic and hydro chemical observations in the area and the monthly reports of the algal situations are available on the SMHI web-site: [http://www.smhi.se/oceanografi/oce\\_info\\_data/reports/aarsrapp/annual\\_sv.html](http://www.smhi.se/oceanografi/oce_info_data/reports/aarsrapp/annual_sv.html)

### 3.2 Norway

The year 2006 was as a whole the warmest year, ever together with 1934 and 1990 (1.8 °C above normal). For western Norway and Trondelag, the mean temperature was new record high. Only in the spring (March-May) the temperature was below normal (0.4 °C below). In

fall it was 2.2 °C above the normal, and in large areas of Southern Norway (especially along the coast), the fall was the warmest since 1867 (start of time series).

The average rainfall was 110% of the normal. The rain fall was relatively highest in Western Finnmark (150-175%), while Møre og Romsdal and Trøndelag only had 75-100% of the normal precipitation. The rainfall was lowest during summer (90%) and highest in the fall (120%) which is reflected in the river runoff (Fig. 5).

In the beginning of the year the temperature in the North Sea was 0.5-1.0 °C above the normal in most areas. A cold spring lowered the surface temperature, and the temperature was normal towards summer. However, an exceptionally warm summer and fall gave rise to temperatures of 2-4 °C above the normal during the second half of the year. Relatively highest temperatures were detected in southerly and easterly (Norwegian) areas. These were the highest temperatures observed since measurements started 100 years ago.

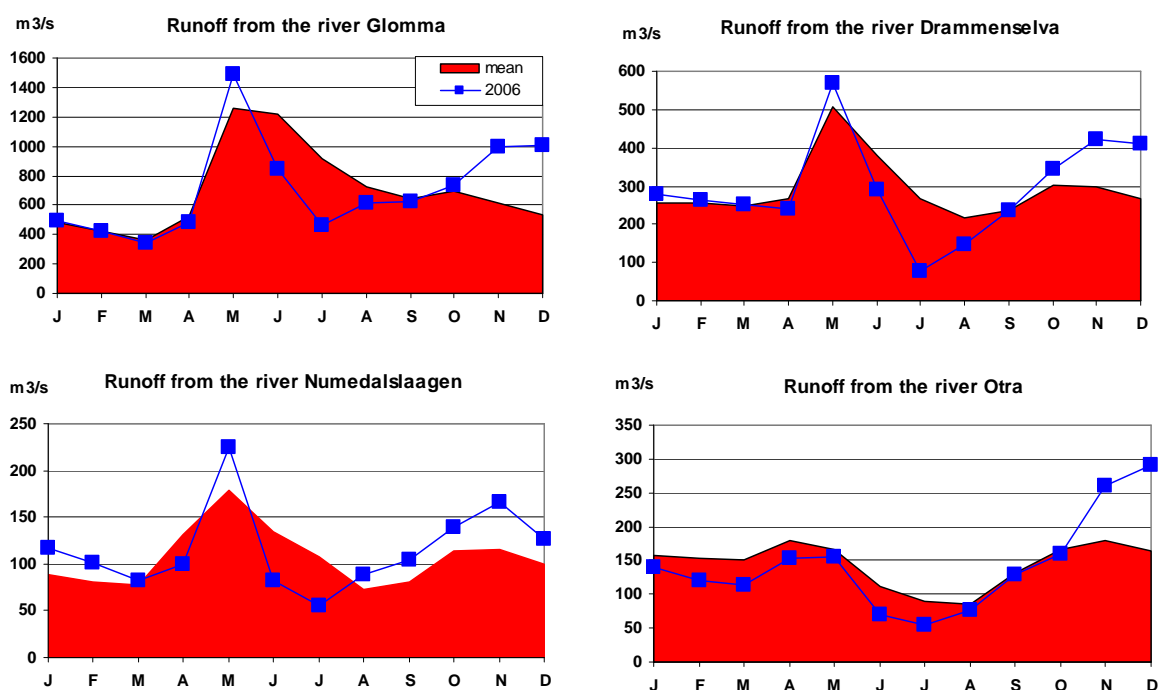


Fig. 5. Measured river runoff 2006 compared to long time average. River runoff data are from Norwegian Water Resources and Energy Directorate.

In Skagerrak the winter concentrations of inorganic nitrogen were low, both in the Norwegian and Danish part. This indicates a low inflow of water from the German Bight with the Jutland current. Also the N:P ratio in April was low compared to previous years (since 2000). The spring bloom in Skagerrak started approximately one month earlier than normal (see Fig. 6). Also, in 2006 the recruitment of many important North Sea fish stocks (sandeel, Norway pout, cod, haddock and herring) was unsuccessful. Further information and a better overview with detailed descriptions can be obtained from the web-site: [http://www.imr.no/produkter/publikasjoner/havets\\_ressurser/2007](http://www.imr.no/produkter/publikasjoner/havets_ressurser/2007).

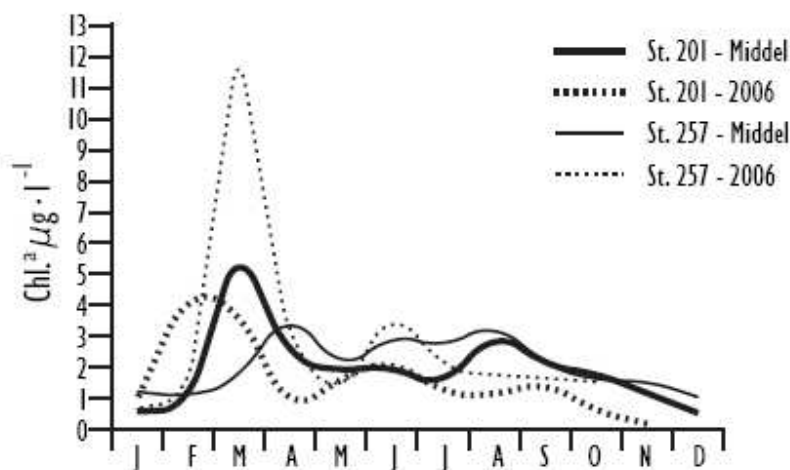


Fig. 6. Monthly means of chlorophyll-a in the upper 30m outside Torungen lighthouse near Arendal (station 201) and the upper 25m outside Hirthals (station 257) in 2006. Dotted lines show the value for 2006 and the solid lines show the long term mean for the period 1980-1995 (st.201) and 1988-1995 (st.257). For station 257 chlorophyll values are missing for november and december (from Naustvoll and Skogen, 2007).

### 3.3 Denmark

As shown in Fig. 7 the Danish runoff from the catchment area in 2006 varied around the long time average value for the period 1991-1998.

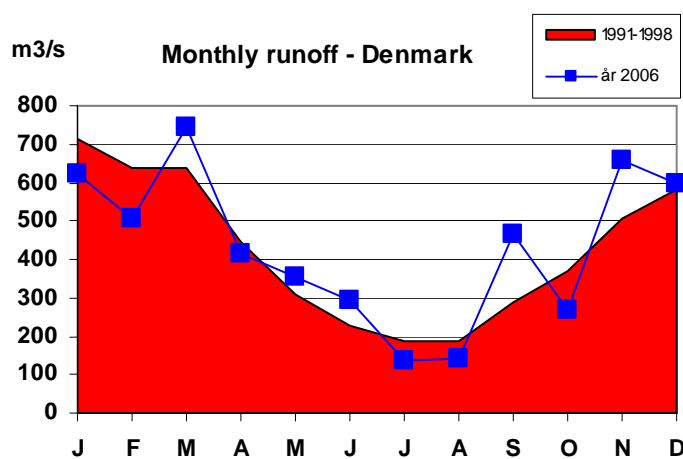


Fig. 7. Runoff from the Danish catchments compared to the long time average. Data from the Danish National Environmental Research Institute.

### 3.4 Finland

In Finland, year 2006 was warmer than long-term average. The mean air temperatures in Southern (Helsinki-Vantaa), Central (Jyväskylä) and Northern (Sodankylä) parts of the country were 6.1, 4.1 and 0.6 °C. This is 1.1, 1.2 and 1.4°C above the 30-year (1971-2000) average, respectively. The monthly mean temperatures were lower than the average in February and March, and above the average for the rest of the year. The greatest difference between the long-term monthly average and the monthly mean temperature in 2006 was detected in December in all parts of the country (Finnish Meteorological Institute).

The total rainfall in 2006 was, in general, lower than the average (1971-2000), so that in Southern Finland the rainfall was 558 mm (-92 mm), in Central Finland 508 mm (-130 mm) and in Northern Finland 408 mm (-99 mm). The month with the highest total rainfall was October in Southern and Central Finland, and September in Northern parts of the country. In comparison to the mean of the monthly averages from years 1971-2000, the decrease in rainfall was greatest during the summer months (Finnish Meteorological Institute).

Summer and autumn surface temperatures of Finland's adjacent sea areas (Gulf of Bothnia, Åland Sea, Northern Baltic Proper and the Gulf of Finland) were, in 2006, commonly above the average. These temperature values were exceptionally high during October in the Gulf of Bothnia, Åland Sea (2-3°C above the average) and Northern Baltic Proper (3°C above the average) and during the whole autumn (excluding mid-September and the beginning of November) in the coastal areas of the Gulf of Finland. In most areas, due to cold weather, the water temperature dropped down to an average level in November, but rose again (1-2°C above the average) in December (Olsonen, 2007).

