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SWEDISH NATIONAL REPORT ON EUTROPHICATION STATUS IN THE KATTEGAT AND THE SKAGERRAK

OSPAR ASSESSMENT 2002

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PREFACE

The occurrence and wide distribution of eutrophication effects due to excess nutrient loading in certain parts of the North Sea are an issue of concern. Elevated nitrogen and phosphorus concentrations are clearly detectable in many estuaries and along most of the coastline from northern France to Denmark, sections of the south-eastern English coast, and in parts of the Skagerrak and the Kattegat. It is generally acknowledged that the high nutrient load can cause increased biomass and extensive phytoplankton blooms. These may occasionally include harmful species. Negative impacts include periodic disturbances such as oxygen depletion and subsequent increased mortality of benthic organisms, as well as long-term changes in the abundance and diversity of animal and plant communities.

The Contracting Parties of the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) have agreed to take all possible steps to prevent and eliminate pollution and to take the necessary measures to protect the maritime area against adverse effects of human activities. OSPAR's objective with regard to eutrophication is to combat eutrophication in the OSPAR maritime area, in order to achieve a healthy marine environment where eutrophication does not occur by 2010.

Following this, the Commission has undertaken to identify by 2002 the eutrophication status of all parts of the Convention Area which will reported to the OSPAR Ministerial Meeting in 2003. This report comprises an assessment of the eutrophication status of the Swedish parts of the Kattegat and Skagerrak as a contribution to this joint evaluation.

1 BACKGROUND, ASSESSMENT PROCEDURE AND CRITERIA

-Sverker Evans, Swedish EPA

1.1 Background

The Kattegat and the Skagerrak (Fig. 2.1) with surface areas of about 22 000 and 32 000 km^2 and mean depths of 23 m and 210 m, respectively, connect the brackish Baltic Sea with the North Sea, where the salinity is almost oceanic. Water of Baltic origin forms a surface layer in the Kattegat with a salinity increasing from 15 PSU in the southeast to 25 PSU in the northwest. Water originating from the North Sea is found below a pronounced halocline at a depth of about 15 m. The salinity in the deep water ranges from 32 to 34 PSU. The Kattegat surface water is bounded to the north by a sharp surface front, on average directed from Skagen towards the northeast. From here on the low-saline water of Baltic origin follows the Swedish and Norwegian coasts in the Skagerrak as a low-saline current (Rosenberg et al., 1996).

The anthropogenic input of nutrients from land and changed nutrient ratios primarily affect the coastal zone. Nutrient related problems are widespread in the Kattegat and the eastern Skagerrak. Negative impacts include periodic disturbances of the ecosystem such as oxygen depletion and the subsequent increased mortality of benthic organisms, as well as changes in the abundance and diversity of the different animal and plant communities, e.g. increased phytoplankton blooms including, occasionally, harmful species. As a result of periodic oxygen depletion in the Kattegat bottom water, fishing for Norwegian Lobster has almost ceased in this area. In view of the storage of nutrients in the sediments, recovery times may be of the order of decades.

1.2 Assessment procedures

OSPAR adopted the Common Procedure for the Identification of the Eutrophication Status of the Maritime Area of the OSPAR Convention ("the Common Procedure") in September 1997 (OSPAR, 1997). The Common Procedure is an integral part of the Strategy to Combat Eutrophication. The purpose of the Common Procedure is to characterise the eutrophication status of each part of the Convention Area.

This procedure comprises two steps. The first step is a Screening Procedure to identify areas, which are likely to be non-problem areas with regard to eutrophication. The second step is the Comprehensive Procedure, which should enable a classification of the maritime area in terms of problem areas, potential problem areas and non-problem areas with regard to eutrophication.

- "problem areas with regard to eutrophication" are those areas for which there is evidence of an undesirable disturbance to the marine ecosystem due to anthropogenic enrichment by nutrients;

- "potential problem areas with regard to eutrophication" are those areas for which there are reasonable grounds for concern that the anthropogenic contribution of nutrients may be causing or may lead in time to an undesirable disturbance to the marine ecosystem due to elevated levels, trends and/or fluxes in such nutrients;

- "non-problem areas with regard to eutrophication" are those areas for which there are no grounds for concern that anthropogenic enrichment by nutrients has disturbed or may in the future disturb the marine ecosystem.

The timetable within the Strategy to Combat Eutrophication states that the Commission will take the necessary steps, so as to achieve the identification by the year 2002 of the eutrophication status of all parts of the maritime area. Contracting Parties will identify the eutrophication status of their parts of the maritime area, i.e. apply the Common Procedure, but the Commission will assess the results of its application by Contracting Parties. The Common Procedure is without prejudice to existing and future legal requirements, including European Community legislation where appropriate.

The Screening Procedure

The Screening Procedure is a preliminary ("broad brush") process which is likely to be applied once only in any given area. The Screening Procedure is intended to identify those areas, which in practical terms are likely to be non-problem areas with regard to eutrophication. However, the status of

the areas will be re-assessed by applying the Common Procedure if there are grounds for concern that there has been a substantial increase in the anthropogenic nutrient load.

France, Iceland, Ireland, Norway, Portugal, Spain and the UK have applied the Screening Procedure to some or all of their waters. Sweden have not applied the Screening Procedure since there was sufficient information to indicate that its waters was impacted by excess nutrients and thus required further steps in the assessment procedure.

The Comprehensive Procedure

Following the application of the Screening Procedure, all areas not identified as non-problem areas with regard to eutrophication are subject to the Comprehensive Procedure. Monitoring shall be undertaken in accordance with the minimum monitoring requirements for potential problem areas with regard to eutrophication in accordance with the Nutrient Monitoring Programme, adopted by OSPAR 1995.

The Comprehensive Procedure is an iterative procedure and may be applied as many times as necessary. The outcome of the Comprehensive Procedure should enable a classification of the maritime area in terms of problem areas, potential problem areas and non-problem areas with regard to eutrophication. In the case of potential problem areas with regard to eutrophication, preventive measures should be taken in accordance with the Precautionary Principle. Moreover, there should be implementation of monitoring and research in order to enable a full assessment of the eutrophication status of each area concerned within five years of its being characterised as a potential problem area with regard to eutrophication. In the case of problem areas with regard to eutrophication, (i) measures shall be taken to reduce or to eliminate the anthropogenic causes of eutrophication, (ii) reports shall be provided on the implementation of such measures, and (iii) assessments shall be made of the effectiveness of the implementation of the measures on the state of the marine ecosystem.

Assessment criteria and their assessment levels and area classification within the Comprehensive Procedur

The Comprehensive Procedure consists of a set of assessment criteria that may be linked to form a holistic and common assessment of the eutrophication status of the maritime area. In addition, the Common Procedure contains a checklist of qualitative assessment parameters for use in a holistic assessment (Appendix A).

In order to enable Contracting Parties to undertake a harmonised assessment of their waters subject to the Comprehensive Procedure it was necessary to develop a number of the qualitative assessment criteria into quantitative criteria that could be applied in a harmonised way. On the basis of common denominators within a wide range of qualitative and quantitative information provided by Contracting Parties on the criteria and assessment levels already used from those in the checklist in the Common Procedure, a set of assessment criteria were selected and further developed into quantitative criteria for use in a harmonised assessment. For each criterion an assessment level has been derived based on a level of elevation with the exception of nutrient inputs for which there should also be an examination of trends. The level of elevation is defined, in general terms, as a certain percentage above a background concentration. The background concentration is, in general terms, defined as salinity related and/or region specific derived spatial offshore and/or historical background concentration.

In order to allow for natural variability in the assessment, the level of elevation is generally defined as the concentration of more than 50 % above the related and/or region specific background level (e.g. DIN and DIP concentrations, winter N/P- ratio).

The assessment criteria selected for further development can be divided into the following categories:

Category I.	Degree of nutrient enrichment;
Category II.	Direct effects of nutrient enrichment;
Category III.	Indirect effects of nutrient enrichment;
Category IV	Other possible effects of nutrient enrichment.

A full description of the procedure is given in Appendix B.

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2 Scientific Assessment

DEGREE OF NUTRIENT ENRICHMENT

The Swedish assessment of the eutrophication status in the Kattegat and Skagerrak follows the guidelines of OSPAR Common Procedures outlined in Appendix B. An overview of the area is presented in Fig. 2.1, including borders delimiting the Skagerrak and Kattegat towards the North Sea and the Danish Straits.

This report is based on Swedish monitoring data, while occasionally other countries data are included as well. We made use of historical data to the full extent possible. The data analysis is done separately for offshore and inshore waters. These water bodies are delimited by a dynamic relevant parameter – the internal Rossby Radius of deformation. The average length of the internal Rossby radius in Skagerrak (5.4 km) and Kattegat (7.3 km) was calculated using hydrographic data. Inshore waters are then defined as those water bodies located between this borderline and the mainland or major islands.

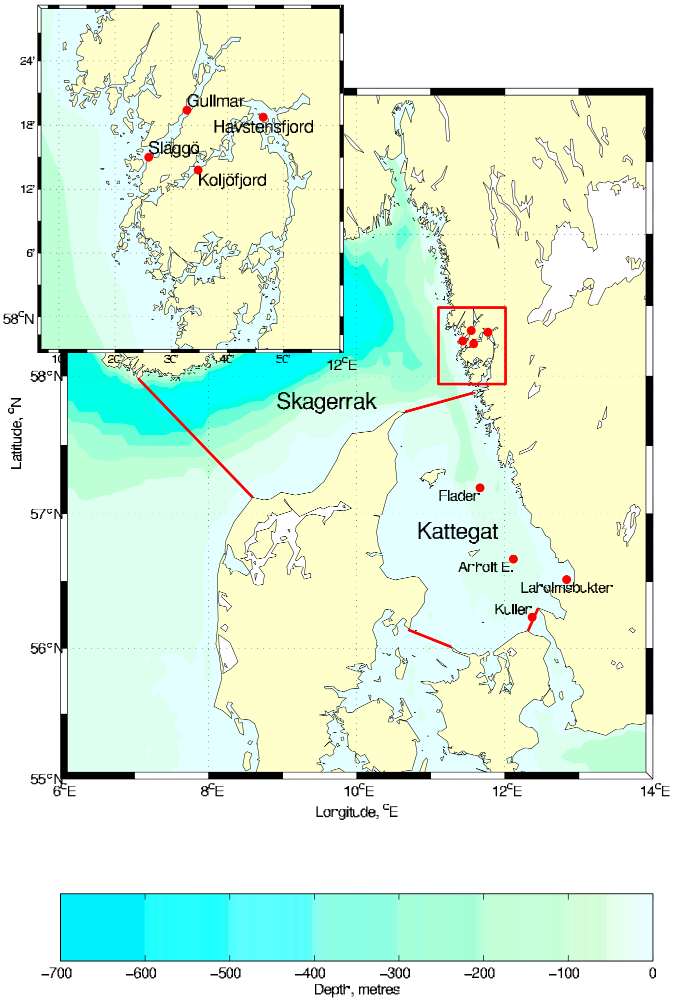

Fig. 2.1: Overview map of the eastern North Sea, covering the Skagerrak and Kattegat areas. Single specific sites from where time series are being used in this report are marked.

Experts on different marine disciplines evaluate and conclude on topics targeted by the OSPAR Common Procedure.

2.1 Nutrient enrichment and long-term natural variability

2.1.1 Inputs from land, atmosphere and adjacent seas

Input from land

- Maja Brandt & Bertil Håkansson, SMHI

The runoff to Skagerrak and Kattegat is highly variable and vary from year to year as well as from decade to decade (Fig. 2.1.1). Freshwater inputs were lower than the long-term average during mid 1950s, early and mid 1970s and early 1990s, while higher than average conditions prevailed during mid 1960s, mid and late 1980s and late 1990s. However, no significant trend during this 50 years period could be found. The runoff from the Swedish catchment area to Skagerrak and Kattegat is dominated by River Göta älv. This runoff is correlated with the total runoff to the Baltic Sea, which is on average about 15 times larger and comparable with the runoff from e.g. the Mississippi River (Rabalais & Turner 2001). This fresh water discharge is mixed with salt water in the Baltic Sea and thus enters Kattegat as a brackish water mass with nutrient contents typical for Baltic conditions. Both nitrogen and silicate concentrations are lower than the corresponding contents in the rivers entering the Swedish West Coast and waters entering from the North Sea water.

The nutrient load to the coastal seas is determined, to a large extent, by perturbations in the runoff, whereas nutrient concentrations are rather stable. Hence runoff is a good indicator for nutrient load variability. The runoff, total nitrogen (TN) and total phosphorus (TP) loads to the Skagerrak and Kattegat is shown in Fig. 2.1.2. Clearly the TP and TN loads are higher during the 1980s and 1990s as compared to early 1970s. The former increased 50 % while the latter increased with about 40 % in Kattegat. No trends were discernible, neither in runoff, nor in the TP and TN loads.

Gross load of nutrient to surface water has been calculated from diffuse and point sources for the period 1985-1999 (Swedish EPA, 2002). Calculations of diffuse leaching from land are based on long-term monitoring records from small catchments and model calculations. Municipal and industry discharges are mainly based on measured nutrient discharges in- 2000 (or if missing from 1996 to 1999). Rural discharges are estimated from population equivalents and emission factors.

For nitrogen, these calculations also consider retention processes in soil and ground water (below the root zone), lakes and rivers that affect each source during the transport towards the sea, so that the nitrogen net load to the sea is calculated and validated against the measured load in the rivers. Thus, source apportionment for nitrogen and phosphorus are based on net load and gross load, respectively (Figures 2.1.3 and 2.1.4). Direct point sources to the seas are included.

The land-use of the catchments draining to the Öresund (sub-region Öresund) is dominated by arable land (65 %). Both the sub-regions Kattegat and Skagerrak are dominated by forest (65 % and 58 %). The sub-region Kattegat is large and dominated by the large river Göta älv, which discharges near the boarder between Kattegat and Skagerrak and actually affects both.

In the small sub-region Öresund the contribution from arable land dominates (77 % of the total net nitrogen load and 59 % of gross phosphorus load). The leaching from arable land for the sub-regions Kattegat and Skagerrak contribute with nearly half of the total load (47-53 % for nitrogen, 43-44 % for phosphorus). The point sources (urban, rural and industrial discharges) from inland and direct to the sea contribute by about 16-19 % for nitrogen and 34-39 % for phosphorus. The contribution of atmospheric nitrogen deposition on lakes to Kattegat is significant (14 %) due to the large lake Vänern, drained by the river Göta älv.

The anthropogenic load is calculated as total load minus background load estimated as losses from unmanaged land. Note that the anthropogenic TP load is based on gross load, which means the load at the sources, whereas the TN load includes retention and therefore provides the actual load to the sea.

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Table 1. Antropogenic load for nitrogen (based on net load) and for phosphorus (gross load) (tonnes/year). Point sources include discharges from municipal and industrial plants. Period 1985-1999.

Sub-region	Nitrogen			Phosphorus		
	Diffuse leaching	Point sources	Sum	Diffuse leaching	Point sources	Sum
Öresund	4 600	1 300	5 900	90	50	140
Kattegatt	21 800	6 200	28 000	610	420	1 030
Skagerrak	2 000	700	2 700	80	60	130

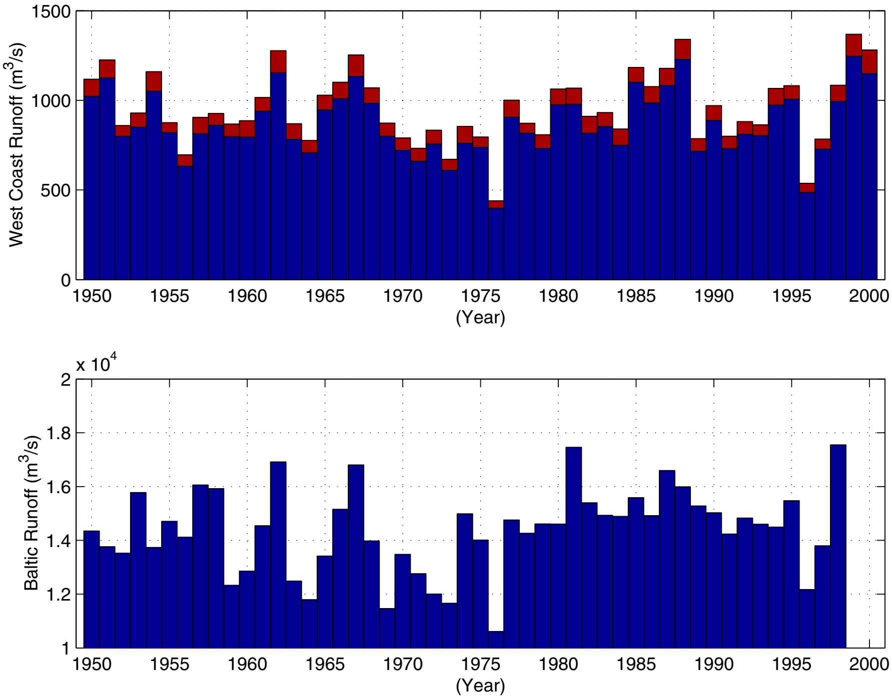

Figure 2.1.1: Observed runoff to the Kattegat (blue) and Skagerrak (red) from Sweden is shown as stacked bars. The Göta River is considered to discharge to the Kattegat area, which gives rise to the large differences in runoff between Skagerrak and Kattegat. The lower panel shows the total runoff to the Baltic Sea, which enter the Kattegat.