The winter nutrient conditions of the Gulf of Bothnia and the Gulf of Finland, in 2006, were typical for the sea areas in question. In the Åland Sea the phosphate concentration was slightly above, and the nitrate+nitrite ( $\text{NO}_3+\text{NO}_2$ ) concentrations slightly below, the long-term average. In the Northern Baltic Proper, the phosphate concentration was on the same level as during the last decade, and the  $\text{NO}_3+\text{NO}_2$  concentration corresponded well with the observations from the last five-year period (Olsonen, 2007).

In 2006, the phytoplankton spring bloom peak was reached in early April, in both, the Gulf of Finland and the Northern Baltic Proper. The bloom was most intensive in the Gulf of Finland and the spring bloom maximum detected at the Northern Baltic Proper was only half the one in the previous. All in all, the intensity of the 2006 spring bloom was around the 1992-2005 average (Olsonen, 2007).

Cyanobacteria started to increase in the Northern Baltic Proper and the Gulf of Finland at the end of June. Despite the warm weather, only occasional cyanobacterial blooms were detected within the sea areas surrounding Finland before August, when cyanobacteria abundance increased especially in the Eastern Gulf of Finland. Small-scale cyanobacterial blooms were detected also in the Southern Bothnian Sea and the Archipelago Sea. The most abundant cyanobacterial species observed were non-toxic *Aphanizomenon flos-aquae* and potentially toxic *Anabaena* spp. (Olsonen, 2007).

## 4 Methods

For the evaluation of results the following definitions will be used.

1. Surface layer = Average for the depth interval 0-10m. For the model results we use the 5m model value to represent the surface layer.
2. Winter = Average for the period January-February
3. Summer (production period) = Average for the period March-October

Observational data for the period 2001-2006 from stations situated in the North Sea, Skagerrak, Kattegat, Great Belt, Öresund, Arkona Basin, Bornholm Basin, SE Gotland Basin, E Gotland Basin and N Gotland Basin (Fig. 1, Table 1) are used in the present comparison of model results and in-situ data. Mean values and standard deviation for a selected set of variables from the year 2006 are computed and compared to the 6 year average 2001-2006.

*Table 1. The stations used in the comparison of model results and in-situ data, their positions and the source from where the data is extracted.*

Sea Area	Station name	Latitude	Longitude	Data source
<b>North Sea:</b>	Noordwijk70	+ 52 35.1	+ 003 31.9	Dutch data, <a href="http://www.waterbase.nl">www.waterbase.nl</a>
<b>Skagerrak:</b>	Å17	+ 58 16.5	+ 010 30.8	SMHI database, SHARK
<b>Kattegat:</b>	Anholt East	+ 56 40.0	+ 012 07.0	SMHI database, SHARK
<b>Great Belt:</b>	FYN, 6700053	+ 55 30.5	+ 010 51.8	mads, <a href="http://www.dmu.dk">www.dmu.dk</a>
<b>Öresund:</b>	W Landskrona	+ 55 52.0	+ 012 45.0	SMHI database, SHARK
<b>Arkona basin:</b>	BY02	+ 55 00.0	+ 014 05.0	SMHI database, SHARK
<b>Bornholm basin:</b>	BY05	+ 55 15.0	+ 015 59.0	SMHI database, SHARK
<b>SE Gotland basin:</b>	BCS III-10	+ 55 33.3	+ 018 24.0	SMHI database, SHARK
<b>E Gotland basin:</b>	BY15	+ 57 20.0	+ 020 03.0	SMHI database, SHARK
<b>N Gotland basin:</b>	BY31	+ 58 35.0	+ 018 14.0	SMHI database, SHARK

The mean value (Mv) and standard deviation (Sd) of surface layer (0-10 m) winter time observations (January-February) for salinity (S), dissolved inorganic nitrogen and phosphorus (DIN and DIP), and the ratio DIN/DIP are computed. The Mv and Sd of chlorophyll-a (CHL) for the production period in the surface layer (0-10m) are from March-October. The Mv and Sd for the late summer lower layer dissolved oxygen concentrations (O<sub>2</sub>) are computed from a depth below 40 m at Anholt, W Landskrona and BY02, from 80 m at BCSIII-10, from 90 m at BY05, from 200 m at Å17 and BY15 and from 250 m at BY31 in the period August-September.

To compare the model results with observations we use a cost function ( $C_i$ ) which is computed from:

$$C_i = \left| \frac{M_i - D}{Sd} \right| \quad \text{Eq 1}$$

where  $C_i$  is the normalized deviation (in  $Sd$  units) between model results and in-situ data for the model  $i$ .  $M_i$  is the mean value of the 2006 model results for model  $i$  ( $i$ =IMR, DHI, SMHI or FIMR),  $D$  is the mean value of the 2006 in situ data, and  $Sd$  is the long term (2001-2006) standard deviation of the in situ data.

One may note that the value of  $C_i$  becomes large if the modeled mean value differs much from the mean value of the in situ data. The cost function may also obtain high values when the standard deviation is very small. Finally one should bear in mind that the model data are sampled every day while the sampling of in situ data may vary between variables and between different seasons and locations.

The following ranges are used for the interpretation of the cost function values of the models.

<b>Good</b>	$0 \leq C < 1$ std. deviations
<b>Reasonable</b>	$1 \leq C < 2$ std. deviations
<b>Poor</b>	$2 \leq C$ std. deviations

The following plots will be presented for all models.

1. Salinity (winter and summer surface layer average)
2. Winter surface layer average DIN, DIP ( $\mu\text{mol/l}$ ), and DIN/DIP ratio
3. Chlorophyll a summer surface layer average ( $\mu\text{g Chl/l}$ )
4. Annual surface layer chlorophyll a maximum ( $\mu\text{g Chl/l}$ )
5. Annual dissolved oxygen minimum at bottom layer ( $\text{ml/l}$ )
6. Annual integrated production of Diatoms/Non-Diatoms (carbon)
7. Annual integrated total production ( $\text{gCm}^{-2}\text{yr}^{-1}$ )

The average salinity from the models is computed and used as a reference for the area specific threshold values of ecological quality indicators. In the Skagerrak and North Sea only values from IMR and DHI were used. In the Kattegat are model values used from all models. In the Danish Straits and Öresund are model values only used from DHI, SMHI and FIMR. From the Baltic Sea only the SMHI and FIMR model values were used. The assessment areas with separate threshold values (Table 2) are described by colors and basin numbers (Bnr) in Fig. 8. Due to that models sometimes show somewhat different results at different areas a weighted average value is calculated and used in the assessment.

The weighted average value between models is computed (Eq 2.) for all the variables used for the assessment, except for the lower layer oxygen minimum concentrations. For this variable the minimum value from the models are used instead.

Since the accuracy of models differs between parameters and areas (Table 5), weighted average values of the models have been used to calculate the environmental assessments. The weighted average value between the models is defined as:

$$ModelAverage = C \cdot \sum_{i=1}^4 \left( \frac{1}{C_i + 0.1} \cdot M_i \right) \quad Eq 2$$

where  $M_i$  is the value from model  $i$  and  $C_i$  is the cost function value (Table 5) for model  $i$  and  $C$  is defined as:

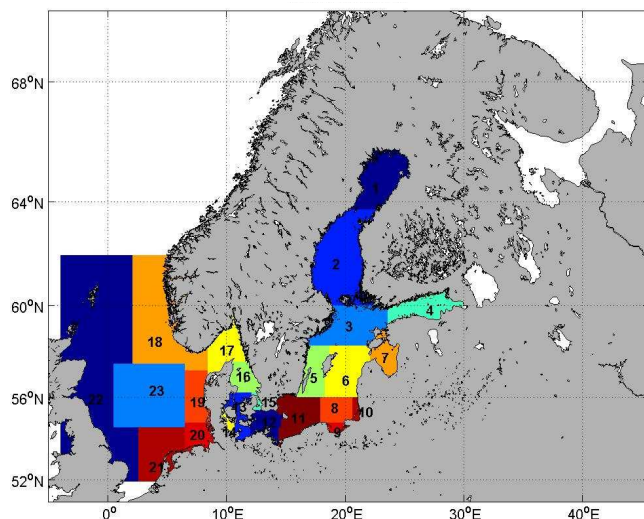
$$C = \frac{1}{\sum_{i=1}^4 W_i} \quad Eq 3$$

Where  $W_i$  is the weight for the model  $i$  and defined as:

$$W_i = \frac{1}{C_i + 0.1} \quad Eq 4$$

The weighted average value was calculated for all assessment parameters and areas except for the lower layer dissolved oxygen minimum concentration. For this value the minimum value from the

different models was used. In areas where no observations, and therefore no cost function values could be calculated, a simple average between the models is used.



*Fig. 8. The North Sea, Skagerrak, Kattegat and the Baltic Sea are divided into 23 sub-basins with separate threshold values for the ecological quality indicators. Areas in each basin have same assessment threshold values. Areas west of Great Britain are not included in the assessment.*

The reference and threshold values for the Baltic Sea, the Danish Straits, the Öresund and the Kattegat are from the Helcom (2006) report. For Skagerrak and the North Sea the reference values and threshold values are from the OSPAR (2005) report. For the N/P reference value the Redfield ratio was used and the threshold value was taken from Table A1 in Appendix and is used in all basins. The threshold values were calculated by multiplying the reference value with 1.5 when only reference values were available. Reference values of DIN and DIP for the central North Sea are from QSR (1993). The assessments of the eutrophication status in the different basins in the model area are mainly based on the procedure suggested by the OSPAR Common Procedure (c.f. Appendix). However, the Helcom (2006) classification is used for the oxygen status.

Table 2. Reference values and threshold values used in the present report with origin from Helcom (2006) and OSPAR (2005).