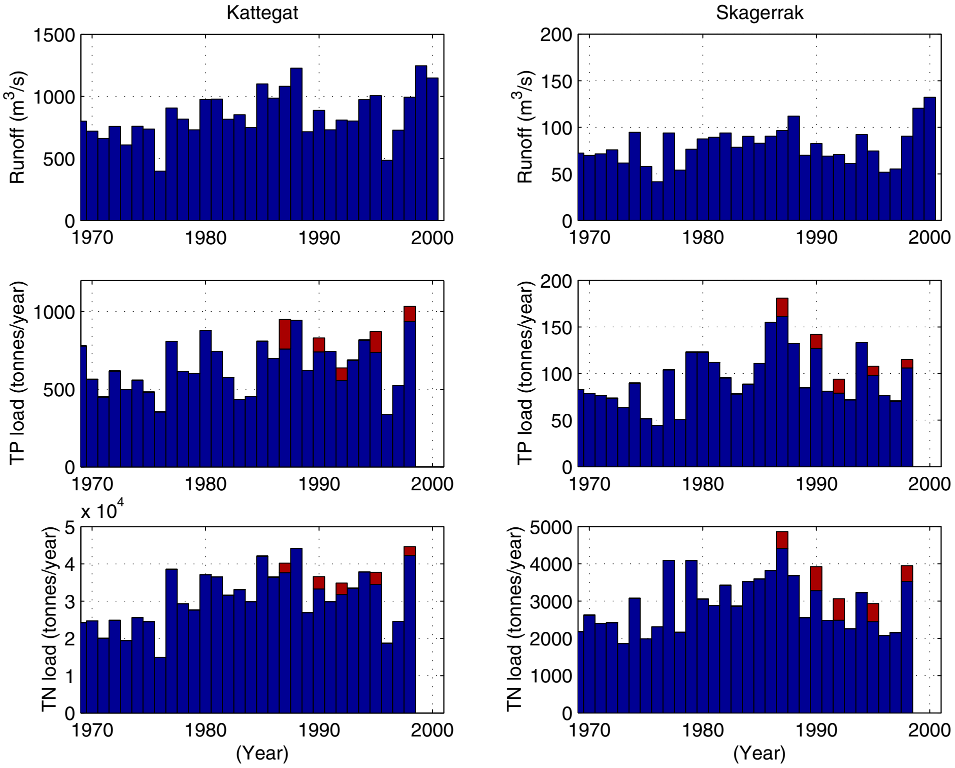

Figure 2.1.2: Observed runoff, total Phosphorus and total Nitrogen entering the Kattegat and Skagerrak areas. The stacked red bars show point sources on top of river load on nutrients.

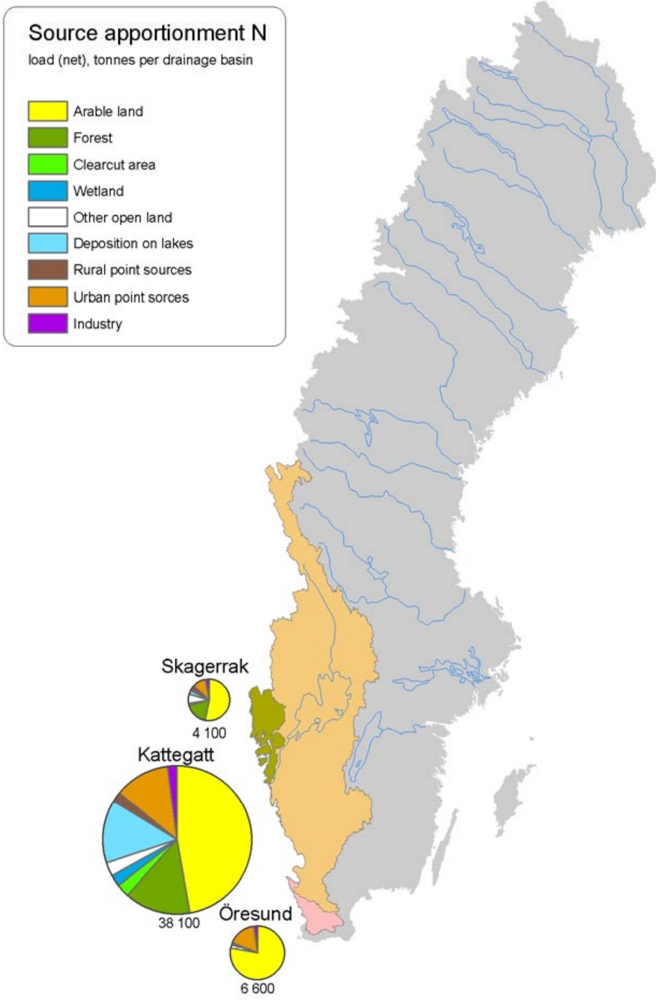

Fig. 2.1.3: Source apportionment for nitrogen net load including point sources that goes direct to the sea. Period 1985-1999.

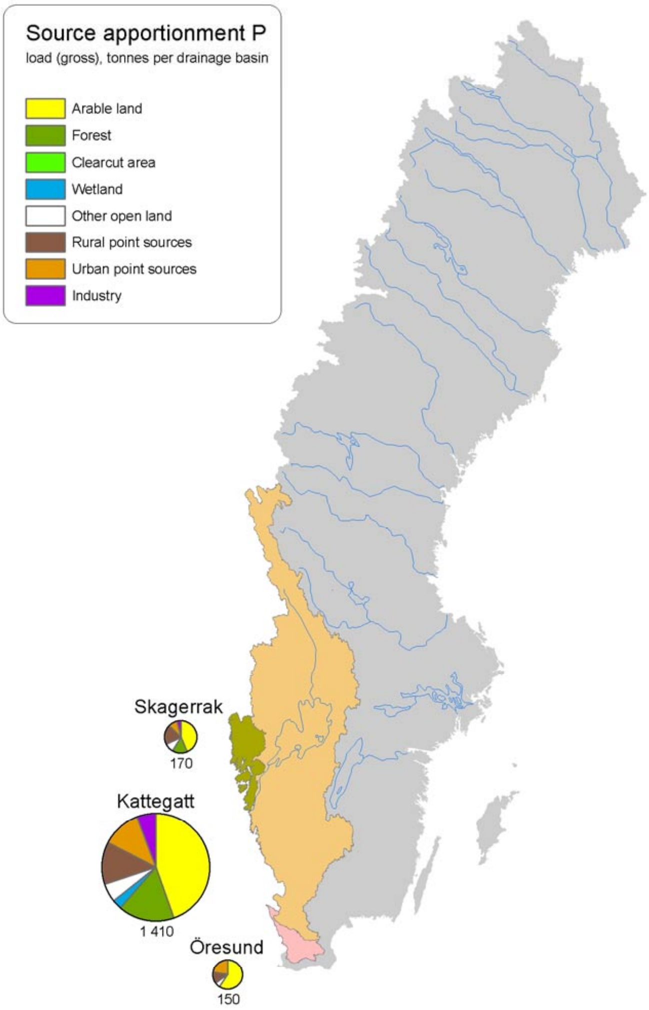

Fig. 2.1.4: Source apportionment for phosphorus gross load including point sources that goes direct to the sea. Period 1985-1999.

Atmospheric deposition

- Bertil Håkansson, SMHI

Atmospheric deposition of nitrogen composes a large proportion of the total nitrogen load to the area. This deposition is calculated using the large area model EMEP as boundary condition to the high resolution MATCH model. Both models use observations and point source emissions assimilated into the model system. It was found that MATCH data exagarate the deposition to some extent compared to EMEP data. Since much more input data is available for the Swedish MATCH model this results are presented here in Table 2. Based on two years of data we find that the TN deposition to Kattegat and Skagerrak is ca 20000 and 33000 tonnes per year, respectively. The geographical distribution of atmospheric deposition is shown in the Fig. 2.1.5. Inshore waters along the Swedish coast have higher deposition, affecting the level of nitrogen content.

Transports from adjacent seas

- Lars Andersson, SMHI

The Skagerrak and the Kattegat constitutes the outer part of the transition zone between the estuarine Baltic Sea and the oceanic North Sea.

In Skagerrak there is an almost permanent cyclonic circulation. The average circulation amounts to 0.8 ± $0.3*10^6$ m^3s^{-1} (Rydberg et al. 1996). Considerable short time variations occur due to shifting

Table 2. Calculated atmospheric deposition of NOx and NHx in Kattegat and Skagerrak based on the Swedish MATCH model TN is the sum of reduced (NHx) and oxidised (NOx) nitrogen.

Area/Parameter	NOx (tonnes/year)	NHx (tonnes/year)	TN (tonnes/year)
Kattegat 1998	9380	8910	18290
Kattegat 1999	11340	10990	22330
Skagerrak 1998	14990	14650	29640
Skagerrak 1999	18560	17950	36510

winds, south-westerly winds reinforce the circulation while north-easterly winds weaken it (Aure and Saetre 1981). Skagerrak receives water from three different sources. Kattegat surface water with salinities of 20-30 enters at an average of $0.055*10^6$ m^3s^{-1} (Andersson and Rydberg, 1993). Atlantic water, with salinities of 35-35.5, enters along the west side of the Norwegian Trench forming intermediate and deep water (Furnes et al 1986). A mixture of North Sea waters in the salinity range 31-35 enters Skagerrak from west and south-west, mainly as surface water. Water of low salinity indicates recirculation of Baltic water or, occasionally, river water from the southern North Sea.

The Kattegat has a typical two layer stratification, were the halocline is located at a depth of 15 m. The deep water consists of Skagerrak water while the surface water, with salinities between 15 and 30, is a mixture of deep water and water entering from the Baltic. The amount of freshwater leaving the Baltic is shown in Fig. 2.1.1. This figure shows the long-term changes in the outflow. However, there is also a clear annual cycle in this outflow both in the water transport as well as in nutrient concentrations (Fonselius, 1995; Andersson and Rydberg 1993).

Nutrient exchange between different sea areas has been estimated by calculations based on measurements as well as from numerical models. The results are difficult to compare, since some calculations only deal with surface layer transports, based on a fixed depth or salinity, while others have been done for a full cross channel section. Also, some estimates are done for total nitrogen and/or total phosphorus while others deal with the inorganic fractions. The table below is taken from a paper by Rydberg and Björk, 2001, and shows a compilation of estimates of nutrient transport between different sea areas.

Table 3. The transport of nutrients between the different areas has been taken from Rydberg and Björk, 2001. Transport of nutrients in tonnes/month between different sea areas. N.d. means no data.

	Tot-N	Tot-P	DIN	DIP	SiO_3	Ref.
North Sea to the Skagerrak						
Whole year (all watermasses)	320 000	n.d.	170 000	30 000	160 000	1
Whole year (surface water)	24 000	n.d.	14 000	2 500	14 000	1
Skagerrak to the North Sea	n.d.	n.d.	n.d.	n.d.	n.d.	
Skagerrak to Kattegat						
Summer Deep-water	20 000	1 300	7 000	1 100	n.d.	2
Winter Deep-water	42 000	5 800	25 000	3 800	n.d.	2
Kattegat to Skagerrak						
Summer Surface-water	22 000	2 200	0	170	n.d.	2
Winter Surface-water	17 000	1 700	6 800	700	n.d.	2
Kattegat to Skagerrak	12 500	n.d.	n.d.	n.d.	n.d.	3
Baltic to the Belt Sea	8 500	450	500	n.d.	8 000	4, 5

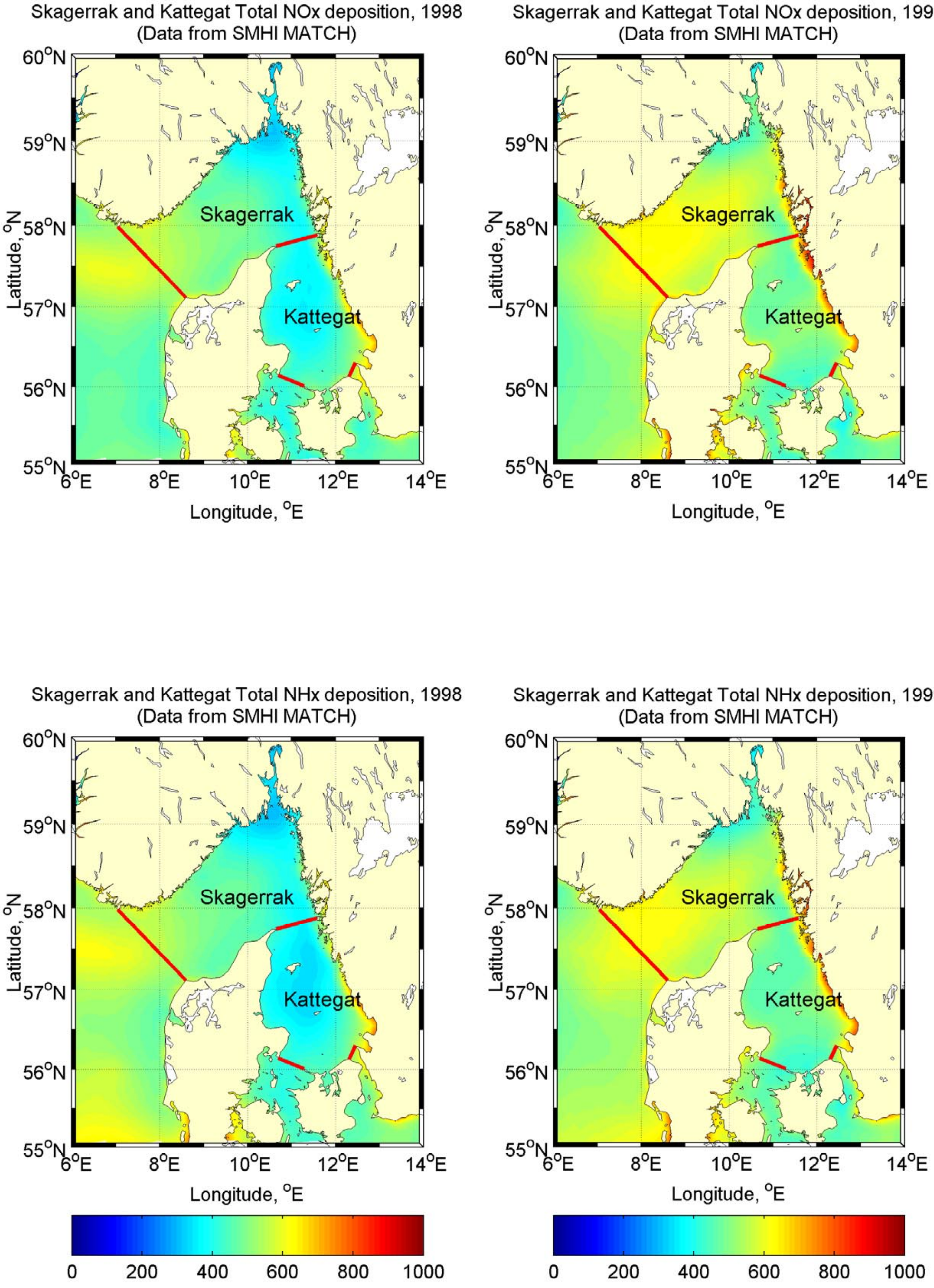

Fig. 2.1.5: The upper panel shows the NOx deposition, while the lower panel shows the NHx deposition during 1998 and 1999. Deposition is given in mgN/m^2.

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2.1.2 Nutrient concentrations and ratios

– Lars Andersson, SMHI

Surface water (0-10 m) nutrient concentrations for the winter period (Dec-Feb) are shown in Fig. 2.1.6a-b for Skagerrak and in Fig 2.1.7a-b for Kattegat. The different nutrients DIN (=NO_2+NO_3+NH_4), DIP (=PO_4) and SiO_3 have been plotted against salinity. In inshore Skagerrak, the concentrations of DIN and SiO_3 are rather low in high saline water compared to the concentrations in freshwater, while the concentration of phosphate is somewhat higher in saline water. In Skagerrak offshore low saline water the DIN concentrations are close to Kattegat offshore waters. At some occasions, water from the southern North Sea with salinity > 30 and very high concentrations of especially nitrogen enter the area.

The time series shows the annual winter mean concentrations each year. For DIP there is no clear trend in the data and off- and inshore waters do not differ, the concentrations are about 0.5 µmol/l during the whole period, except during the 1980s when they were somewhat higher. Neither DIN nor SiO_3 shows any significant trends but DIN appears to be higher during the 1980s and 1990s compared to 1970s. Inshore waters show higher concentrations of DIN and SiO_3 than offshore due to runoff from land. The low concentrations in all nutrients during 1996 and 1997 are due to a very early spring bloom that started already in the beginning of January and normal winter concentrations were never reached.