Basin Nr.	Basin Names	Salinity range psu	DIN	DIP	N/P	CHL	DIN	DIP	N/P	CHL
			Winter ref. value μmol/l	Winter ref. value μmol/l	Winter Ref. value -	Summer ref. value μg/l	Winter thres. value μmol/l	Winter thres. value μmol/l	Winter thres. value -	Summer thres. value μg/l
1	Bothnian Bay	>0	3.50	0.10	16.00	1.00	5.25	0.15	24.0	1.50
2	Bothnian Sea	>0	2.00	0.20	16.00	1.00	3.00	0.30	24.0	1.50
3	N. Gotland Basin	>0	2.00	0.25	16.00	1.00	3.00	0.38	24.0	1.50
4	Gulf of Finland	>0	2.50	0.30	16.00	1.20	3.75	0.45	24.0	1.80
5	W. Gotland Basin	>0	2.00	0.25	16.00	1.00	3.00	0.38	24.0	1.50
6	E. Gotland	>0	2.29	0.35	-	1.90	3.44	0.53	24.0	2.85
7	Gulf of Riga	>0	6.50	0.40	16.00	2.00	9.75	0.60	24.0	3.00
8	Gulf of Riga	>0	4.00	0.13	16.00	1.10	6.00	0.20	24.0	1.65
9	SE. Gotland B	>0	2.50	0.6	10.00	-	3.75	0.90	15.0	2.85
10	Gdansk deep	>0	4.25	0.25	17.00	-	6.38	0.38	25.5	4.50
11	Lithuanian water	>0	5.00	0.30	16.00	3.00	7.50	0.45	24.0	4.50
12	Bornholm basin	>0	1.70	0.34	-	1.90	2.55	0.44	24.0	2.85
13	Arkona Basin	>0	2.44	0.29	-	1.90	3.66	0.44	24.0	2.85
14	Danish straits	>0	2.10	0.52	-	1.20	2.63	0.65	24.0	1.50
15	Danish straits	>0	1.25	0.48	-	0.90	1.56	0.60	24.0	1.13
16	Oeresund	>0	-	-	-	1.70	1.56	0.60	24.0	2.13
17	Kattegat	>0	4.50	0.40	11.25	1.25	5.63	0.50	14.0	1.56
18	Skagerrak	>0	10.00	0.60	16.00	1.50	15.00	0.90	25.0	2.00
19	North SeaNE	>0	-	0.60	16.00	3.00	13.50	0.80	25.0	4.50
20	North Sea Denmark	< 34.5	15.00	0.60	16.00	6.00	26.00	0.80	25.0	9.00
20	North Sea Denmark	>= 34.5	10.00	0.65	16.00	3.00	12.50	0.80	25.0	4.50
21	North Sea SE	< 34.5	12.50	0.55	16.00	3.00	19.00	0.83	25.0	4.50
21	North Sea SE	>= 34.5	8.50	0.60	16.00	2.00	13.00	0.90	25.0	3.00
22	North Sea SV	< 34.5	19.00	0.60	16.00	10.00	28.50	0.80	25.0	15.00
22	North Sea SV	>= 34.5	-	-	16.00	3.00	15.00	0.80	25.0	4.50
23	North Sea V	< 34.5	15.50	0.80	16.00	10.00	21.00	1.20	25.0	20.00
23	North Sea V	>=34.5	10.00	0.80	16.00	7.50	15.00	1.20	25.0	10.00
24	North SeaC	> 0	8.00	0.60	16.00	-	12.00	0.90	25.0	10.00

## 5 Comparison to in-situ data

In-situ data from 2006 indicate lower concentrations of winter DIN, DIP and DIN to DIP ratios in all the studied sea areas relative to the 6 year average. The summer chlorophyll concentrations in 2006 are on the same level as the average value or a little less. The lower layer oxygen concentrations were improved in the Kattegat, Danish Straits, Öresund, Arkona and Bornholm Basins relative to the 6 year average (Table 3).

The model results from 2006 (Table 4) indicate reasonable or good cost function values for most variables (Table 5) except for a poor description of lower layer oxygen concentrations at almost all stations except for at the stations in the Baltic Sea (SMHI). The model results show also poor result for salinity in the Baltic Sea (SMHI) and in the North Sea (DHI, IMR). The cost function results are shown in Table 5. The model results in Skagerrak and Kattegat area in the SMHI model and FIMR model are affected by the open boundary.

Table 3. Observations from 2006 (above) and from 2001 to 2006 (below). Mean values (Mv) and standard deviations (Sd) of surface layer winter concentrations of S, DIN ( $\mu\text{mol/l}$ ), DIP ( $\mu\text{mol/l}$ ), DIN/DIP ratio, the production period CHL ( $\mu\text{g/l}$ ) and the lower layer mean O<sub>2</sub> (ml/l).

Observations		DIN		DIP		N/P		CHL		O <sub>2</sub>		S	
Period	Station:	Mv	Sd	Mv	Sd	Mv	Sd	Mv	Sd	Mv	Sd	Mv	Sd
2006	N70	3.94	0.90	0.37	0.05	10.60	2.40	2.03	0.88	-	-	35.16	0.05
	Å17	3.86	2.85	0.36	0.16	8.55	5.76	0.74	0.57	5.52	0.12	31.28	3.92
	Anholt	1.27	1.04	0.43	0.17	2.49	1.50	1.51	1.24	3.37	0.60	19.29	0.88
	Great Belt	6.60	1.70	0.65	0.14	-	-	3.20	1.20	3.20	1.00	-	-
	W Landskrona	4.10	1.38	0.76	0.08	5.35	1.44	2.50	3.52	3.34	0.57	13.00	7.29
	BY02	2.56	0.04	0.77	0.01	3.31	0.05	2.16	1.35	3.68	1.02	7.98	0.004
	BY05	1.98	0.02	0.75	0.01	2.63	0.03	2.09	1.24	0.65	0.96	7.36	0.002
	BCSIII	2.12	0.01	0.59	0.01	3.61	0.03	2.43	1.45	1.83	1.05	7.33	0.001
	BY15	2.21	0.02	0.62	0.01	3.55	0.04	2.47	0.99	-2.13	0.23	7.44	0.003
	BY31	3.04	0.07	0.69	0.01	4.43	0.07	2.31	1.16	-0.59	0.09	6.92	0.001
2001-2006	N70	7.30	2.70	0.44	0.09	16.10	4.50	2.88	2.40	-	-	35.04	0.21
	Å17	6.40	1.91	0.49	0.09	12.47	3.56	0.73	0.51	5.64	0.18	32.47	2.05
	Anholt	5.28	2.17	0.49	0.14	10.58	3.62	1.99	2.11	3.21	0.68	22.82	3.06
	Great Belt	6.40	1.70	0.63	0.13	-	-	3.20	1.20	3.20	1.00	-	-
	W Landskrona	5.46	1.66	0.63	0.14	9.36	3.86	2.25	2.77	2.70	0.91	13.30	6.68
	BY02	3.53	1.08	0.59	0.14	6.30	1.99	2.44	1.17	3.66	0.91	7.92	0.30
	BY05	2.98	0.72	0.63	0.15	4.99	1.56	2.47	1.41	-0.29	1.85	7.35	0.24
	BCSIII	3.18	0.62	0.66	0.21	5.11	1.40	2.93	1.55	2.42	1.33	7.23	0.16
	BY15	3.17	0.53	0.64	0.16	5.32	1.74	3.30	1.88	-1.26	2.24	7.22	0.17
	BY31	3.70	0.45	0.69	0.17	5.90	2.44	2.57	1.56	-0.31	0.38	6.66	0.29

Table 4. Model results from the IMR, DHI, SMHI and FIMR models in year 2006, mean values. See definitions of the variables in Table 3.

Model Station:	2006 Year	DIN	DIP	N/P	Chl	O2	S
N70	DHI	7.00	0.60	12.6	5.90	3.63	34.60
	IMR	5.10	0.40	12.8	1.20	5.43	34.30
Å17	DHI	7.70	0.60	14.1	4.50	5.73	28.80
	IMR	10.5	0.50	21.0	0.70	6.19	29.70
	FIMR	3.77	0.72	5.23	1.45	-	24.19
Anholt	DHI	5.60	0.40	12.8	2.30	4.48	18.60
	IMR	7.30	0.40	18.3	0.50	5.67	23.80
	SMHI	1.76	0.41	4.33	2.32	8.50	16.20
	FIMR	3.64	0.67	5.41	1.75	-	17.08
GreatBelt	DHI	5.80	0.50	11.3	2.70	4.06	15.30
	IMR	5.70	0.60	9.50	1.20	6.12	14.10
	SMHI	1.92	0.43	4.49	2.61	6.11	16.73
	FIMR	3.81	0.68	5.64	1.81	-	12.70
Wlanskrona	DHI	7.10	0.60	12.5	3.90	2.66	11.80
	SMHI	1.68	0.45	3.76	2.80	7.46	11.33
	FIMR	3.40	0.66	5.12	1.83	-	10.16
BY02	DHI	7.70	0.50	14.2	3.10	2.94	7.40
	SMHI	1.30	0.52	2.47	2.16	6.65	7.37
	FIMR	2.75	0.62	4.46	1.81	-	8.08
BY05	SMHI	2.42	0.59	4.09	1.67	3.27	6.50
	FIMR	2.60	0.65	4.00	1.77	-	7.68
BCSIII	SMHI	2.37	0.56	4.20	1.54	6.71	6.69
	FIMR	3.08	0.58	5.28	1.67	-	7.45
BY15	SMHI	2.42	0.59	4.12	1.57	-1.39	6.76
	FIMR	3.11	0.48	7.29	1.56	-	6.50
BY31	SMHI	2.65	0.50	5.31	1.57	-1.19	5.98
	FIMR	3.66	0.48	7.66	1.13	-	6.68

Table 5. Cost function value ( $C_i$ ) of year 2006. Upper, middle and lower rows shows the  $C$  value when available for the IMR, SMHI and DHI models, respectively. See definitions of the variables in Table 3.

Model CF Station:	2006 Year	DIN	DIP	N/P	ChI	O2	S
N70	DHI	1.13	2.56	0.44	1.61	-	2.67
	IMR	0.43	0.33	0.48	0.35	-	4.10
Å17	DHI	2.01	2.61	1.56	7.32	1.20	1.20
	IMR	3.47	1.51	3.50	0.08	3.77	0.77
	FIMR	0.05	3.95	0.93	1.39	-	3.45
Anholt	DHI	1.99	0.20	2.85	0.38	1.62	0.22
	IMR	2.77	0.20	4.35	0.48	3.36	1.47
	SMHI	0.22	0.16	0.51	0.39	7.50	1.01
	FIMR	1.09	1.79	0.81	0.11	-	0.72
GreatBelt	DHI	0.47	1.15	-	0.42	0.86	-
	IMR	0.53	0.38	-	1.67	2.92	-
	SMHI	2.75	1.71	-	0.49	2.91	-
	FIMR	1.64	0.20	-	1.16	-	-
Wlanskrona	DHI	1.81	1.12	1.85	0.50	0.75	0.18
	SMHI	1.46	2.18	0.41	0.11	4.54	0.25
	FIMR	0.42	0.67	0.06	0.24	-	0.42
BY02	DHI	4.78	1.90	5.47	0.80	0.81	1.93
	SMHI	1.18	1.73	0.42	0.004	3.28	2.03
	FIMR	0.17	1.09	0.58	0.30	-	0.32
BY05	SMHI	0.60	1.07	0.93	0.30	1.42	3.61
	FIMR	0.85	0.68	0.88	0.23	-	1.33
BCSIII	SMHI	0.41	0.11	0.42	0.57	3.68	3.91
	FIMR	1.55	0.02	1.19	0.49	-	0.72
BY15	SMHI	0.39	0.22	0.33	0.48	0.33	4.09
	FIMR	1.68	0.89	2.15	0.48	-	5.65
BY31	SMHI	0.88	1.10	0.36	0.47	1.56	3.21
	FIMR	1.39	1.22	1.32	0.76	-	0.83

## 6 Model assessment

The model results for the variables used in the assessment of ecological quality indicators are presented here. The weighted average values of the variables computed from the model results using the cost function values (eq. 1, 2, 3, 4) are used for the classification of the eutrophication status according to the threshold values (Table 2) valid for each area (Fig. 8). Where possible, the results of the assessments are presented.

### 6.1 Winter situation

#### 6.1.1 Salinity

The average wintertime surface layer salinity (Fig. 9) shows increasing concentrations from the Northern Bothnian Sea and Eastern Gulf of Finland, where the salinity is close to 0, to the central North Sea where the salinity is about 35 in. Both the IMR and DHI models show the fresher water coming from the southern North Sea via the Jutland Coastal current, before it is mixed with the low salinity water coming from the Kattegat and forms the Norwegian Coastal current. The salinity in Skagerrak is underestimated by the FIMR model, while the IMR and DHI models simulate it good and reasonably, respectively, according to the cost function values.

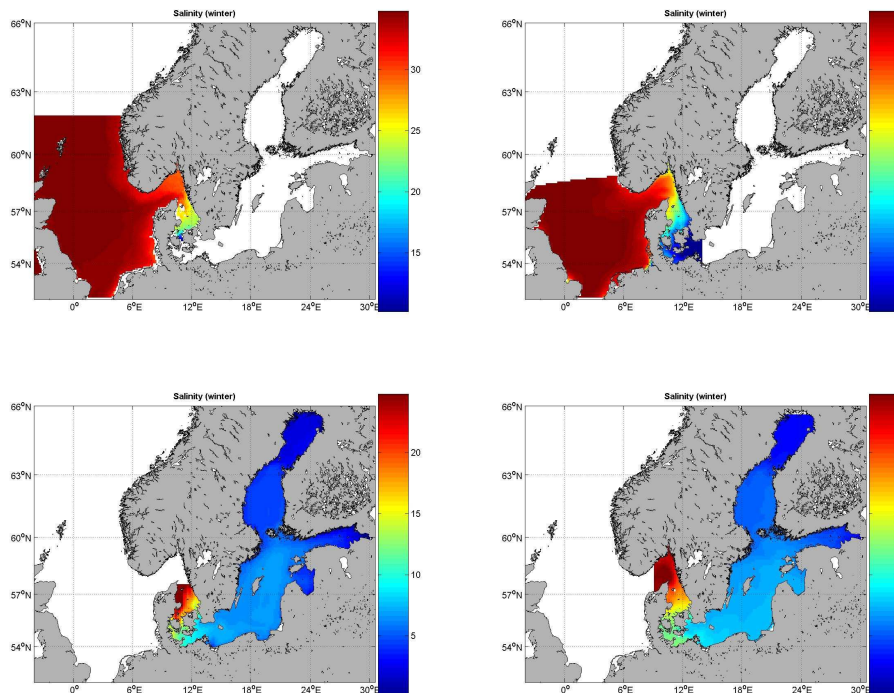


Fig. 9. Winter average surface layer salinity. Observe that the scales differs; in the upper figures the scale goes from 10 to 35 and in the lower figures the scale goes from 0 to 25. Upper Left: IMR, Upper Right: DHI, Lower Left: SMHI and Lower Right: FIMR.

### 6.1.2 DIP

The average wintertime surface layer DIP (Fig. 10) in general shows values below 1  $\mu\text{molP/l}$ . The highest concentrations are found in the western North Sea in the DHI model, along the Danish west-coast in the IMR model, at the river mouths in the Baltic Sea and in the central Baltic Proper in the SMHI model and in the eastern Gulf of Finland in the FIMR model. According to the cost function and the in-situ data it seems that the DHI model overestimates the DIP concentrations in the Skagerrak and North Sea while the IMR model show reasonable and good results, respectively. The FIMR model seems to overestimate the DIP in both Skagerrak and in Kattegat. The other models show good results in the Kattegat according to the cost function values, and all models seems to show good or reasonably good results in the Great Belt. The SMHI and the FIMR models simulate the DIP concentrations reasonably or good in southern Baltic Sea and the Baltic Proper.

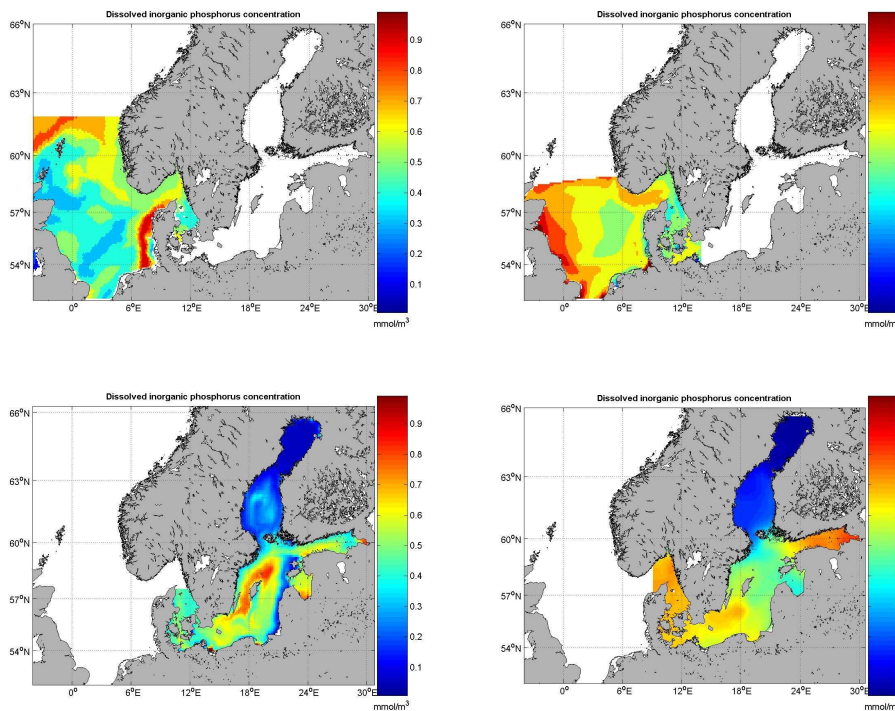


Fig. 10. Winter average surface layer DIP ( $\mu\text{molP/l}$ ). Upper Left: IMR, Upper Right: DHI, Lower Left: SMHI and Lower Right: FIMR.

### 6.1.3 DIN

The average wintertime surface layer DIN (Fig. 11) in general shows values below  $15 \mu\text{molN/l}$ . The highest concentrations are found in the western North Sea, along the continental coast and the Danish west-coast (IMR, DHI) and at river mouths in the Baltic Sea (SMHI). There is a clear discrepancy between all the models concerning the Kattegat. In the southern North Sea the IMR and the DHI model are good and reasonable, respectively according to the cost function and in-situ data. In the Skagerrak both the IMR and DHI models overestimates the DIN values meanwhile the FIMR model show good results. In Kattegat it seems that the IMR, DHI and FIMR models may overestimate the DIN concentrations mean while SMHI model shows good result. In the Great Belt on the other hand all models somewhat under estimates the DIN value, however, the IMR and DHI show good results, the FIMR model reasonable good and SMHI under estimates too much and show poor result. In the southern and Baltic Sea and in the Baltic Proper the SMHI and the FIMR models show good or reasonably good results.