The ratios between the different nutrients show an increasing trend for the Redfield ratio, which since 1985 has exceeded 16 for inshore waters and approached 16 in offshore waters in the 1990s. The DIP/SiO_3 is clearly below 0.125 in inshore waters, while this ratio vary around the same value in offshore waters. The reason for the low ratio in inshore waters is the runoff load of high silicate concentrations. For the same reason the DIN/SiO_3 is around one in inshore waters and around 1.5 in offshore waters.

The mixing diagrams for Kattegat (Fig. 2.1.7a) shows clearly the influence of the Baltic Sea. Both DIN and DIP have lower concentrations in the low saline offshore water, while silicate shows higher values. The low saline water approaches the nutrient concentrations found in the Baltic Sea. A similar trend is found in inshore water except for DIN which slightly increase with decreasing salinity while silicate is increasing more strongly with decreasing salinity, approaching freshwater levels.

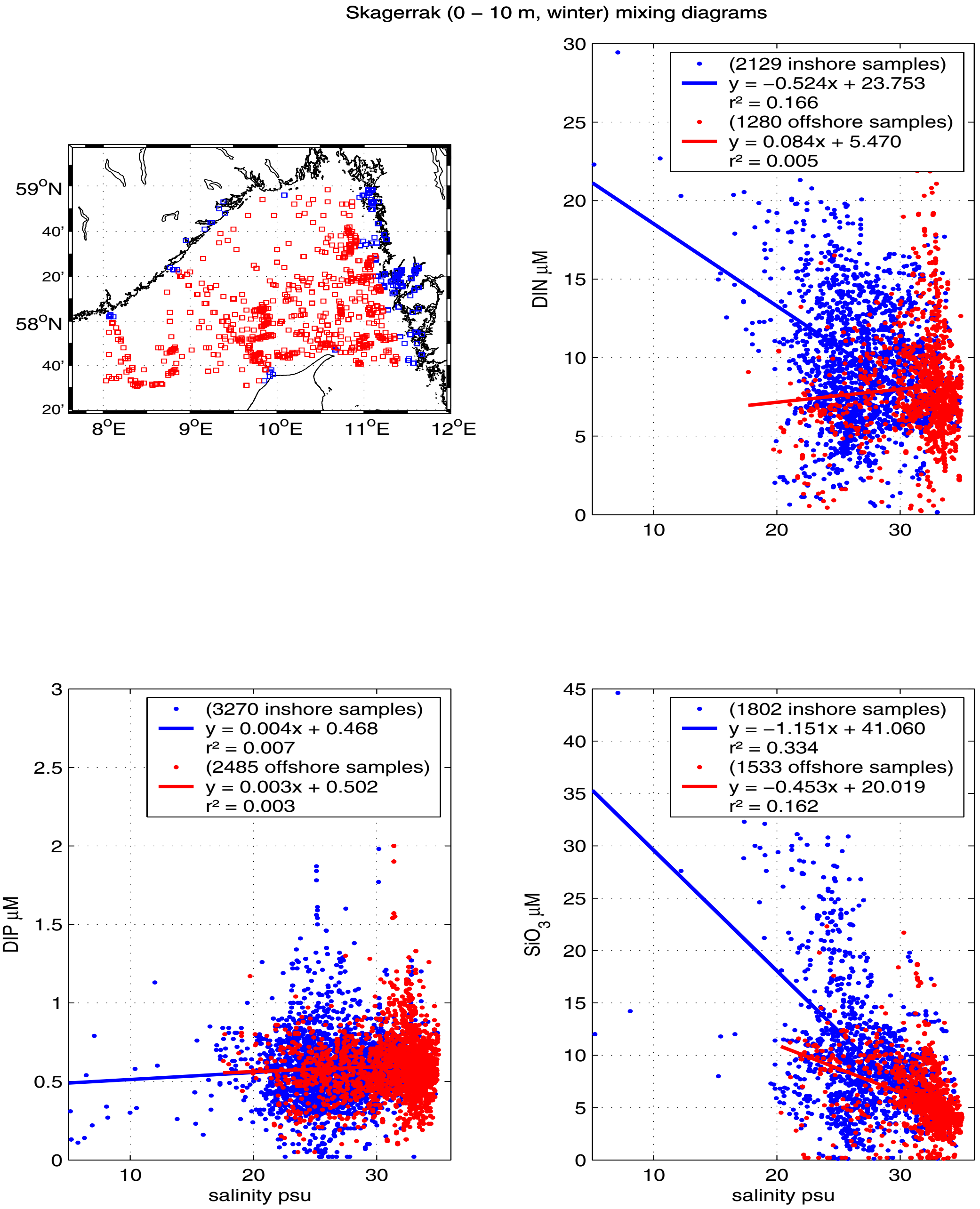

Fig. 2.1.6a: Mixing diagrams for nutrients in Skagerrak offshore (red dots) and inshore (blue dots) waters.

Except for some extreme silicate values all nutrients shows the same behaviour. The concentrations were rather constant during the late 1960s and the 1970s, then the levels increased during the 1980s but has decreased again since 1990. Note also here the extreme early spring bloom in 1997. In- and offshore waters show both the same levels and variability.

Also in Kattegat the Redfield ratio (Fig. 2.1.7b) shows an increasing trend although the ratio has been below 16 almost all the time. Inshore water shows a slightly higher ratio than offshore water. There are no trends in DIN/SiO_3 or DIP/SiO_3 and the ratios are below 1 and 0.125 except for some rare occasions.

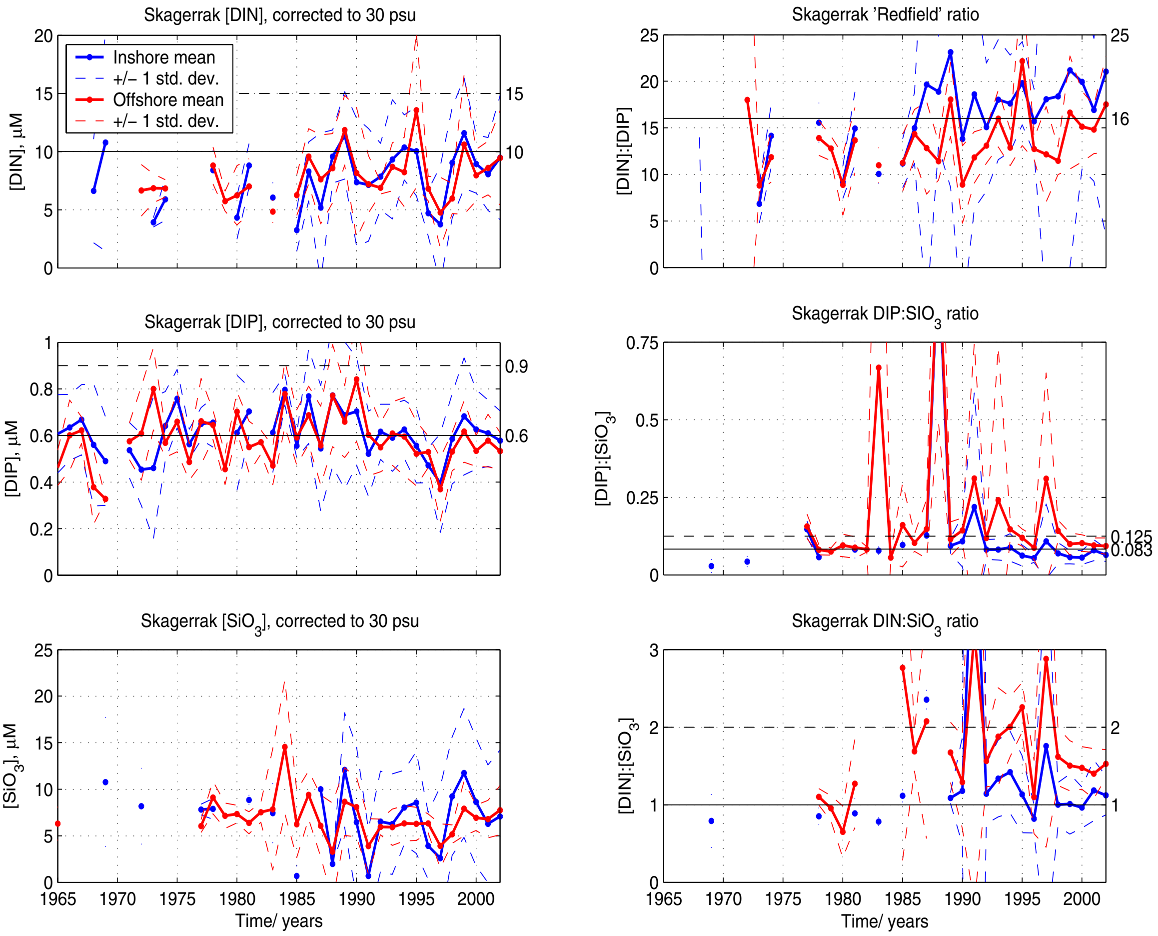

Fig. 2.1.6b: Time series of average nutrient concentrations and nutrient rations, including one standard deviation, of Skagerrak offshore (red dots) and inshore (blue dots) waters. Background value given by solid line and critical value given by dashed line.

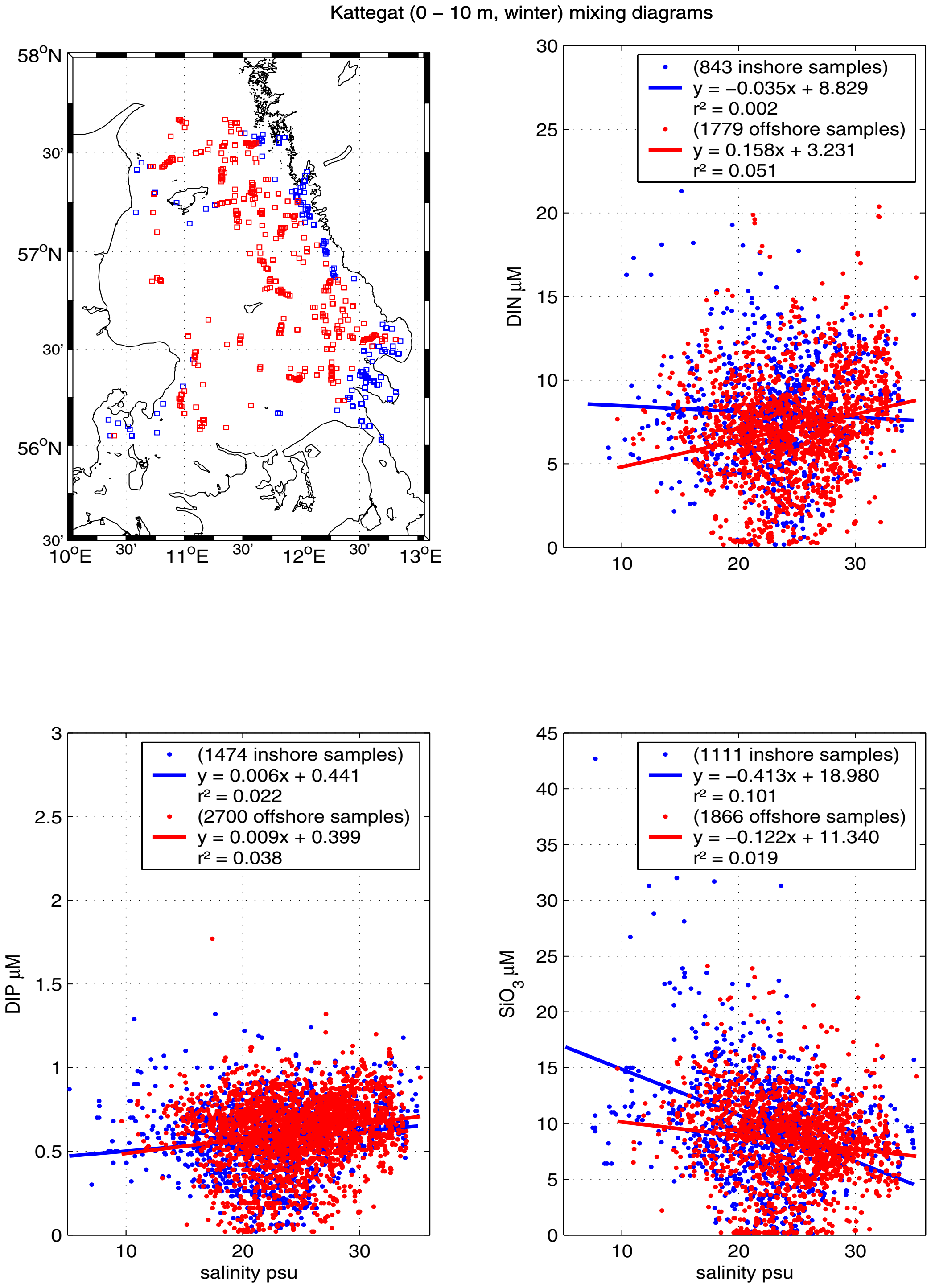

Fig. 2.1.7a: Mixing diagrams for nutrients in Kattegat offshore (red dots) and inshore (blue dots) waters.

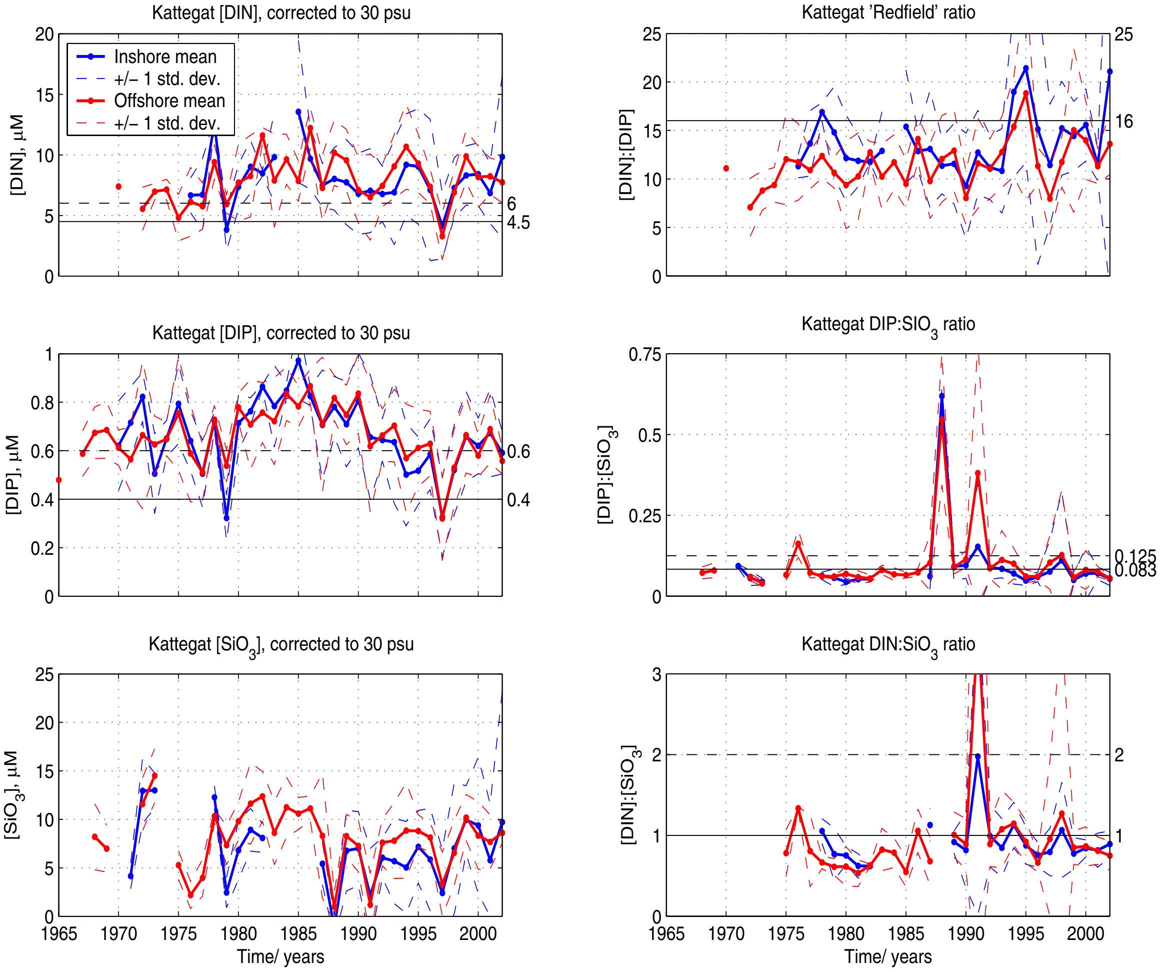

Fig. 2.1.7b: Time series of average nutrient concentrations and nutrient rations, including one standard of variation, of Kattegat offshore (red dots) and inshore (blue dots) waters. Background value given by solid line and critical value given by dashed line.

DIRECT EFFECTS

2.2 Direct effects of nutrient enrichment

2.2.1 Chlorophyll

– Lars Andersson & Bertil Håkansson, SMHI

Chlorophyll a is a state parameter often used as a measure (indicator) of phytoplankton biomass. Chlorophyll a concentrations in the Skagerrak and Kattegat surface layer during the growing season has been plotted against salinity in Fig. 2.2.1. There seems to be a peak in concentrations, in Kattegat around 20 PSU and in Skagerrak at 25 PSU. Similar salinity dependent Chlorophyll a distributions at inshore and offshore waters where major rivers enters, such as Mississippi and Amazon rivers (Rabalais & Turner, 2001) and in the German Bight, are often observed.

There are no trends in the material, the growing season mean concentrations seems to lie around 2 µg/l in both offshore areas, while the inshore Kattegat waters are close to 2.5 µg/l and inshore Skagerrak waters vary around 3 µg/l. With a few exceptions the four areas variation in average chlorophyll content is similar. However, as an example of the existence of reverse conditions, the years 1987 and 1988 indicated higher Chlorophyll a contents in inshore Skagerrak and offshore Kattegat. During the later part of the 1990s the levels were somewhat higher in all four areas (Fig. 2.2.1).

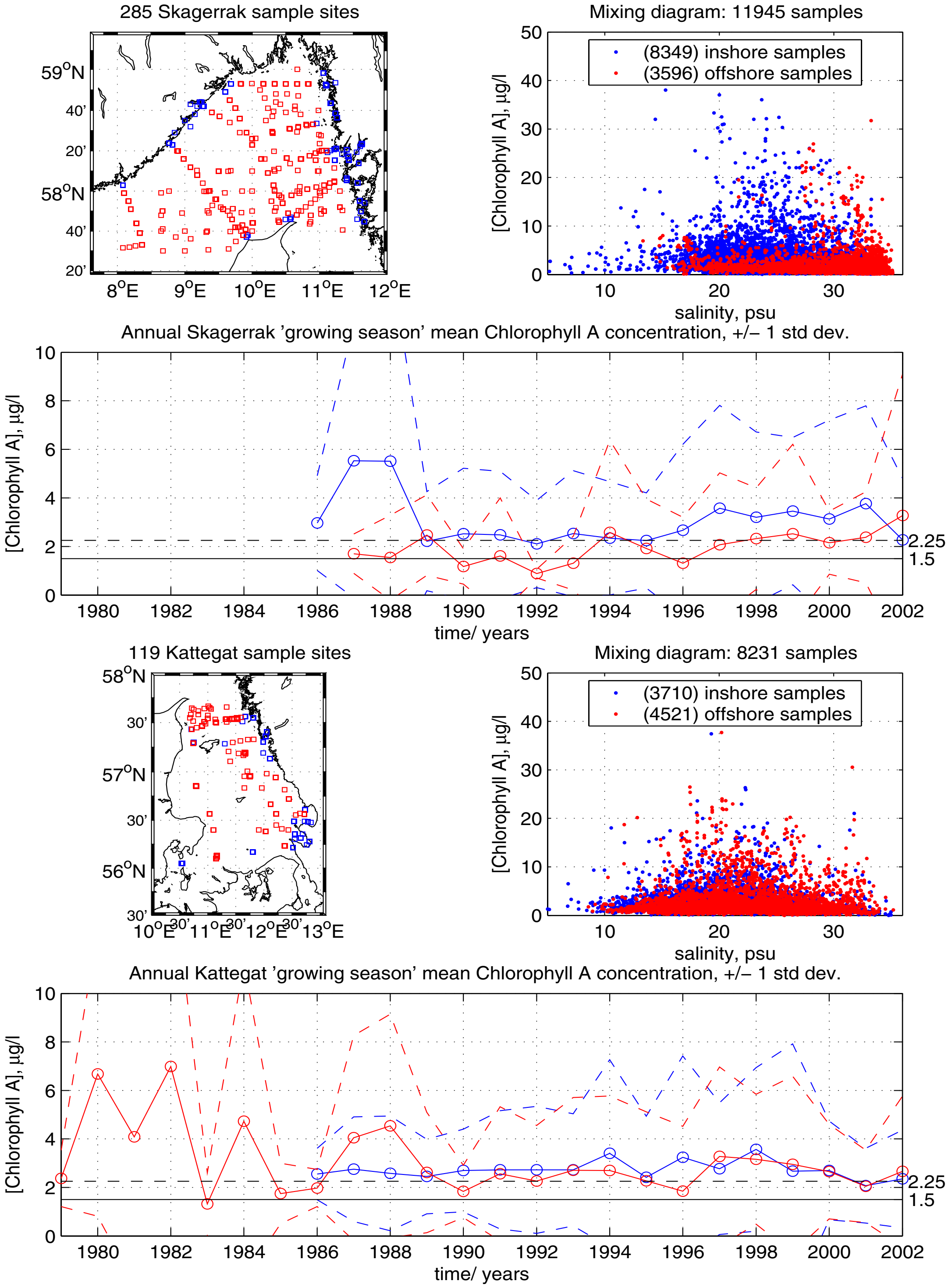

Fig. 2.2.1: Mixing diagrams and time series of horizontally averaged Chlorophyll a concentrations during the growing season in Skagerrak and Kattegat in- (blue dots) and offshore (red dots) waters.

2.2.2 Primary Production in the Gullmar fjord

– Odd Lindahl, Kristineberg Marine Research Station

Primary production 1985 - 1999

Primary phytoplankton productivity has been measured using the ^{14}C incorporation technique *in situ* since 1985 in the mouth area of the Gullmar Fjord, situated on the west coast of Sweden (Figure 2.1). An analysis of the time-series data set of primary production (1985-1999) revealed an increase over time in measured productivity ($p<0.001$) (Fig. 2.2.2) and also in the calculated production ($p<0.01$) (Fig. 2.2.3). The mean annual production has increased from around 230 gC m^{-2} $year^{-1}$ 1985-86 to almost 250 gC m^{-2} $year^{-1}$ at present. The 10-year means of 1985 – 1994 was 240 gC m^{-2} $year^{-1}$ and of 1991 – 2000 256 gC m^{-2} $year^{-1}$, respectively. The mean annual increase in production was 1.2%, or approximately 3 gC m^{-2} $year^{-1}$. The monthly contribution to the annual production during summer (May to September) was about 15% and the May - September made up about 80% of the total annual production (Fig. 2.2.4).

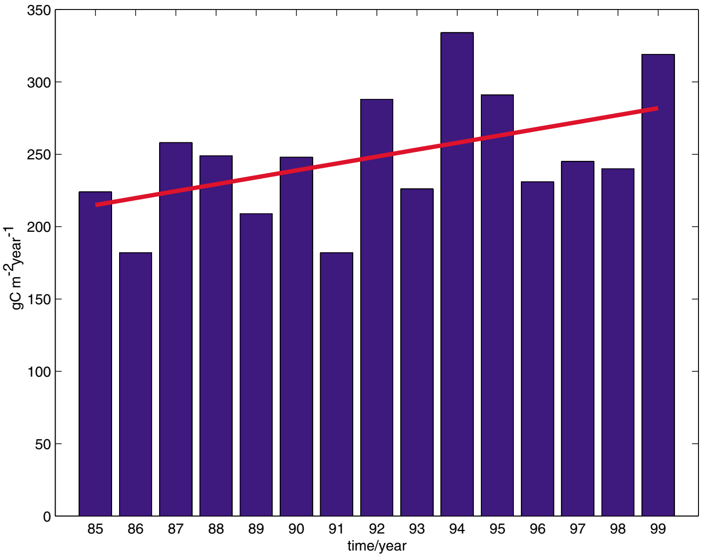

Fig. 2.2.2 Mean annual primary production (1985-1999)

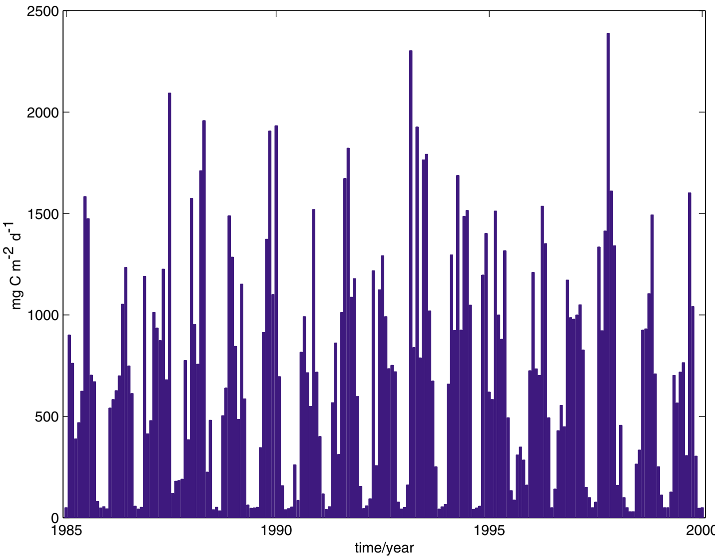

Fig. 2.2.3 Montly mean primary production 1985 - 2000 in the Gullmar Fjord.

Basic facts of the time-series

- ^{14}C-technique *in situ* at 10 depths; 0 - 20 m
- 4-hours incubation around noon
- Light factor method used to calculate daily production.
- No change of measuring protocol during series.
- Altogether 328 measurements 1985 - 2001; annual mean = 19.
- For a more comprehensive description of the measuring protocol and method used, see Lindahl (1995).

Antropogenic effects and climate variability

In general, the phosphate supply to the Skagerrak/Kattegat area has been reported to decrease,while the nitrate supply has been unchanged or decreased since 1985 (Forum Skagerrak, 2001). As a result, the decreasing trend of nutrient supply did not co-vary with the observed increase in primary productivity.

Attempts have been made to study the effect of weather/climatic forcing on the physical-chemical

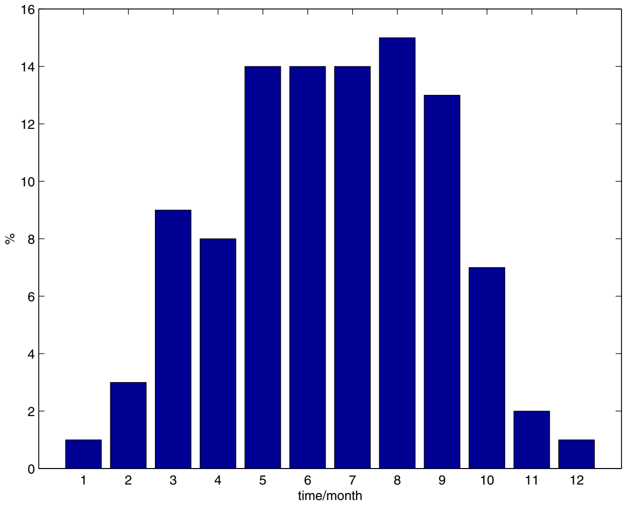

Fig. 2.2.4 The monthly contribution to the annual production.

processes related to the primary productivity. A direct correlation between the winter (December - March) NAO index and measured productivity in May was found (Belgrano et al., 1999). Further, the study on climate forcing suggests an indirect link between the North Atlantic Oscillation index (NAO), the supply of nutrients to Kattegat, wind direction and the primary production in the Gullmar Fjord with a six monts time-lag (Lindahl et al ., 1998).

Artificial neural networks (ANN) was applied to the primary production time-series data. The best networks configurations were found for a no-lag case where the wind regime played an important role in the availability of deep-water nutrients in the euphotic zone (Belgrano et al., 2001). Another study carried out just outside the mouth area of the Gullmar Fjord showed that the deep-water nitrogen concentration was the most important factor for the chlorophyll concentration of the surface water, although the processes was not identified (Hagberg, 2002). Based on these results, it has been suggested to further test whether the availability of deep-water nutrients has changed over time, as a result of the climate variability caused by the strong positive NAO index during the late 1980s and especially during the 1990s (Lindahl, et al., 2002).

Table 4: Literature data on primary production of the Kattegat area.

	gC m^{-2} år^{-1}	Reference
1954–1960	67	Steeman Nielsen (1958)
1985–1993	190	Heilman et al. (1994)
1984–1993	230	Richardson & Heilman (1995)

Long-term development of the primary production

By using literature data on annual production values from the Kattegat area (Table 1) and by assuming that the production over time of the Gullmar Fjord has developed more or less in parallel with Kattegat, a development of the primary production has been estimated starting 1960 up till today (Fig. 2.2.5). The "back-ground" production was set to 100 gC m^{-2} year^{-1}, which was somewhat higher according to what Steeman Nielsen (1958) calculated for the southern Kattegat area for the period 1954-1960. This higher value was presumably more likely taking into account methodological and site differences. The development of the daily mean production in the Kattegat area (EEA report no 4, ref. Richardson and Ærtebjerg, 1991) together with the estimates on the annual production for the Kattegat area calculated by Heilman et al. (1994) and Richardsson and Heilman (1995) was used for the estimation of production of the period 1960 – 1985 of the Gullmar Fjord. The increase in production during this period was caused by eutrophication according to Richardson and Ærtebjerg (1991), since the increase took part during the

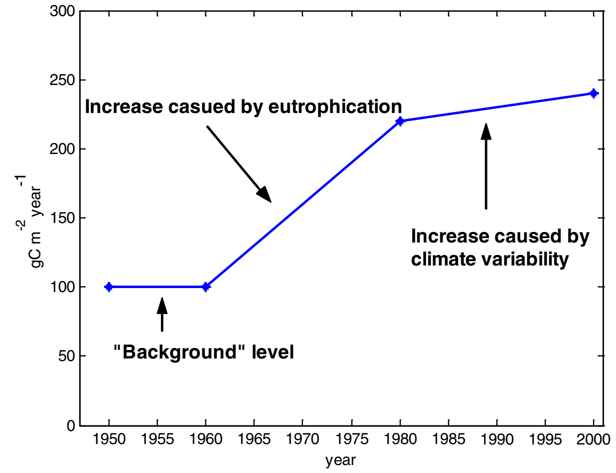

Fig. 2.2.5 Estimated development of primary production between 1950 and 2000.

summer half of the year when nutrients were supposed to be the limiting factor for phytoplankton growth. The final part of the Gullmar Fjord long-term primary production time-series is the actual measurements carried out 1985-2001, where the increase in production seems to have been caused by climate forcing as mentioned above.

The development of the primary production in the Gullmar Fjord can thus be divided into three different parts; i) the period before strong antrophogenic impact ending during the 1950s, ii) the increase was due to antrophogenic eutrophication starting 1960 and ending during the mid-1980s and iii) the increase mainly due to climate forcing (climate variability) starting during the mid 1980s. It should be pointed out that this estimated development might of course not be exact, neither in timing nor in the slopes of the curve (Fig. 2.2.5). Further, that the eutrophication effect and the climate forcing partly may have affected the productivity in parallel and at the same time.

Sedimentation and environmental effect

An analysis of datasets on the relationship between primary phytoplankton production and sedimentation of particulate material close to the bottom of

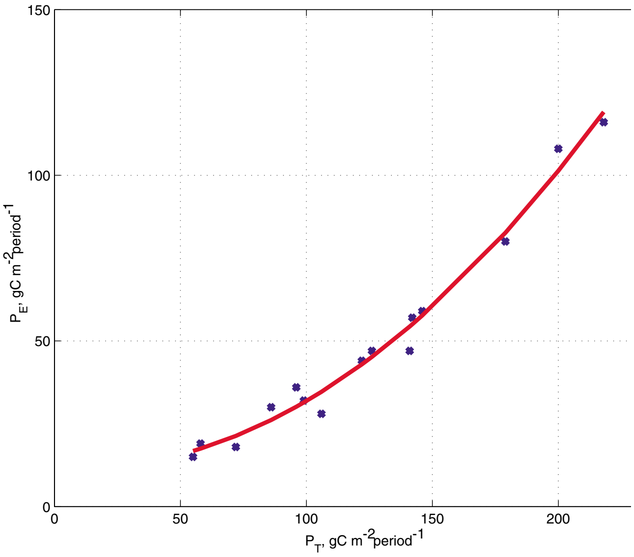

Figure 2.2.6 Correlation between total primary production and exported production (sedimentation). Redrawn from Wassman, 1990.

the photic zone has been compiled by Wassman (1990). The data used was mainly selected from simultaneous, time-integrated measurements derived over intervals covering most of the productive season (>6 months). The data represented coastal waters of the boreal zone of the North Atlantic. Wassman revealed through a regression analysis that the sedimentation (= export production, P_E) was positively and nonlinearly correlated with total

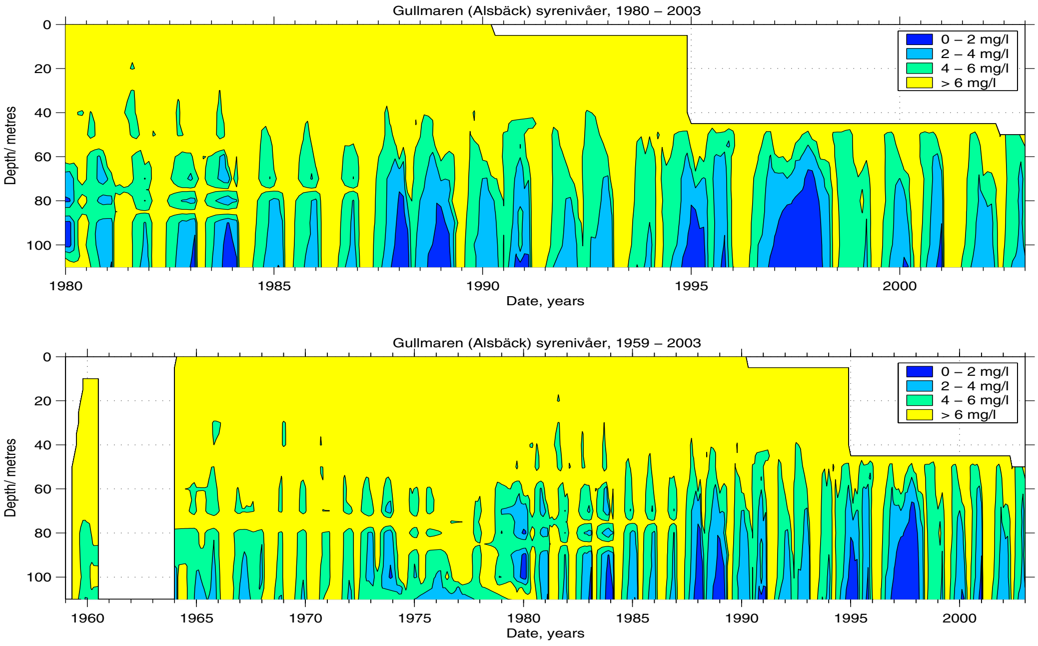

Figure 2.2.7 Oxygen concentration in the deep water of the Gullmar Fjord.

production (P_T). Best fit was found by a power equation ($r^2 = 0.94$).