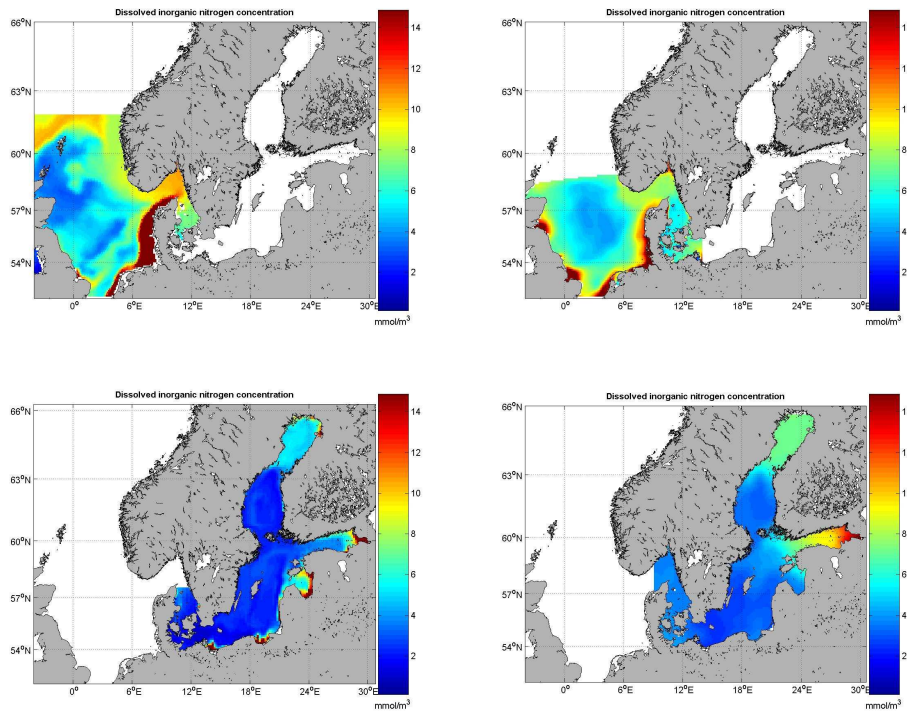


Fig. 11. Winter average surface layer DIN ( $\mu\text{molN/l}$ ). Upper Left: IMR, Upper Right: DHI, Lower Left: SMHI and Lower Right: FIMR.

#### 6.1.4 DIN to DIP ratio

The average wintertime surface layer DIN/DIP ratio (Fig. 12) in general shows values below 16 (Redfield molar ratio). Higher values are found at the rivers in Kattegat and Skagerrak in the IMR model, and along the continental coast and the Danish west-coast in the IMR and DHI models. There is a clear difference between the IMR, DHI and SMHI-FIMR models concerning the Kattegat. According to the cost function and the in-situ data it seems that the IMR and DHI models may overestimate the DIN/DIP ratio in this area, however, the DHI model not as much as the IMR model. The DHI, SMHI and FIMR models seem to show good results in the southern Baltic Sea and Baltic Proper, however, the DIN/DIP ratio seems to be overestimated by the DHI model in the Arkona basin and by the FIMR model in the Baltic Proper.

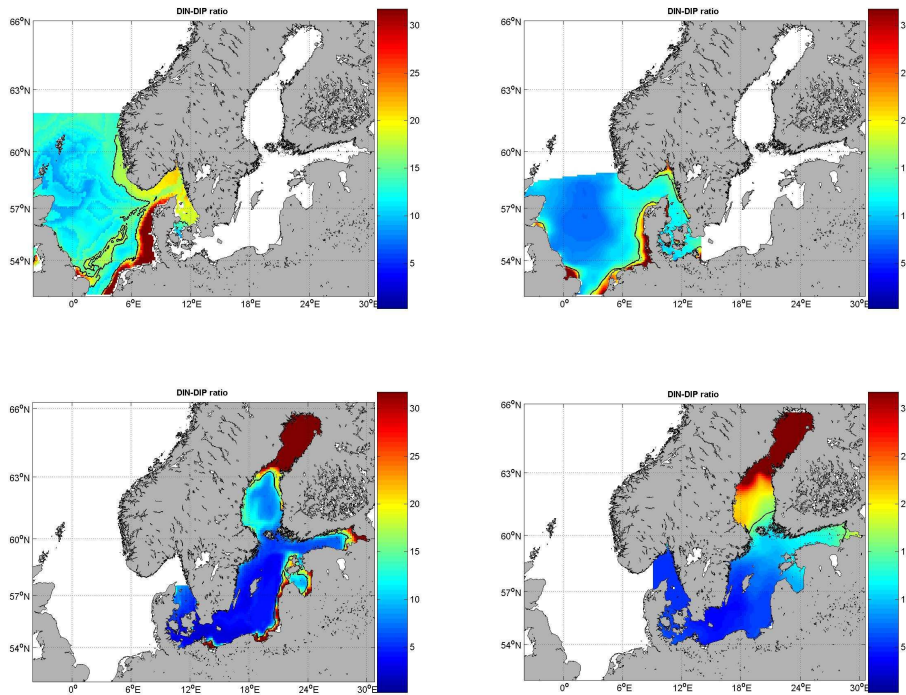


Fig. 12. Winter average surface layer DIN to DIP ratio. The contour line indicates the isoline of the Redfield molar ratio (16). Upper Left: IMR, Upper Right: DHI, Lower Left: SMHI and Lower Right: FIMR.

## 6.2 Summer situation

### 6.2.1 Salinity

The average summertime surface layer salinity (Fig. 13) shows increasing concentrations from the Northern Bothnian Sea and Eastern Gulf of Finland, where the salinity is close to 0, to the central North Sea where the salinity is about 35 in. Both the IMR and DHI models show the fresher water coming from the southern North Sea via the Jutland Coastal current, before it is mixed with the low salinity water coming from the Kattegat and forms the Norwegian Coastal current. The salinity is lower in the eastern North Sea in the IMR and DHI models during summer compared to winter values (Fig. 9), probably due to a somewhat higher river runoff. The salinity in Skagerrak is underestimated by the FIMR model, while the IMR and DHI models simulate it good and reasonably, respectively, according to the cost function values.

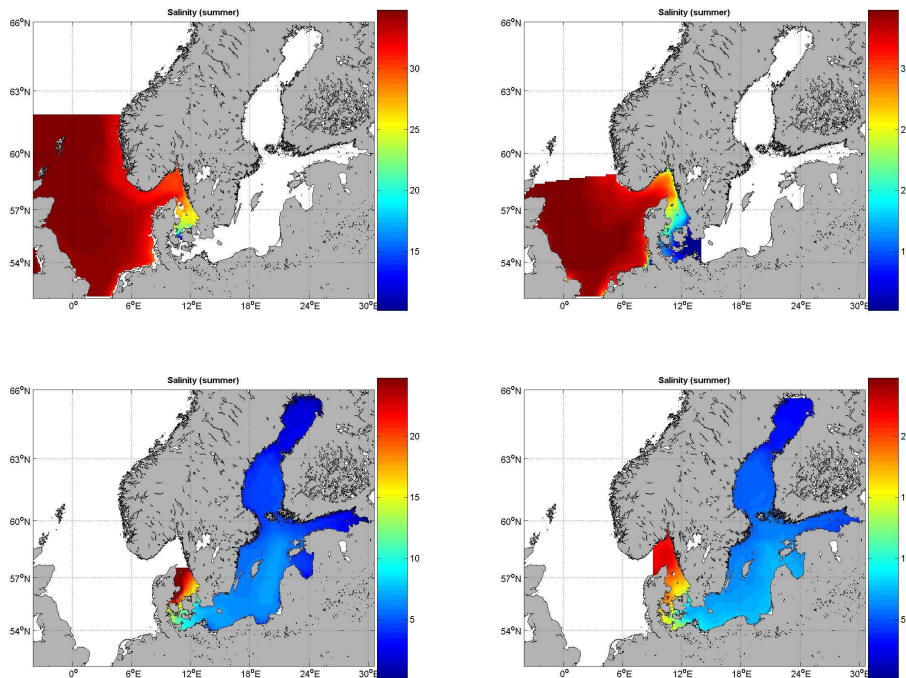


Fig. 13. Summer average surface layer salinity (psu). Observe that the scales differs; in the upper figures the scale goes from 10 to 35 and in the lower figures the scale goes from 0 to 25. Upper Left: IMR, Upper Right: DHI, Lower Left: SMHI and Lower Right: FIMR.

### 6.2.2 Chlorophyll-a

The average summertime surface layer chlorophyll-a (Fig. 14) shows clear discrepancy between the models. Highest values are simulated at the coasts of the North Sea and at the river mouths in the Baltic Sea. The majority of the Baltic Sea, the Kattegat and the central North Sea show lower concentrations. According to the cost function and the in-situ data it seems that the IMR model results are good, but in the low-end of the chlorophyll-a concentration. The DHI model results are too high and categorized as reasonable to bad in the North Sea and the Skagerrak, but show good results in the Kattegat, Danish Straits, Öresund and Bornholm Basin. The SMHI and the FIMR model show good results in the Southern Baltic Sea and in the Baltic proper.