By using Wassman´s relationship between P_T and P_E , the sedimentation (P_E) can be estimated to have increased from approximately 60 gC m^{-2} $year^{-1}$ during the 1950's to about 120 gC m^{-2} $year^{-1}$ in the mid 1980's and further to almost 150 gC m^{-2} $year^{-1}$ at the end of the century (Figure 2.2.6). This corresponds to an increase of the organic load to the water-column of Gullmar Fjord below the photic zone of about 250% in 40 years. However, it should be pointed out that the ralationship nowadays is more or less out of range and has to be checked to be valid also at the present levels of production. It is likely that this large increase of supply of organic matter may be responsible for a considerable part of the nowadays frequently observed low values of oxygen concentration of the deep water of the Gullmar Fjord (Figure 2.2.7, Forum Skagerrak, 2001) as well as observed changes in the soft-bottom benthic community (Forum Skagerrak).

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2.2.3 Phytoplankton indicator species and harmful algal blooms

- Bengt Karlson, SMHI

Summary and conclusions

Harmful algal blooms is still a serious problem in the Kattegat-Skagerrak area. The fishery, the aquaculture industry and the tourism are affected. The blooms of *Chattonella* spp. in the Kattegat-Skagerrak area in May-June 1998 and in March 2002 are new phenomena that may be eutrophication related. Blooms of *Dinophysis* spp. occur yearly along the Kattegat-Skagerrak coast. The period of high DST (Diarrhetic Shellfish Toxin) content in blue mussels seem to have increased. Also new areas now have mussels containing DST. However, the limited monitoring data on *Dinophysis* spp. show no increase in abundance. *Alexandrium* spp. occur on occasion with events of PST (Paralytic Shellfish Toxin) content in blue mussels. Also strong blooms of potentially toxic diatoms belonging to the genus *Pseudo-nitzschia* have been observed, but no effects of ASP (Amnesic Shellfish Poisoning). The 2.5 fold increase in primary production comparing the 1990s with the 1950s is clearly eutrophication related. A high frequency monitoring programme for harmful algal blooms is missing in Sweden.

Overview of data

The Swedish National monitoring programme for phytoplankton in the Kattegat and the Skagerrak today include three sampling locations: Släggö at the mouth of the Gullmar fjord, Å17 in the western part of the central Skagerrak and Anholt E in the central Kattegat. The official database BIOMAD, maintained at Stockholm University, currently contain data from 1986 to 2001. Since phytoplankton sampling at Å17 started in August 1999 no data is presented here. Two other stations have been part of the national programme: Hallands Väderö and Brofjordens angöring. The data from these stations has been used in this assessment. Locations of sampling stations are shown in Figure 2.2.8. Sampling has usually been performed using a tube to integrate over depth. Sometimes several different depth intervals has been sampled in this way. In this assessment the data has been treated equally independent of depth. Data on phytoplankton abundance are also produced by the regional monitoring programmes along the Swedish West Coast, e.g. “Water Quality Association of the Bohus Coast” and programmes along the coasts of Halland and Skåne. These data have not been available for this assessment. Other data that has been used include short term studies on phytoplankton abundance in connection with blooms.

Figure 2.2.8. Map showing the location of sampling stations.

Harmful algal blooms

The blooms of *Chattonella* spp. in the Kattegat-Skagerrak area in May-June 1998 and in March 2001 are new phenomena that may be eutrophication related. A *Chattonella*-bloom also occurred in year 2000 but it was observed mainly in the southern part of the North Sea. This flagellated genus belongs to the algal class Raphidophyceae. The alga damages the gills of fish. In 2001 about 1100 tons of caged salmon was lost in Norway. In Sweden no effects were observed. In 1998 both wild and caged fish died because of the alga.

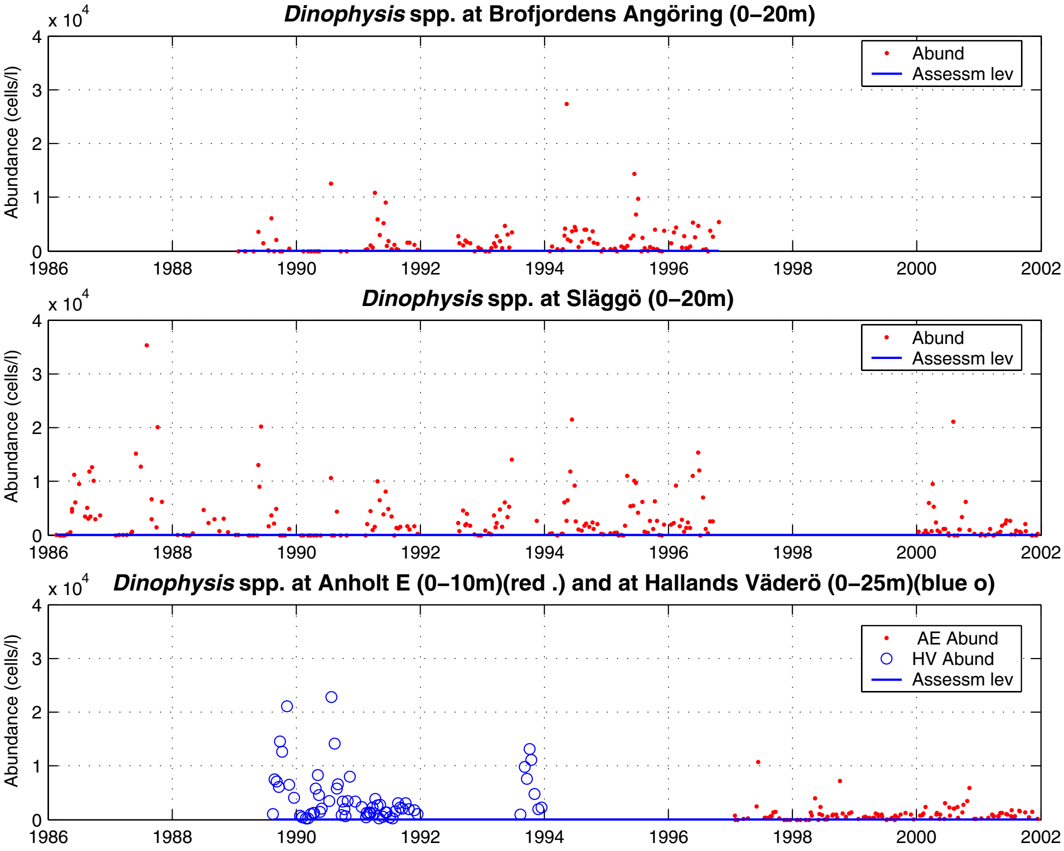

Figure 2.2.9. The abundance of *Dinophysis* spp. at four stations in the Skagerrak-Kattegat, OSPAR assessement level is 100 cells l^{-1}.

Blooms of species belonging to the Raphidophyceae have never been observed in this area before. However, they are well known from Japanese waters and also from the Pacific coast of Canada (British Columbia). A hypothesis proposing that *Chattonella* sp. is an introduced species has been put forward. This is possible e.g. by transport i ballast water of ships. However, reanalysis of phytoplankton samples from 1993 indicate that the species was present in the Lysekil area already at that time. The species blooming here seem to be different than the species known elsewhere.

Blooms of *Dinophysis* spp. occur yearly along the Kattegat-Skagerrak coast. The blooms have low biomass but a few hundred cells of *Dinophysis* spp. in the water may result in toxic mussels. The most common species are *D. acuminata, D. norvegica* and *D. acuta*. Since the available data set is fairly limited in time no conclusion regarding connections between eutrophication and *Dinophysis* abundance can be made. Data is presented in figure 2.2.9.

Species belonging to the PSP-producing genus *Alexandrium* are observed most years along the west coast of Sweden. The most important species are *A. tamarense, A. minutum* and *A. ostenfeldii.* Data is presented in figure 2.2.10.

The dinoflagellate *Karenia mikimotoi* (syn. *Gyrodinium aureolum, Gymnodinium mikimotoi)* and *Prorocentrum* spp. occur occassionally in the area. No large blooms have been observed the last few years (Fig. 2.2.10).

The diatom genus *Pseudo-nitzschia* is common in the area (Fig. 2.2.13). In 1993 a strong bloom occurred in the Kattegat-Skagerrak. Several species belonging to this genus produce domoic acid, the cause of ASP (Amnesic Shellfish Poisoning). No toxic effects were observed during that bloom but in year 2001 the toxin has been found in low concentrations in shellfish in Norway and Denmark. Shellfish harvesting has perodically been banned in e.g. Scotland because of high concentration of domoic acid.

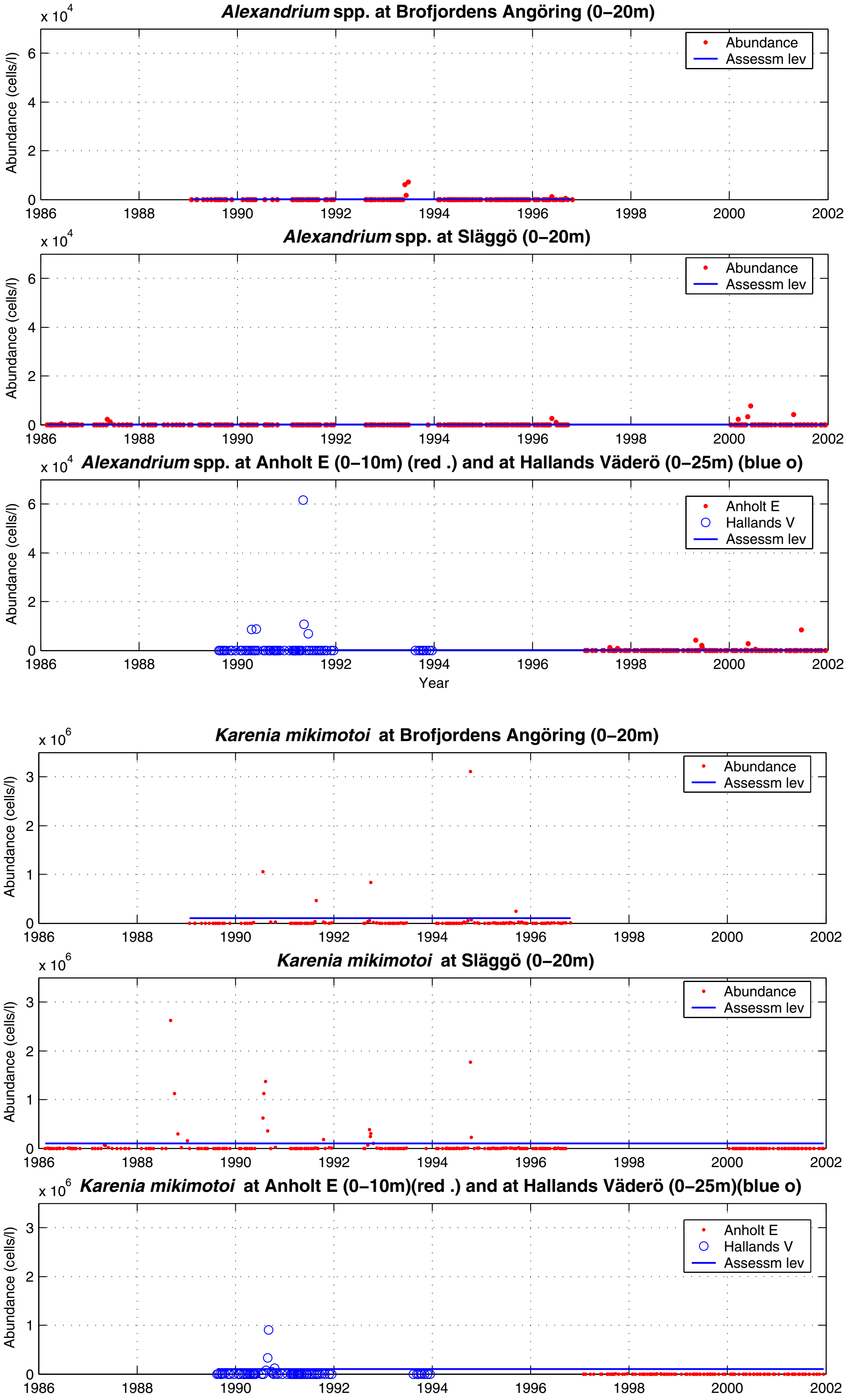

Figure 2.2.10. The *Alexandrium* spp. and *Karenia mikimotoi* (lower panel) at four stations in the Skagerrak-Kattegat. Assessments levels are found in appendix D.

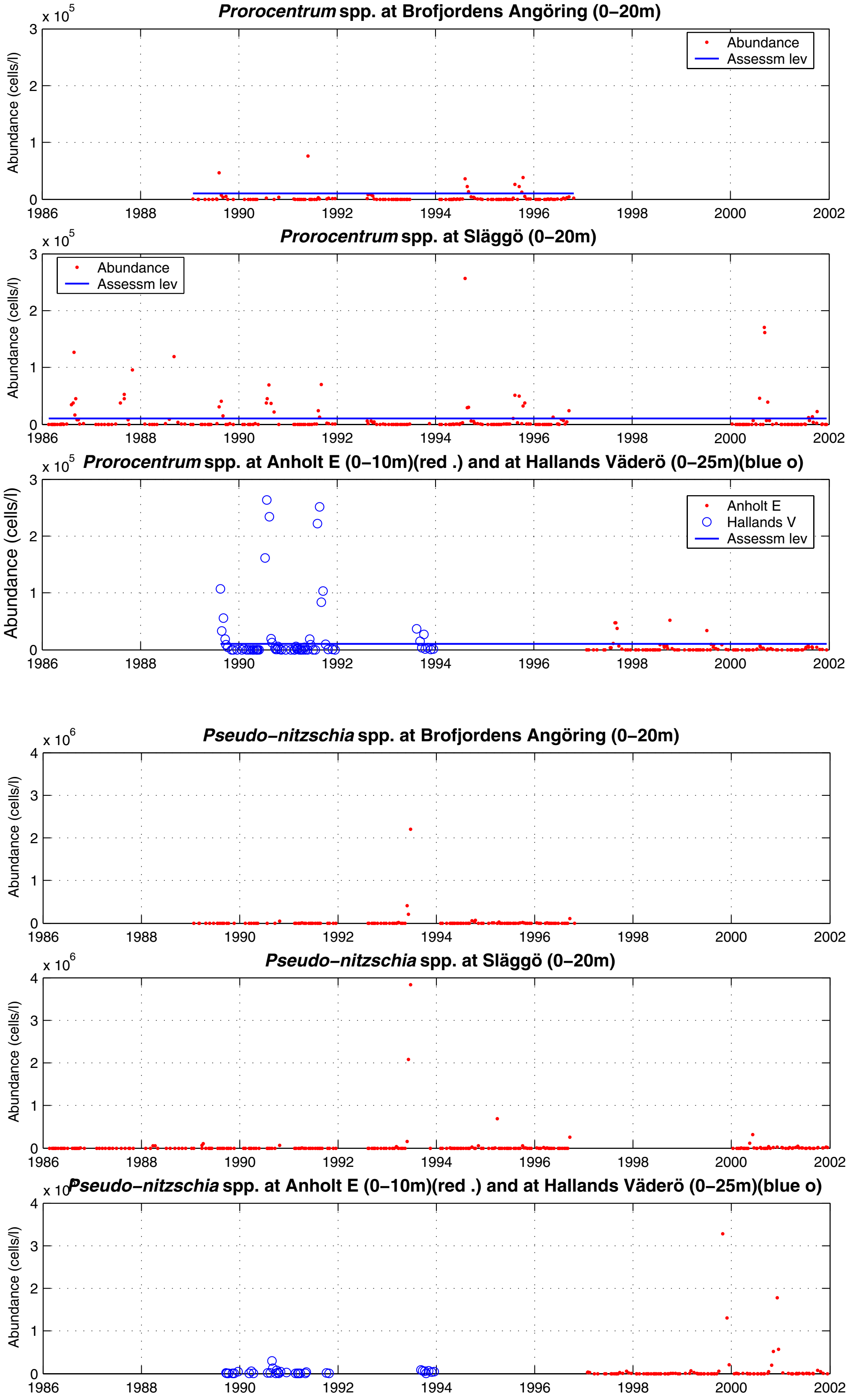

Figure 2.2.11. The *Prorocentrum* spp. and *Pseudo-nitzschia* spp.(lower panel) at four stations in the Skagerrak-Kattegat. Assessments level for *Prorocentrum* spp. is found in appendix D. No assessement level exist for *Pseudo-nitzschia* spp.