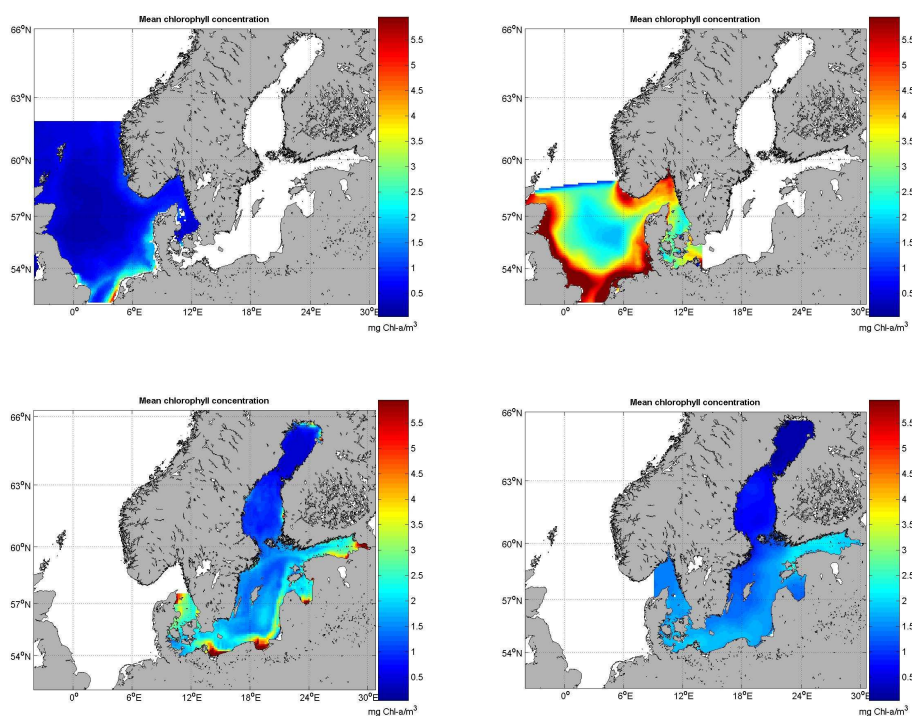


Fig. 14. Summer average surface layer chlorophyll-a ( $\mu\text{g/l}$ ). Upper Left: IMR, Upper Right: DHI, Lower Left: SMHI and Lower Right: FIMR.

### 6.3 Oxygen conditions

The annual bottom layer oxygen minimum (Fig. 15) in general shows lowest values ( $< 0$  ml/l) in the Baltic Proper. There is a clear discrepancy between the IMR and DHI models in the North Sea and Skagerrak. According to the cost function and the in-situ data it seems that the bottom layer oxygen concentrations in the Skagerrak and Kattegat, are overestimated by the IMR model and the DHI model which show poor and reasonably results, respectively. In the Great Belt, Öresund, Danish Straits and the Arkona Basin the DHI model show good results while the SMHI model overestimates the bottom layer oxygen concentrations and show poor results. In the Kattegat, Bornholm Basin, and Baltic Proper SMHI show poor or reasonably results, except for in East Baltic Proper where the model results are good.

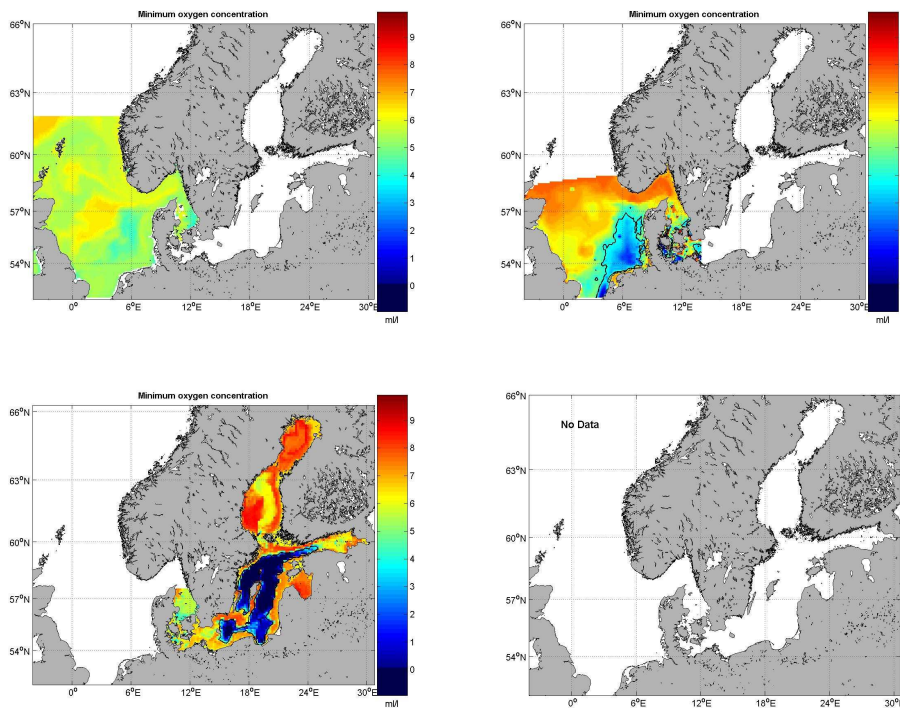


Fig. 15. Annual bottom layer dissolved oxygen minimum concentration (ml/l). Upper Left: IMR, Upper Right: DHI, Lower Left: SMHI and Lower Right: FIMR.

## 6.4 Primary production

The vertically integrated annual primary production (Fig. 16) in general shows highest values along the eastern and southern parts of the North Sea. In the south eastern parts of the North Sea the production exceeds  $350 \text{ gCm}^{-2}\text{yr}^{-1}$  while the production in Skagerrak exceeds  $150 \text{ gCm}^{-2}\text{yr}^{-1}$ . The central parts of the North Sea show the lowest production but with clear differences between the models. The difference between the results of the IMR and DHI models, in general, follows the patterns of summertime average chlorophyll-a (Fig. 14).

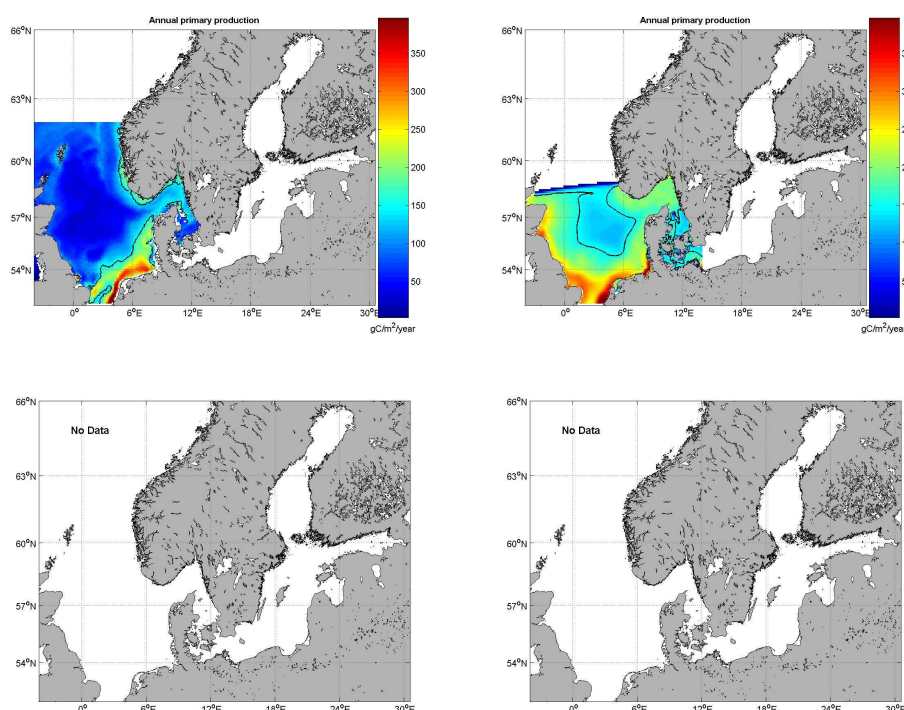


Fig. 16. Annual primary production ( $\text{gCm}^{-2}\text{yr}^{-1}$ ). The contour line indicates the  $150 \text{ gCm}^{-2}\text{yr}^{-1}$  isoline. Upper Left: IMR, Upper Right: DHI, Lower Left: SMHI and Lower Right: FIMR.

## 6.5 Maximum chlorophyll-a

The maximum annual surface layer chlorophyll-a (Fig. 17) follows closely the patterns of summertime average chlorophyll-a (Fig. 14). There is a clear discrepancy between the IMR and DHI models in the North Sea. The discrepancy is also clear between the DHI model and the other models in the Skagerrak and in the Kattegat, the maximum chlorophyll-a concentration of the DHI model results are generally much higher. For this report, no in-situ data were available for comparison.

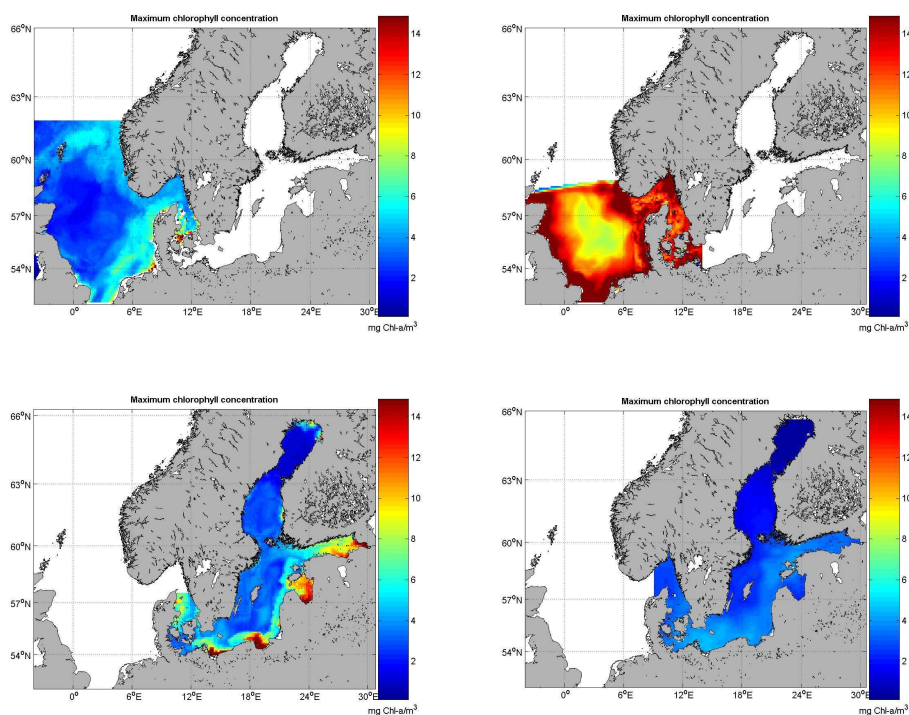


Fig. 17. Maximum annual surface layer chlorophyll-a concentrations ( $\mu\text{g/l}$ ). Upper Left: IMR, Upper Right: DHI, Lower Left: SMHI and Lower Right: FIMR.