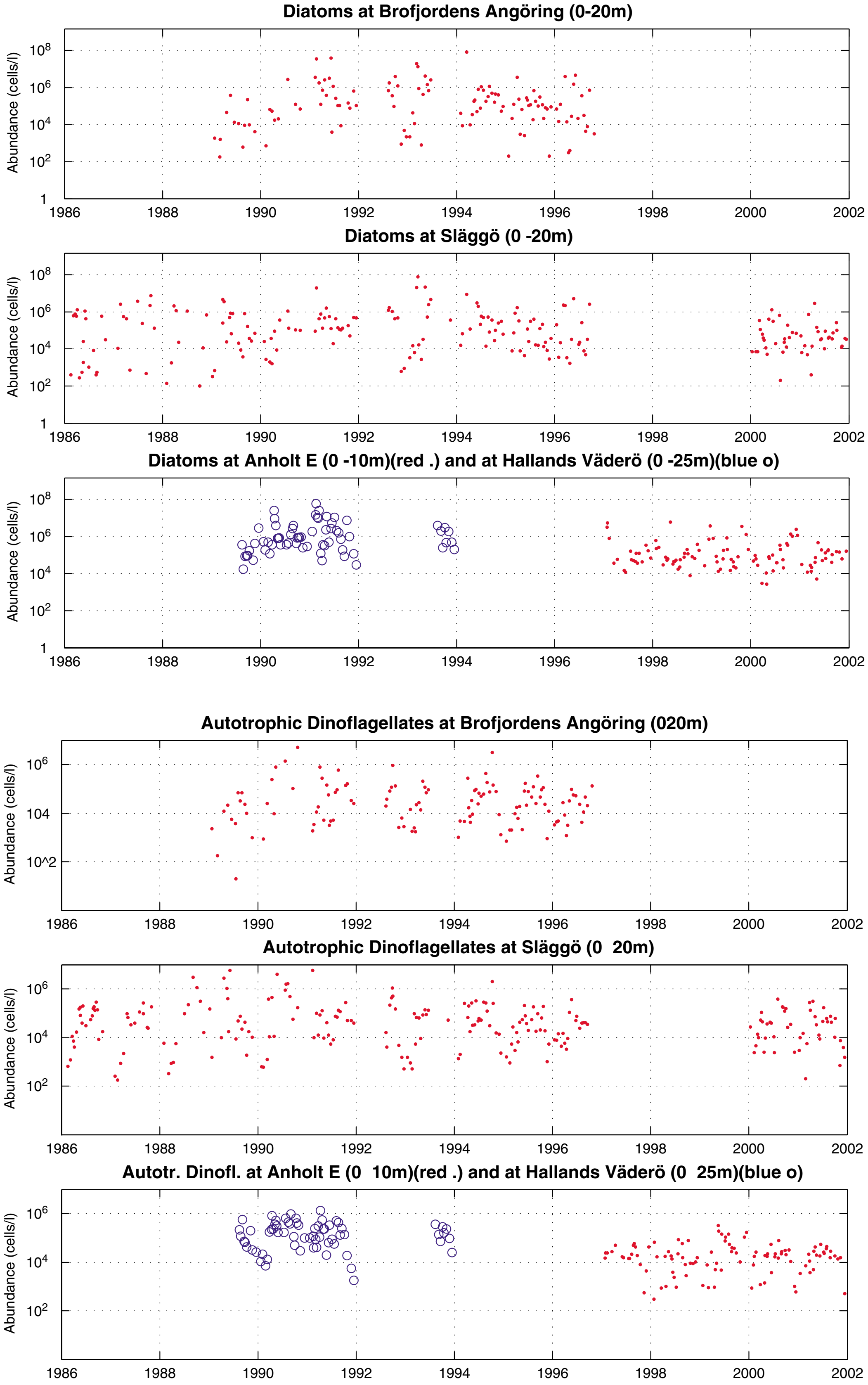

Figure 2.2.12. The abundance of diatoms (upper panel) and autotrophic dinoflagellates (lower panel) at four stations in the Skagerrak-Kattegat.

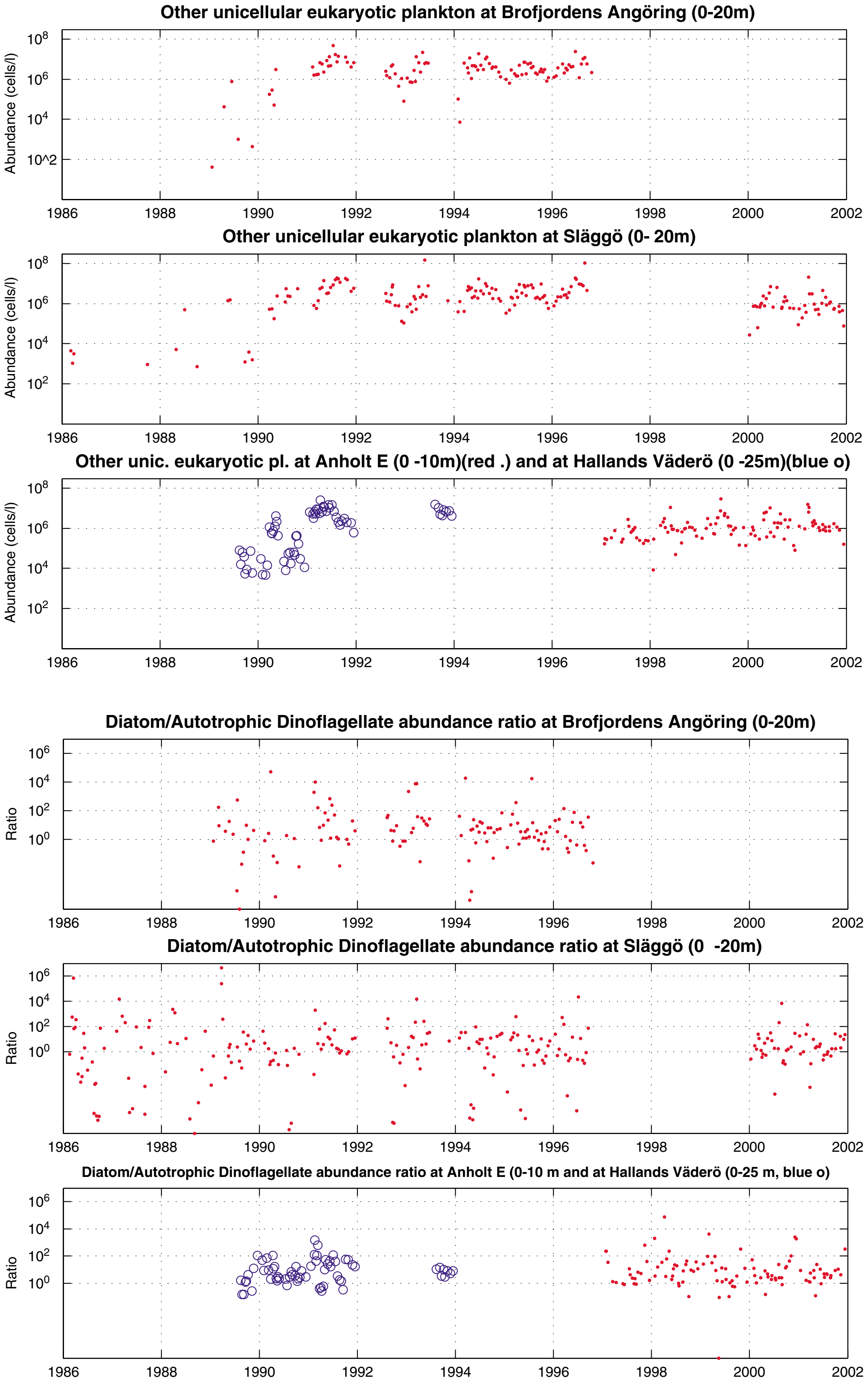

Figure 2.2.13. The abundance of other unicellular eukaryotic plankton (upper panel) and the ratio of the abundance of diatoms/ abundance of autotrophic dinoflagellates (lower panel) at four stations in the Skagerrak-Kattegat.

Table 5. Data used for the production of graphs. Sampling continues at Släggö and Anholt E but data is not yet available.

Station	**Latitude**	**Longitude**	**Period(s)**	**Frequency**	**Depth**
Anholt E	N 56º 40.0’	E 12º 07.0’	1997-2001	ca. 24/year	0-10 m
Hallands Väderö	N 56º 29.5’	E 12º 32.0’	1989-1997	ca. 24/year	0-5, 5-10, 10-15, 15-20, 20-25 m
Släggö	N 58º 15.5’	E 11º 26.0’	1986-1996 2000-2001	ca. 24/year	0-5, 5-10, 10-15, 15-20 m
Brofjordens angöring	N 58º 15.5’	E 11º 13.5’	1989-1996	ca. 20/year	0-5, 5-10, 10-15, 15-20 m

Table 6. Occurrence of phytoplankton indicator species in the Skagerrak-Kattegat 1990-2001. The table shows both occurrence at abundance over detection limit and the occurrence at abundance higher than assessment level (see appendix D.

	No. of samples	**% *Alexandrium* spp.**	**% *Alexandrium* spp. > Assessment lev.**	**% *Dinophysis* spp.**	**% *Dinophysis* spp. > Assessment lev.**	**% *Chatonella* spp.**	**% *Chatonella* spp. > Assessment lev.**	**% *Chrysochromulina* spp.**	**% *Chrysochromulina* spp. > Assessment lev.**	**% *Karenia mikimotoi***	**% *Karenia mikimotoi* > Assessment lev.**	**% *Noctiluca* sp.**	**% *Noctiluca* sp. > Assessment lev.**	**% *Phaeocystis* sp.**	**% *Phaeocystis* spp. > Assessment lev.**	**% *Prorocentrum* spp.**	**% *Prorocentrum* spp. > Assessment lev.**
Brofjordens Angöring	126	4	4	81	79	0	0	3	0	33	4	2	0	2	0	40	7
Släggö	233	4	4	80	76	2	1	10	3	21	6	0	0	1	0	46	16
Anholt E	108	8	8	88	84	6	1	50	3	4	0	0	0	4	1	38	6
Hallands Väderö	66	8	8	100	100	0	0	59	15	18	5	3	0	0	0	58	26
All stations total:	533	5	5	84	81	2	0.6	22	3.6	20	4	0.8	0	2	0.2	45	13

After the devastating bloom of *Chrysochromulina polylepis* in 1988 the interest in the haptophyte genus *Chrysochromulina* has been strong. The method used in the Swedish phytoplankton monitoring programme is the Utermöhl method (sedimentation chamber). Using this method it is usually impossible to identify smaller phytoplankton, including *Chrysochromulina* spp., to the species or genus level. This holds true also for several other toxic or noxious species. Thus the information on abundance of smaller blooms of *Chrysochromulina* is lacking.

Algal blooms and eutrophication

The time series for the total number of diatoms and autotrophic dinoflagellates (Fig. 2.2.12), other phytoplankton (Fig. 2.2.13) and in Fig. 2.2.13 the ratio of diatom abundance/abundance of autotrophic dinoflagellates is shown. No clear trend is evident in these data. This indicates that no evident shift in eutrophication affecting phytoplankton has taken place. Since the available database do not cover a period with lower eutrophication than present no clear conclusions can be made regarding the effects on harmful algal blooms from this. However, in other areas, e.g. Hongkong, data exist that clearly shows a correlation with eutrophication/urbanisation and the frequency of harmful algal blooms. Phytoplankton in general are clearly favoured by eutrophication. The primary productivity in the Skagerrak-Kattegat area has increased 2.5-fold from the 1950s to the period 1990-2000 (Odd Lindahl, chapter 2.2.2).

2.2.4 Macrophytes including Macroalgae

- Jan Karlsson, Tjärnö Marine Biological Laboratory (TMBL)

Monitoring and survey programmes

In 1993, regular macrophytobenthos monitoring started at the Swedish West Coast with 6 localities in the coastal part of the eastern Skagerrak being monitored yearly (e.g. Karlsson 2000, 2001a). Regional programmes that include monitoring of macroalgae in the Kattegat have been run by the County Administrative Board of Halland (Carlsson 1993, 1996) and in the Kattegat as well as in the Skagerrak, by the Bohus Coast Water Quality Association (Näslund 1992, 1994, 1995). The Bohus coast Water Quality Association also runs a survey of floating algal mats in shallow-water bays, which include the northern part of the Kattegat and the Skagerrak (Moksnes & Pihl 1995, Pihl et al. 1997, Pihl & Svensson 1998, Pihl et al. 2001).

In addition to these programmes there are several general surveys of the phytobenthos (Grevby, 1997, 1998, Gustafsson in prep., Karlsson 1986, 1995b, 1999b, 2001b, c, 2002, Karlsson et al. 2000, Loo et al. 1996, Lunneryd & Åberg 1983, Pedersén & Snoeijs 2001).

The Danish marine monitoring programmes which include benthic vegetation and cover both coastal and open sea areas in the Kattegat, have been operational and from 1994, running at full scale. (Dahl et al. 1995, 2001, Kaas et al. 1996, Jensen et al. 1997, Ærtebjerg et al. 1998, Markager et al. 1999 and references therein). Hence, some results, mainly from open sea environments will be cited, as they most probably are relevant for conditions in adjacent Swedish waters.

The species number decreases from about 350 species in Skagerrak to approximately 150 at the entrance of the Baltic Proper (Nielsen et al. 1995), partially as a result of decreased salinty and light penetration. The major part of the reduction in species number takes place over a relative short geographic distance in the Sound and Belt Sea area (Nielsen et al. 1995). Coastal areas differ from open sea areas, too. Open sea localties in the Kattegat have a higher species richness than coastal localities in the Skagerrak, which in turn are richer than localities in the coastal part of the Kattegat (Pedersén & Snoeijs, 2001). A peak in species richness, attributed to the occurrence of halophile red algae less tolerant to sedimentation, has been noted at depths between 18-22 m (data from 1989-90, Pedersén & Snoeijs 2001) and at 14-18 m (data from 1997, Karlsson 2001b) at open sea localities in the Kattegat. These findings suggests spatial, and probably also temporal variation, although the Danish monitoring programme reports no significant temporal variation for species richness in their open sea localities monitored along the northern Kattegat-western Baltic Proper gradient (Dahl et al. 2001). Recent surveys in the northern part of the inshore Kattegat show a peak in the mean number of taxa at 6-10 m (Karlsson 2002) and for coastal localities in the Skagerrak at 8 m. Some temporal variation was found at depths above 3 m or below 16 m (Karlsson 2001a).

The depth distribution of macroalgae normally increases with increasing distance from the coast because of decreasing water turbidity. The maximum depth for erect macroalgae (*Coccotylus truncatus, Delesseria sanguinea, Bonnemaisonia hamifera (tetrasporophyte)*) at localities in the open sea in the central Kattegat recorded so far is 29 m (Lilla Middelgrund, Karlsson 2001b), which is comparable to conditions in the open Skagerrak (Fredriksen & Rueness 1989, Karlsson 1995b, Lunneryd & Åberg 1983). Here erect macroalagae (*Phycodrys rubens*) have been encountered down to 32 m (Karlsson 1995c). Somewhat shallower levels, partially explained by differences in the hard bottom depth distribution, have been reported from Kim's Top and Stora Middelgrund (Nielsen & Dahl 1992, K. Dahl pers. obs), and from the middle and northern parts of the Swedish Kattegat coast, where erect macroalgae have been recorded down to 24-25 m (Gustafsson in prep., Karlsson 1986, 2001c, 2002, Karlsson et al. 2000). On most localities investigated in the Danish monitoring program, the lack of hard bottom substrate per se puts a limit to the maximum depth distribution of benthic algal communities.

In the open parts of the Kattegat the up-right vegetation covers about 95-100% of the hardbottom substrate in a complex, multilayered pattern down to depths of approximately 15 m (Ærtebjerg et al. 1998). Below 15 m, the erect vegetation in general is single layered and the cover gradually becomes thinner, ending up with only red and brown crusts. An overall significant increase in the vegetation cover was observed at localities in the open northern and central parts of the Kattegat in 1996-97, compared to the average conditions in the period 1990-98. The increase in total area covered was not correlated with an increase in species numbers (Aertebjerg et al. 1998). In June 1998 on the other hand, a significant decrease in vegetation cover was observed (Markager et al.1999). The increase in macro algal cover in 1996-97 (Aertebjerg et al. 1998) is not fully understood. Year to year variation in irradiation, measured as hours of sunshine over land, did not correlate with the changes in vegetation cover. However the low nutrients load to Kattegat in 1996-97 caused by two dry years, may explain the observed increase in vegetation cover. Low nutrients load may have resulted in reduced pelagic plankton biomass and, because of this, increased light penetration to the seabed. (Markager et al., 1999).