## 6.6 Diatoms to Non-Diatoms production ratio

The vertically integrated annual primary production of diatoms relative to non-diatoms (Fig. 18) shows that in general non-diatoms dominate the total phytoplankton biomass. Diatom production is larger mainly in some local areas in the Kattegat, in the southern North Sea and in the northern Atlantic waters. There is also an indication of enhanced production of diatoms at the Norwegian coast and in the frontal areas between coastal waters and central North Sea and Skagerrak waters.

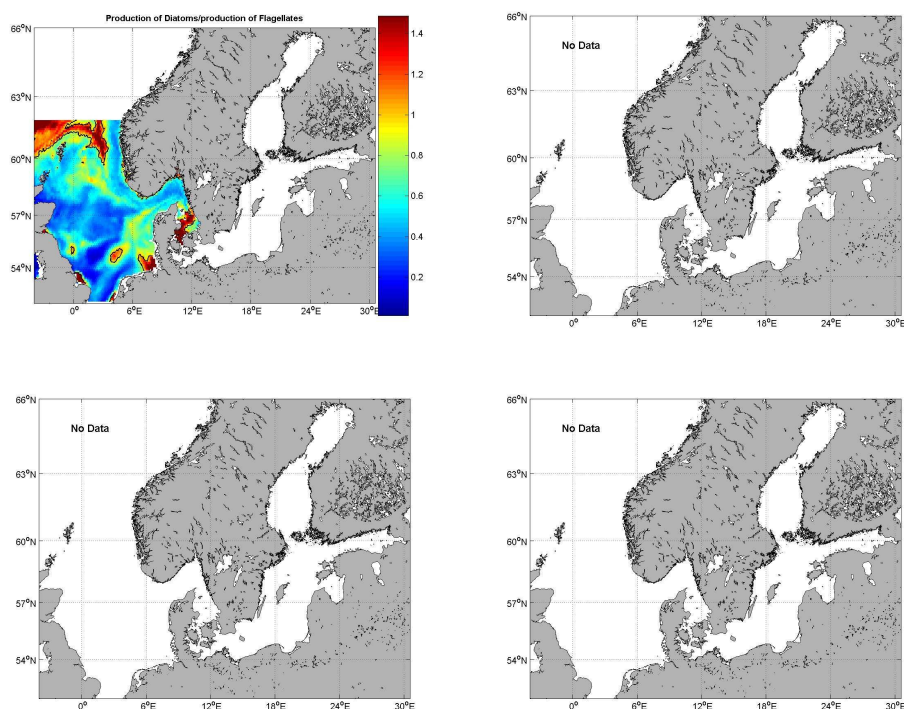


Fig. 18. The ratio of annual production of diatoms to non-diatoms. The contour line indicates the isoline of equal production (ratio=1). Upper Left: IMR, Upper Right: DHI, Lower Left: SMHI and Lower Right: FIMR.

## 6.7 Eutrophication status

The assessment of eutrophication status according to the threshold values for winter DIN and DIP (causative factors) are shown in Fig. 19. The assessment indicates elevated levels of DIP in large parts of the Baltic Proper, the Riga Bay and in the Gulf of Finland. For DIN elevated levels are indicated at some coastal regions of the southern North Sea, in the Danish Straits, in the eastern and north Baltic Proper, in the Gulf of Finland, in the Bothnian Bay and along the coasts in the Riga Bay and in the Bothnian Sea. The N/P ratio (Fig. 20) show higher values along the southern coasts of the North Sea, in the Bothnian Bay, in the easternmost Gulf of Finland and along the coastal area of the east Baltic Proper.

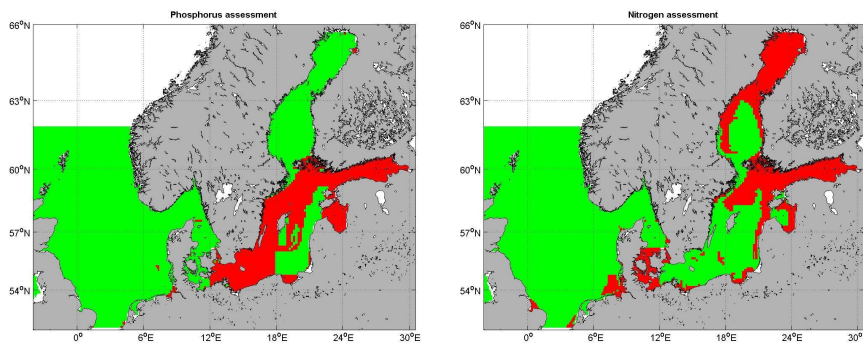


Fig. 19. Assessment results of DIP (left) and DIN (right). The assessment levels are indicated by colors, green (good), red (bad).

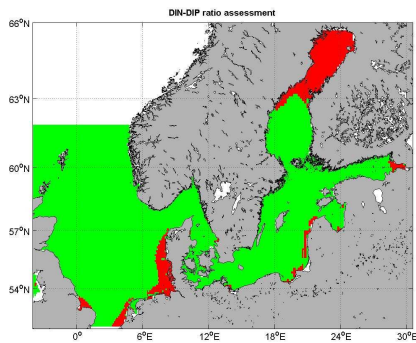


Fig. 20. Assessment results of the DIN/DIP ratio. The assessment levels are indicated by colors, green (good), red (bad).

The assessment of eutrophication status according to the threshold values for summer chlorophyll-a concentrations (direct effects) (Fig. 21; left) indicates elevated levels in the river mouths areas in the southeastern North Sea and in the Baltic Sea and in the whole Kattegat, the Danish straits, Riga Bay and the Gulf of Finland, and in small areas south of Gotland and east of Öland.

The assessment of eutrophication status according to the annual minimum oxygen concentrations (indirect effects) (Fig. 21; right) indicates decreased oxygen levels ( $O_2 < 2.8$  ml/l) in large parts of the eastern North Sea and at some locations in the southern Baltic Sea. Toxic levels ( $O_2 < 1.4$  ml/l) are found in the southeastern North Sea, in the Bornholm Basin and in the Baltic Proper. Also some local areas in the Danish straits show toxic levels in the oxygen concentrations.

There is a lack of reference values for an assessment of the eutrophication status for primary production, maximum chlorophyll-a and diatoms to non-diatoms ratio.

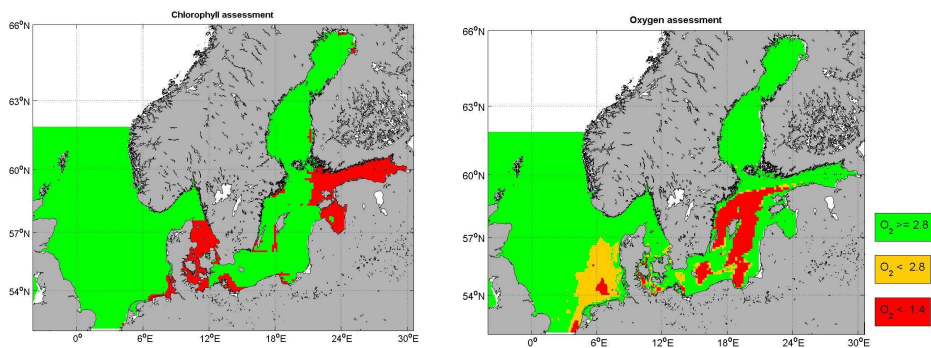


Fig. 21. Assessment results of summertime average chlorophyll-a (left). The assessment levels are indicated by colors, green (good), red (bad). Assessment results of annual minimum oxygen concentrations (right). The assessment levels are indicated by colors, green ( $O_2 \geq 2.8$  ml/l), orange ( $O_2 < 2.8$  ml/l, toxic level), red ( $O_2 < 1.4$  ml/l).

The assessment of the eutrophication status according to the integration of the categorized assessment parameters (Table A 2) indicates that the entire Southeastern part of the North Sea, the Kattegat, the Danish Straits, the Gulf of Finland and the Bay of Riga area as well as parts of the Arkona Basin, the Bornholm Basin and the Baltic Proper may be classified as problem areas (Fig. 22). The Bothnian Bay and parts of the Baltic Proper, the Bornholm Basin and the Arkona Basin are classified as potential problem areas.

One should note that the results in some areas may be questionable due to the assessment methods used in the report. The results are based on a pretty rough division of the modeled area into different basins and threshold values are valid for areas covering coastal as well as open water. Improving the number of threshold values and observations as a base for the assessment is important in order to make good assessments which can be used in environmental and political discussions.

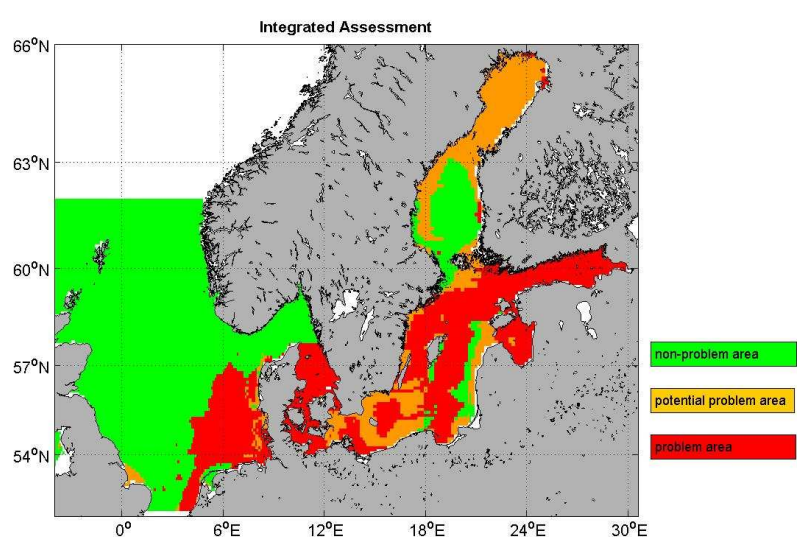


Fig. 22. Assessment results of integrated categorized assessment parameters. The assessment levels are indicated by colors, green (non-problem area), yellow (potential problem area), and red (problem area).

The elevated primary production seem to be the main problem in the Gulf of Finland, Gulf of Riga, Danish Straits, Kattegat and at some of the river mouths and categorize the areas as problem areas. In the North Sea, Bornholm Basin and the Baltic Proper the low bottom layer minimum oxygen concentration seem to categorize the areas as problem areas.

## Conclusions

The present report gives a brief background description of river runoff and meteorological conditions and presents results of four ecosystem models from Nordic countries. The models describe the North Sea, Skagerrak, Kattegat, Danish Straits and the Baltic Sea area. Weighted average values of the different parameters from the four models are calculated using observations and standard deviation at different stations. The weighted average values are used to assess the eutrophication status according to the OSPAR Common Procedure.

The river loadings of nutrients were not computed explicitly in this assessment. The loading of nutrients to sea is to a large extent determined by the river runoff (Håkansson, 2003), the higher runoff the more nutrients are transported to the sea. The river runoff during 2006 was on the whole close to the long time average in the beginning of the year. At spring, when the long and cold winter ended and the snow melting occurred, a higher runoff than normal was observed. The summer period was dry and warm and consequently the river runoff was low. The Swedish rivers in the Bothnian Bay and the Bothnian Sea are to a large extent regulated for electric power and the runoff was closer to the long time average. A rainy ending of the year resulted in a higher river runoff than the long time average in Sweden (also in the regulated rivers), Norway and Denmark.

The winter surface concentrations and ratios of DIN and DIP showed elevated levels in the coastal regions of the southern North Sea, the Gulf of Riga and in the Gulf of Finland, and in parts of the southern Baltic Sea and northern Bothnian Sea. The mean chlorophyll-a concentrations indicated elevated levels in the river mouth areas in the southeastern North Sea and in the Baltic Sea and in the whole Kattegat, the Danish straits, Riga Bay and the Gulf of Finland.

The annual near bottom minimum oxygen concentrations showed decreased levels in large parts of the eastern North Sea and at some spots in the southern Baltic Sea. Depletion levels ( $O_2 < 1.4$  ml/l) are found in the southeastern North Sea, in the Bornholm Basin and in the Baltic Proper. Also some local areas in the Danish straits show oxygen depletion.

The assessment of the eutrophication status according to the integration of the categorized assessment parameters indicates that the entire southeastern part of the North Sea, the Kattegat, the Danish Straits, the Gulf of Finland and the Bay of Riga area may be classified as problem areas as well as parts of the Arkona Basin, the Bornholm Basin and the Baltic Proper. The Bothnian Bay and parts of the Baltic Proper, the Bornholm Basin and the Arkona Basin are classified as potential problem areas.

An area is defined to be a potential problem area if there are increased levels of nutrients relative to the actual threshold value used in that assessment area. The results therefore rely much on the reliability of the threshold values. The assessment results for problem areas depend highly on the variables that relate to direct (chlorophyll) or indirect effects (oxygen) (cf. Appendix Table 2).

Finally: The demonstration project reveal that there is a large need of good references and threshold values for a comprehensive assessment of eutrophication status for many parameters in several sea areas. The division of areas into large boxes could be more accurate if more observation data were available. Methods that even out the sharp gradients between boxes with different threshold values could also be improved.

## 7 Acknowledgement

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## 9 Appendix A; Comprehensive procedure

### **From: OSPAR Integrated Report 2005 on the Eutrophication Status of the OSPAR Maritime Area Based Upon the First Application of the Comprehensive Procedure**

All areas not being identified as non-problem areas with regard to eutrophication through the Screening Procedure are subject to the Comprehensive Procedure which comprises a checklist of qualitative parameters for a holistic assessment (cf. § 4.2.1. in the Common Procedure OSPAR 97/15/1, Annex 24):

The qualitative assessment parameters are as follows:

- a. the causative factors  
the degree of nutrient enrichment
  - with regard to inorganic/organic nitrogen
  - with regard to inorganic/organic phosphorus
  - with regard to silicontaking account of:
  - sources (differentiating between anthropogenic and natural sources)
  - increased/upward trends in concentration
  - elevated concentrations
  - increased N/P, N/Si, P/Si ratios
  - fluxes and nutrient cycles (including across boundary fluxes, recycling within environmental compartments and riverine, direct and atmospheric inputs)
- b. the supporting environmental factors, including:
  - light availability (irradiance, turbidity, suspended load)
  - hydrodynamic conditions (stratification, flushing, retention time, upwelling, salinity, gradients, deposition)
  - climatic/weather conditions (wind, temperature)
  - zooplankton grazing (which may be influenced by other anthropogenic activities)
- c. the direct effects of nutrient enrichment
  - i. phytoplankton;
    - increased biomass (e.g. chlorophyll a, organic carbon and cell numbers)
    - increased frequency and duration of blooms
    - increased annual primary production
    - shifts in species composition (e.g. from diatoms to flagellates, some of which are nuisance or toxic species)
  - ii. macrophytes, including macroalgae;
    - increased biomass
    - shifts in species composition (from long-lived species to short-lived species, some of which are nuisance species)
    - reduced depth distribution
  - iii. microphytobenthos;
    - increased biomass and primary production
- d. the indirect effects of nutrient enrichment
  - i. organic carbon/organic matter;
    - increased dissolved/particulate organic carbon concentrations
    - occurrence of foam and/or slime
    - increased concentration of organic carbon in sediments (due to increased sedimentation rate)
  - ii. oxygen;

- decreased concentrations and saturation percentage
- increased frequency of low oxygen concentrations
- increased consumption rate
- occurrence of anoxic zones at the sediment surface (“black spots”)
- iii. zoobenthos and fish;
  - mortalities resulting from low oxygen concentrations
- iv. benthic community structure;
  - changes in abundance
  - changes in species composition
  - changes in biomass
- v. ecosystem structure;
  - structural changes
- e. other possible effects of nutrient enrichment
  - i. algal toxins (still under investigation - the recent increase in toxic events may be linked to eutrophication)

Table A 1. The agreed Harmonised Assessment Criteria and their respective assessment levels of the Comprehensive Procedure

Assessment parameters	
Category I	Degree of Nutrient Enrichment
	<b>1 Riverine total N and total P inputs and direct discharges (RID)</b> Elevated inputs and/or increased trends (compared with previous years)
	<b>2 Winter DIN- and/or DIP concentrations</b> Elevated level(s) (defined as concentration >50 % above salinity related and/or region specific background concentration)
	<b>3 Increased winter N/P ratio (Redfield N/P = 16)</b> Elevated cf. Redfield (>25)
Category II	Direct Effects of Nutrient Enrichment (during growing season)
	<b>1 Maximum and mean Chlorophyll <i>a</i> concentration</b> Elevated level (defined as concentration > 50 % above spatial (offshore) / historical background concentrations)
	<b>2 Region/area specific phytoplankton indicator species</b> Elevated levels (and increased duration)
	<b>3 Macrophytes including macroalgae (region specific)</b> Shift from long-lived to short-lived nuisance species (e.g. <i>Ulva</i> )
Category III	Indirect Effects of Nutrient Enrichment (during growing season)
	<b>1 Degree of oxygen deficiency</b> Decreased levels (< 2 mg/l: acute toxicity; 2 - 6 mg/l: deficiency)
	<b>2 Changes/kills in Zoobenthos and fish kills</b> Kills (in relation to oxygen deficiency and/or toxic algae) Long term changes in zoobenthos biomass and species composition
	<b>3 Organic Carbon/Organic Matter</b> Elevated levels (in relation to III.1) (relevant in sedimentation areas)
Category IV	Other Possible Effects of Nutrient Enrichment (during growing season)
	<b>1 Algal toxins (DSP/PSP mussel infection events)</b> Incidence (related to II.2)

Table A 2. Integration of Categorised Assessment Parameters

	Category I Degree of nutrient enrichment	Category II Direct effects	Category III and IV Indirect effects/ other possible effects	Classification
a	+	+	and/or +	problem area
b	-	+	and/or +	problem area
C	+	-	-	potential problem area
D	-	-	-	non-problem area

(+)= Increased trends, elevated levels, shifts or changes in the respective assessment parameters in Table 1

(-) = Neither increased trends nor elevated levels nor shifts nor changes in the respective assessment parameters in Table 1

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.

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