In the southern-most part of the Kattegat no year to year changes have been detected, partially because of the intense grazing by sea urchins (*Strongylocentrotus droebachiensis*) (Markager et al.1999). Pedersén & Snoeijs (2001) found that in general, the vegetation cover was significantly higher in open sea localities in the Kattegat compared with coastal sites in the Kattegat and the Skagerrak. A phenomena occurring along the Skagerrak-Kattegat coastal gradient, described as "haline submergens" (Kylin 1906, 1944, 1947, 1949, von Wachenfeldt 1975), is the downward migration of upper and/or lower limits of macroalage, and has recently been quantified by Pedersén & Snoeijs (2001). 14 out of 28 of the most commonly found species showed a significantly deeper mean upper growth-limits in the Kattegat compared with the Skagerrak and the fucoids *Fucus vesiculosus* and *F. serratus* were shown to extend their lower growth-limits deeper in the Kattegat compared with the Skagerrak (Pedersén & Snoeijs (2001).

Macrophytobenthos and eutrophication

The impact of eutrophication on macroalgae may involve a reduced abundance or disappearance of large perennial macroalgae, a shift of functional morphologies in the community (eg from coarse, perennial forms to thin sheet-like or filamentous fast growing forms) or a rise of the lower depth limit of growth. Generally, eutrophication results in the dominance of filamentous or tubeformed green algae or sometimes filamentous brown algae. The increased primary production results in huge amounts of organic material, which, when it decomposes, leads to hypoxia or anoxia in the water. Macroalgae species favoured by eutrophication in the Kattegat- can include *Erythrotrichia* sp. (red), *Ectocarpus* sp., *Pilayella littoralis* ("browns"), *Chaetomorpha* sp. *Cladophora* sp., *Enteromorpha* sp., *Percursaria percursa, Rhizoclonium* sp., *Ulva* sp. and *Ulvaria* sp. ("greens").

There are no evident direct links between the nutrient status in the water and effects on macroalgae on the Swedish West Coast. In general, historic data implies that the lower growth depth limit was deeper than today (Kylin1944, 1947, 1949, Sundene 1953). However, the historic data was collected by a dredging method, and the figures given are frequently biased. Hence, it is in most cases impossible to separate methodological constraints from environmental impacts.

Wennberg (1987) reported a severe change in the macroalgal flora at depths between 1-3 m in the south-east part of the Laholm Bay, south-east Kattegat. Based on local surveys performed between 1952-1986, he reported the disapperance of fucoids (*Fucus spiralis*, *F. edentatus*, *F. vesiculosus*, *F.serratus*) over a ten year period, starting in 1972. The fucoids between 0-0,5 m were in general replaced by *Enteromorpha* sp., *Polysiphonia* sp. and *Ceramium* sp., while *F. serratus*, which grew at depths between 0,5-2,5 m was mainly replaced by *Cladophora* sp. During spring, *Pilayella littoralis* and *Acrosiphonia* sp. become dominant. The shift from perennials to opportunistic species in the upper sublittoral coincides with huge amounts of filamentous green algae, mainly *Cladophora* sp., and mussels (*Mya* sp., *Cardium* sp./*Laevicardium* sp.) (Rosenberg & Edler 1981) washed ashore in the south-east part of Laholm Bay.

During the summer periods in 1994-1996, floating mats of filamentous algae occurred in shallow-watered bays (1 m) along the Skagerrak coast and in the north east part of the Kattegat. They covered between 25 % and 50 % of the area available, but with no significant variation between years (Pihl et al. 1997). Between 1994 - 2000, larger areas were affected in the northeast part of the Skagerrak than in the north east Kattegat. The bulk of the floating mats constituted of *Cladophora* sp. and *Enteromorpha* sp. No correlation between the occurrence of filamentous algae and known emissions of nutrients has been found (Pihl et al. 1997).

The Swedish National Monitoring Programme operates in very exposed or semi-exposed environments in eastern Skagerrak. The occurrences of algae associated with eutrophication are in general low and confined to the more sheltered areas, but with considerable variation between years. Thus filamentous brown algae peaked in 1997 with an area of 15 % covered at depths between 3-8 m, while in 1998 being hardly detectable (Karlsson 2001a). Filamentous red algae (mainly *Bonnemaisonia hamifera t-phyte* and *Spermothamnion repens*) showed an increase in the area covered until 1997, when it covered 60 % of the bottom area at depths between 6-14 m. During the following years there was a gradual decrease in the area covered.

Changes in the depth distribution of some species have been noted between 1994-2000. The brown perennials *Halidrys siliquosa, Laminaria hyperborea, L. saccharina,* the “filamentous reds”, *Corallina officinalis* and *Chondrus crispus* (both red algae) all show a more or less narrowing in their ranges, with their upper limits lowered and their lower limits risen (Karlsson 2001a). It has been suggested that an upward shift imply eutrophication in that the light penetration is hindered by increased turbidity due to higher phytoplankton growth and by the sedimentation of plankton when they die (Johansson et al. 1998, Kautsky et al. 1986, Pedersén & Snoeijs 2001).

Anoxia and the occurrence of the sulphurbacteria *Beggiatoa* sp. was widespread in shallow parts along the northern part of the Swedish Kattegat coast in the summers of 1994-1997 (Karlsson 1995a, b, 1996, Karlsson et al. 2000, Loo et al. 1996).

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INDIRECT EFFECTS

2.3 Indirect effects of nutrient enrichment

2.3.1 Oxygen depletion

– Lars Andersson, SMHI

An increase in nutrient concentrations may lead to increased primary production and plant biomass. The degradation of this biomass may in turn lead to oxygen depletion in the deep water. This problem mainly occurs during late summer and autumn when a large amount of algae sinks down into the deep water and when the water column is stratified, so that the exchange of water between the layers is small. The various degrees of oxygen depletion – or hypoxia - show ranges for the various regions/areas: < 2 mg/l: acute toxic (ca. 75 % depletion); 4 - 5 mg/l (ca. 50 % depletion) and < 5 - 6 mg/l: deficient. Oxygen concentrations above 6 mg/l are considered to cause no problems.

The Kattegat is an area where problems with low oxygen concentrations occur regularly. It is characterised by a strong salinity stratification and hampered deep-water exchange, at least in the south-eastern parts. A time series of mean autumnal oxygen concentrations in the deep water for the whole area are shown in Fig 2.3.1. Time series for three different stations in the Kattegat are shown in Figs. 2.3.3. Even if the trend for the whole period is negative both in offshore and inshore waters, it

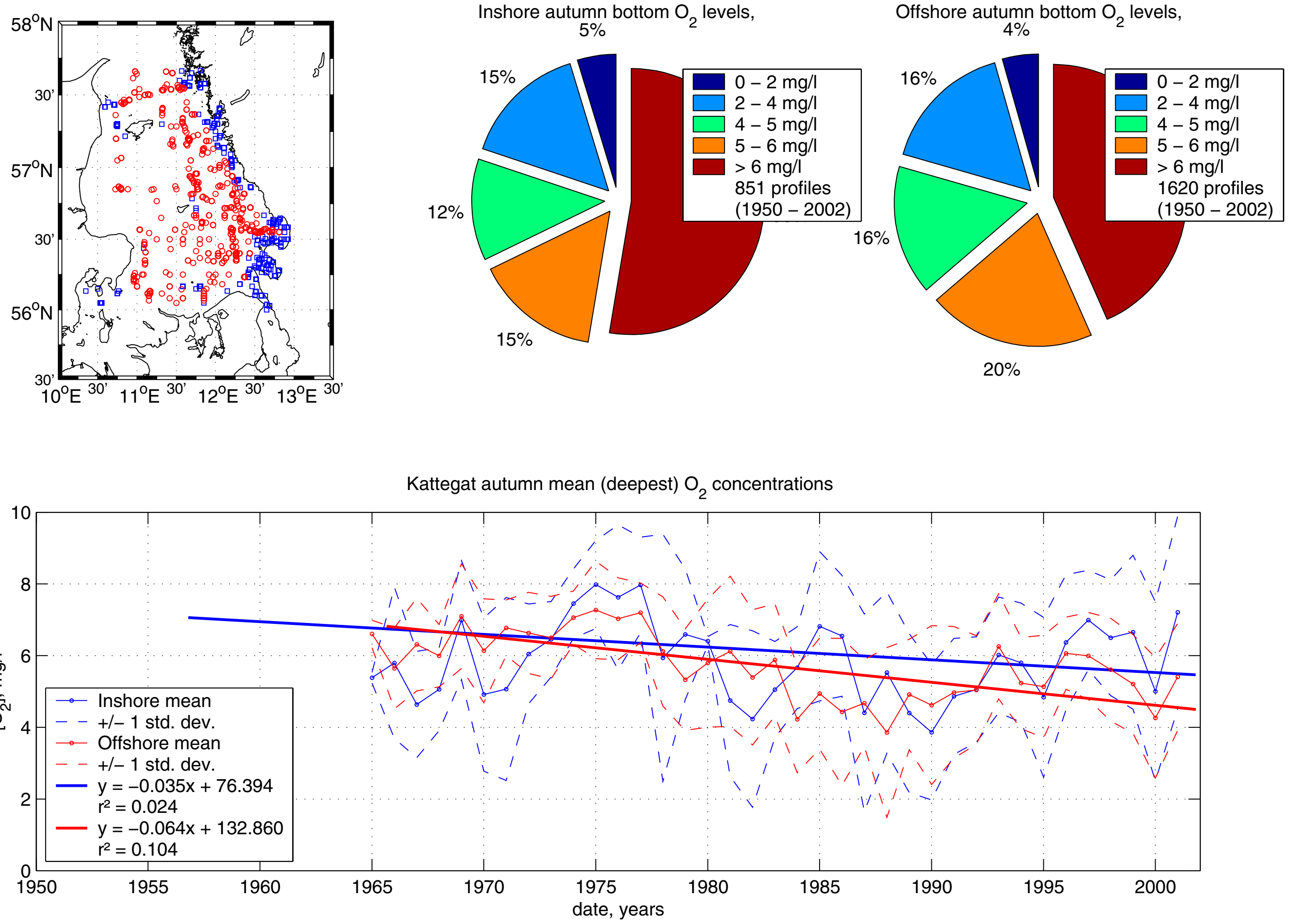

Fig. 2.3.1: Autumnal averaged annual deepwater oxygen concentrations in Kattegat inshore (blue dots and lines) and offshore waters (red dots and lines) are shown as time series and circle diagrams where data is classified into different levels of hypoxia and anoxic conditions.

is obvious that the situation was worst during the late 1980s, and that the situation has become better during the later years. Kattegat in- and offshore waters have a similar evolution in time. Nevertheless, the offshore waters are more frequently affected in time by hypoxia (< 6 mg/l) than inshore waters, 56 % and 47 %, respectively.

The offshore Skagerrak with its open border to the North Sea and large water exchange do not show any signs of problems with low autumnal oxygen concentrations. A time series for the whole area is shown in Fig 2.3.2. There seems to be a negative trend in oxygen concentrations from mid 1950s to mid 1980s but thereafter the values seem to be at a rather constant level. A similar trend is found in the inshore waters, where hypoxia on average strikes the area from 1977 and onwards. Conditions improved during the late 1980s, but were worse again in the 1990s. However, in some fjords and in the coastal area with restricted water exchange, low oxygen concentrations or the formation of hydrogen sulphide (anoxic conditions) occur frequently. Inshore and offshore waters are affected by hypoxia in 43 % and 7 % of the time and bottom oxygen concentrations are about 2 mg/l higher in offshore compared to inshore waters.

A time series from Koljöfjord in the archipelago of Bohuslän is shown in Fig. 2.3.3. At this station hydrogen sulphide frequently appears (hydrogen sulphide is shown as negative oxygen). However the trend is positive and there are signs that the situation is becoming better.

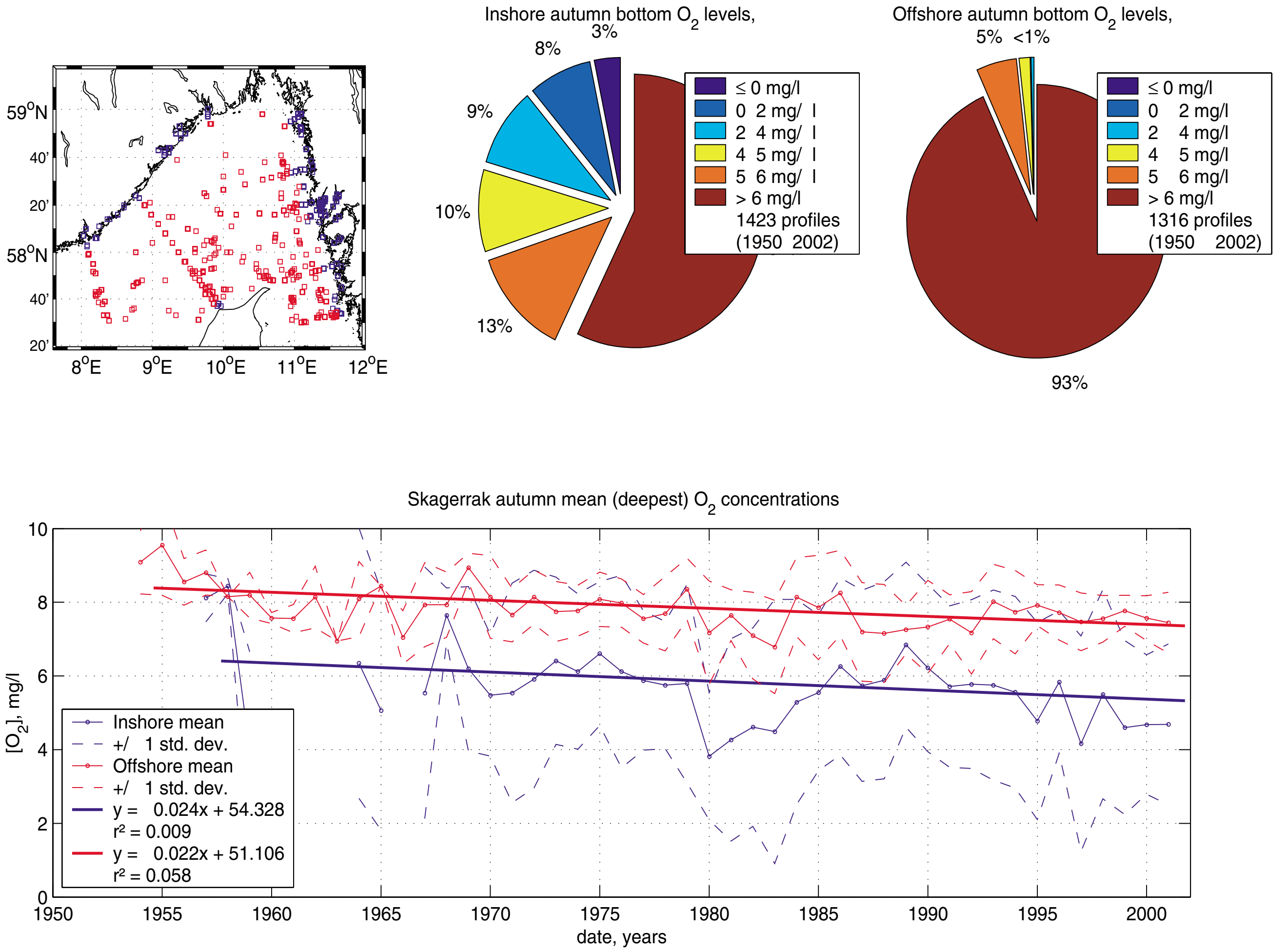

Fig. 2.3.2: Autumnal averaged annual deepwater oxygen concentrations in Skagerrak inshore (blue dots and lines) and offshore waters (red dots and lines) are shown as time series and circle diagrams where data is classified into different levels of hypoxia and anoxic conditions.

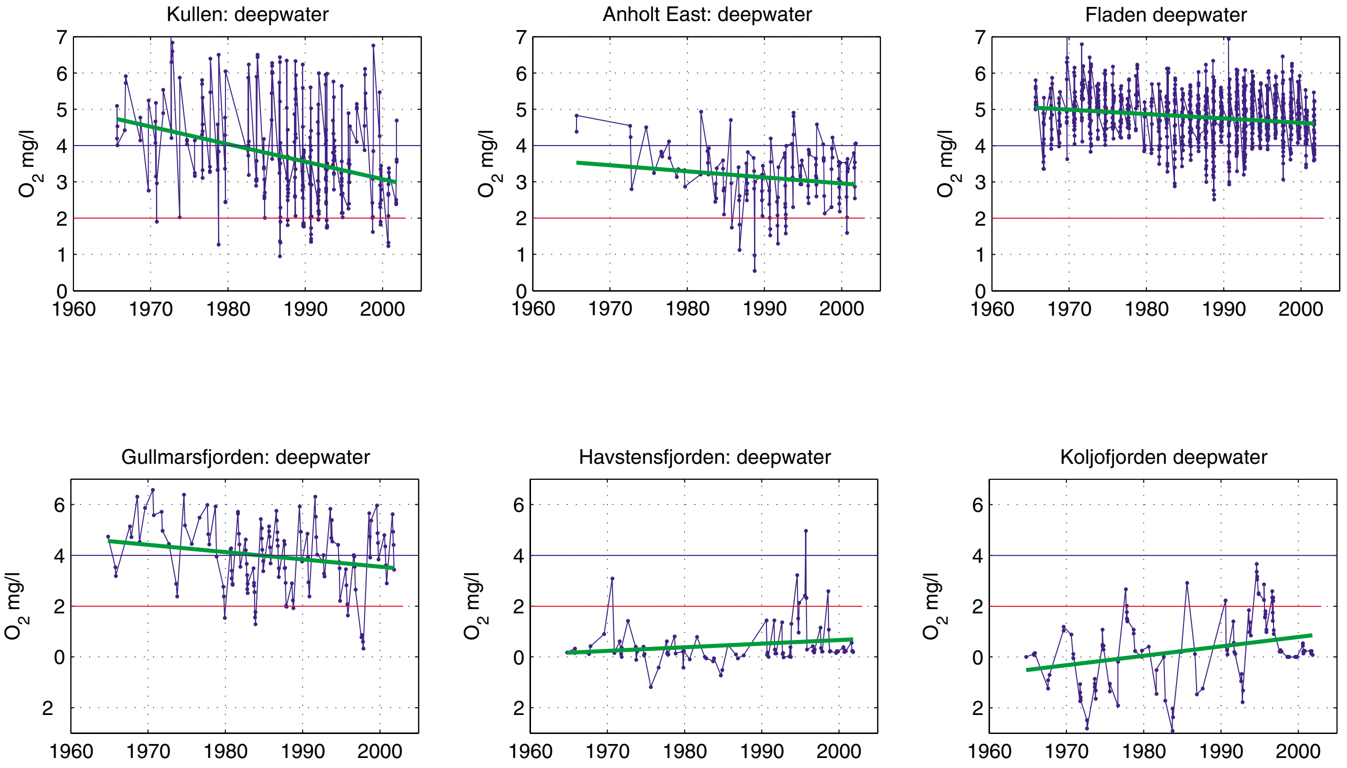

Fig. 2.3.3: Time series of deepwater oxygen levels from Kattegat(Kullen, Anholt, Fladen) and from Skagerrak (Gullmarensfjorden, Koljöfjorden, Havstensfjorden. (cf. Fig. 2.1.1) in offshore Kattegat and inshore Skagerrak.

2.3.2 Changes in zoobenthos and demersal fish

Zoobenthos in the Kattegat

– Rutger Rosenberg, Kristineberg Marine Research Station

Swedish coast

In the early 1980s, widespread oxygen deficiency in the near-bottom water with accompanying effects on the benthos was probably recorded in the Kattegat and the Belt Seas for the first time (Rosenberg, 1985). On the Swedish southeast coast of the Kattegat, the Laholm Bay, the extension of bottom areas with hypoxic water varied between years in the period 1980 through 1990 (Rosenberg et al., 1992; Rosenberg & Loo, 1988). The largest areas with hypoxia (oxygen concentrations <2 ml l^{-1} i.e.<2.8 mg/l) were recorded in the autumns of 1986, 1988 and 1990 with the maximum area affected estimated to be ca 5000 km^2. This seasonal hypoxia was suggested to be correlated with a more than threefold increase in input of N during the 1960s and 1970s via rivers entering the Laholm Bay (Rosenberg et al., 1990). In the 1990s, fewer oxygen recordings were obtained in that area and information is therefore less detailed.

The benthic fauna in Laholm Bay was reduced during periods of hypoxia, both at depths around the halocline and deeper. For example, at a station at 22 m the following invertebrate species were eliminated in the autumn of 1988 (O_2 <1 ml l^{-1} i.e.<1.4 mg/l): *Diastylis rathkei, Amphiura filiformis, Ophiura albida, Euchone papillosa, Scoloplos armiger* and *Terebellides stroemi*. None of these species had re-established in that area two years later, except possibly O. alba. Other species like *Arctica islandica, Corbula gibba, Phoronis muelleri, Heteromastus filiformis* and *Myriochele* sp. survived the period of low oxygen concentrations (Rosenberg et al., 1992). The authors stated that the benthic fauna in that area tolerated oxygen concentrations between 0.5 (0.7 mg/l) and 1.0 ml l^{-1} (2.8 mg/l) (8-15% saturation).

From 1990, investigations in the southeast Kattegat have been less extensive. The benthic fauna at one station at 20 m outside Laholm Bay has improved during the period 1993 to 1997 and seemed then to have responded to improved oxygen conditions in that particular area (Göransson, 2001). In 1999-2001, however, the author found that the conditions were worse in this area, and the number of species, abundance and biomass declined, which most probably were related to hypoxia (minimum 1.2 ml/l (1.7 mg/l) in year 2000). Also in the inner Kungsbackafjord, Göransson recorded that the fauna was reduced, probably due to hypoxia. Along the Swedish Kattegat coast, the benthic fauna was studied on 13 stations in the period 1997 to 2001. At nine of those stations, the number of taxa was lowest in 2001 (Göransson, 2001).

Open Kattegat

In 1984, Pearson et al. (1985) revisited 24 stations (depths 12-69 m) that were sampled by Petersen in 1911/12 in the open Kattegat. At 16 of these stations, the biomasses recorded in 1984 were less than those found early in the century, and at six stations very much less. The changes were partly attributable to decreases of the echinoid *Echinocardium cordatum*. In general, *ophiuroids* and *polychaetes* increased in biomass, whereas echinoids and molluscs decreased. Changes in functional groups showed that suspension feeders and carnivores increased in dominance, whereas deposit feeders decreased. In 1984, the majority of species were smaller in size compared with the situation in 1911/12. In 1989, Josefson and Jensen (1992) re-sampled 13 of the same stations. That study confirmed the small average sizes of the fauna. The greatest reductions in animal size were found in areas were hypoxia had been present. Results from these two investigations strongly suggested that the benthic communities, particularly in the southern Kattegat, were affected by eutrophication-induced hypoxia in the 1980s. Later, a comparison of the faunal biomass over the period 1979 to 1997 was made for the Kattegat within the Danish monitoring programme, and no temporal changes were observed (DMU, 1998). Danish measurements of oxygen in the period 1989 to 1997 showed a significant increase in minimum concentrations (figures not given) for the south Kattegat (DMU, 1998).

Demersal fish species and crustaceans have been severely affected during hypoxic periods in the Kattegat. In the mid 1970s, Bagge & Munch-Petersen (1979) noted that the catches of Norwegian Lobster, *Nephrops norvegicus*, increased during moderate hypoxia at 30 to 50 m depth in the central Kattegat. This correlation was repeated in the southeast Kattegat in the early 1980s (Baden et al., 1990b). The reason for the enhanced catches was that the lobsters left their burrows when oxygen saturations dropped below ~20 %. Following the enhanced catches, however, these authors reported declining catches in hypoxic areas. During the severe hypoxia in 1988, it seemed that *N. norvegicus* was eliminated from at least the south part of the Kattegat. Also, the scientific demersal fishery failed and very few fish were caught in that area because the fish fled the hypoxic waters. Instead, dying invertebrates were caught in trawls at a rate of 200 to 400 kg h^{-1} (Baden et al., 1990a). Thus, many infaunal species had left their burrows in the sediment and were caught by the trawls. Animal behaviour to stretch their bodies from the sediment surface into the water column where a little more oxygen may be available, was reported for several species: *ophiuroids* stand on their arm tips and Norway lobsters on tip-toe (Baden et al., 1990a). Arms of the brittle-star *Amphiura filiformis* are important in the diet of the dab, *Limanda limanda* (Pihl, 1994). Regeneration rates of nipped arms were, however, greatly reduced during hypoxia. Nilsson and Sköld (1996) estimated that a potential of approximately 100 metric tons of regenerating arms, as possible food for flatfish, were lost in the southeast Kattegat during hypoxia in the autumn of 1988.

In summary, since the early 1980s, the benthic fauna has been negatively affected by seasonal hypoxia in the southern Kattegat and in many Danish and Swedish coastal areas. This has also caused negative effects for the demersal fishery. The severity of the effects has varied between years, possibly because of climatic variations.

The Swedish Skagerrak coast

This coastline is rocky with many small islands and fjord-like inlets. In fjords in the central part, significant negative trends in minimum oxygen concentrations (periodically as low as 0 mg l^{-1}) in the bottom water were found over the period from the 1950s or 1960s up to 1984 at 12 sites (20-62 m depth) (Rosenberg, 1990). In some fjords the hypoxia seemed to occur seasonally, whereas in other more enclosed areas it was irregular. Changes in the benthic communities are described below, generally from south to north.

The benthos in the Stigfjord, Ellösfjord and Åbyfjord, which have some direct connection to the open coast, was investigated at 14 sites in 1976 and 1986 at depths between 7 and 27 m. Between these years, significant reductions were recorded in total macrofaunal abundance and biomass (Josefson & Rosenberg, 1988). The authors suggested that the changes could be a result of large-scale eutrophication in the area, as these fjords do not have any local riverine input of nutrients. The Stigfjord and the Ellösfjord (7 to 16 m deep) were re-visited again in the winter 1997/98, and all 14 stations

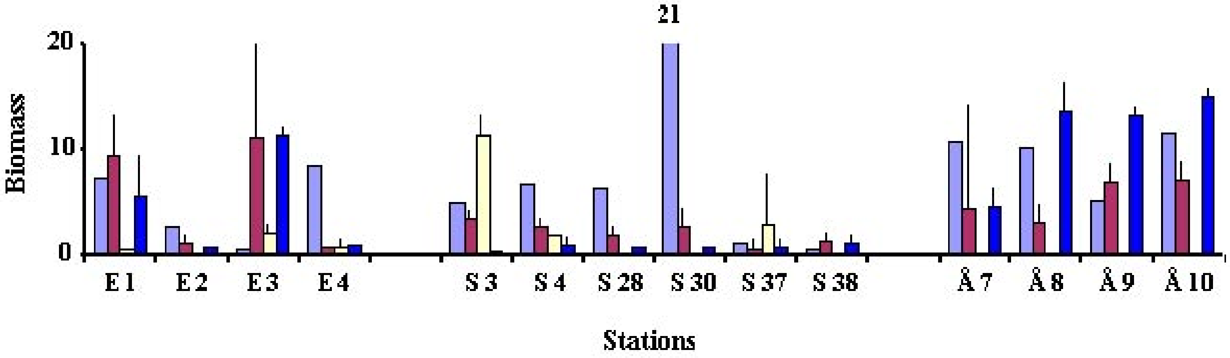

Fig. 2.3.5. Macrofaunal biomasss (g wet weight m^{2}) at stations in the Ellösfjord (E), Stigfjord (S) and Åbyfjord (Å) for the yeras 1976, 1986 (Josefson & Rosenberg, 1988), 1997/98 and 2001 (Rosenberg unpublished), where the first bar is year 1976, etc.

were sampled again in 2001. Conditions had generally gone worse compared with the two earlier dates, and only a few species and individuals were found at most stations and one was azoic in 1997 (Fig. 2.3.5) (Nilsson & Rosenberg, 1998). The extremely low biomass at these shallow stations, often a few grams only, is indeed puzzling. It is not known if hypoxia occurs at these shallow depths above the halocline and oxygen measurements have not been reported.

In fjords located further away from the coast, e.g. the Havstensfjord, sediment profile imaging (SPI) in 1994 demonstrated effects of hypoxia in sediments deeper than at 25 m depth (Nilsson & Rosenberg, 1997). The oxygen conditions had worsened in 1997 and negative effects on the bottoms were recorded in SPIs already from 6 m depth (Nilsson & Rosenberg, 1998). A sill at about 12 m is situated between the Havstensfjord and the Byfjord. The basin inside the sill has been anoxic, probably for centuries beceause of natural conditions. There is no benthic fauna in the Byfjord below the oxycline at about 15 m, and number of species and biomass gradually decline towards this depth (Rosenberg, 1977). An energy-flow model has been presented by Rosenberg et al. (1977), which showed that most of the energy-flow in this eutrophic fjord was channelled through shallow water epifauna, mainly blue-mussels, *Mytilus edulis*. Species being rather abundant in hypoxic waters were *Phoronis muelleri*, *Ophiodromus flexuosus*, *Polydora ciliata*, *Aporrhais pespelicani* and *Corbula gibba* (Rosenberg, 1977).

The Gullmarsfjord has a sill at 40 m and a deep basin with a maximum depth of 118 m. Oxygen concentrations in the deeper part of the fjord generally show a seasonal variation with minimum values before the annual water renewal usually occurring in spring. In the winter 1979/80, the oxygen concentration dropped to 0.2 ml l^{-1} (0.3 mg/l) at 118m depth and the benthic macrofauna was eliminated (Josefson & Widbom, 1988), and the meiofauna was negatively affected (Austen & Widbom, 1991). In 1997, the annual water renewal did not occur, which was the first time on record. As a consequence, oxygen concentrations remained at less than 10 % saturation for more than half of that year at depths less than 100 m, and for a month at depths <80 m. Responses to the declining oxygen concentrations of the benthic sedimentary habitat and the benthic macrofauna were investigated bi-monthly by SPI and grab samples (Nilsson & Rosenberg, 2000). The faunal diversity, abundance and biomass were reduced at depths below 80 m and eliminated below 105 m. Critical oxygen saturation for survival was found to be ~10% (0.7 ml O_2 l^{-1} (1.0 mg/l)). In situ SPIs showed that before reaching critical oxygen concentrations, the tube-building polychete Melinna cristata increased the length of its tubes up to a maximum of almost 10 cm above the sediment surface. This was interpreted as a way to reach water richer in dissolved oxygen. The authors found a strong correlation between changes in the sedimentary habitat quality and changes in diversity, abundance and biomass. Species particularly tolerant of low oxygen concentrations were the deposit feeders *M. cristata, Heteromastus filiformis, Thyasira sarsi* and *Thyasira equalis*. In early 1998, the bottom water was re-oxygenated and colonisation began. Two years later the benthic faunal composition was restored to pre-hypoxic conditions (Rosenberg et al., 2002).

The Bohus Coast Water Conservation Association monitors the benthic fauna on several stations along the Swedish Skagerrak coast at yearly intervals. A statistical analysis showed that the number of species, abundance and biomass all declined at about half of the stations from 1998 to 1999 (Thunberg and Göransson, 2001).

The long and narrow Idefjord at the border between Sweden and Norway has been greatly affected by hypoxia and anoxia from at least the 1960s and up to the early 1990s. The benthic fauna were negatively affected and eliminated along a distance of at least 20 km (Dybern, 1972; Rosenberg, 1980). The main cause for this disturbance was the effluent from the sulphite pulp mill in Halden. When that operation stopped in 1991, the water quality improved and the benthic fauna of the Idefjord has been restored in most areas, but periodic hypoxia appears east of Halden at depths >20 m (Afzelius, 1996).

Open Skagerrak

In 1985, Rosenberg et al. (1987) sampled the benthic macrofauna at 23 stations (10 to 327 m depth) in the open Skagerrak and the outer Oslofjord, which were investigated with similar methods by Petersen in 1914. In 1985, the biomass was found to be overall significantly higher by a factor of 1.8 compared with that in 1914. Significant increases were recorded for polychaete*s* and echinoderms. The community composition had changed considerably between the two dates, with general increases in the deposit feeders *Echinocardium cordatum, Abra nitida* and *Thyasira* spp. and the suspension/deposit feeder *Amphiura filiformis*. The authors suggested that the general biomass increase might have been caused by a general organic enrichment, particularly in the outer Oslofjord.

During 1972 to 1988, Josefson (1990) monitored the benthic macrofauna at 12 stations in the Skagerrak and two in the northern Kattegat (18 to 300 m depth). Total biomass showed a linear increase by a median factor of 1.8, primarily attributable to echinoderms and polychaetes. Josefson (1990) suggested that the investigated area was affected by organic enrichment.

The benthic faunal composition at 11 stations in the outer archipelago and open Skagerrak in the Swedish monitoring programme was compared between the years 2000 and 2001. The differences between years were only minor and related to depth (Agrenius, 2002). No differences related to hypoxia were recorded between these two years.

In summary, many shallow coastal areas at the Swedish Skagerrak coast are clearly disturbed, as demonstrated by low benthic faunal diversity, abundance and biomass. Some of these areas are enclosed and stratified with a temporal decrease in oxygen concentrations. In other coastal areas, the reason for the impoverished benthic fauna is unknown. Some offshore stations showed enhanced benthic faunal biomass, probably due to organic enrichment.

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Fish kills in coastal Kattegat and Skagerrak

– Henrik Svedäng, National Board of Fisheries, Sweden

The status of inshore demersal fish stocks on the Swedish west coast is to a large extent unknown due to lack of studies and reliable fishery statistics, especially during the last twenty years. In order to enlarge our biological and ecological knowledge of coastal demersal fish stocks, the National Board of Fisheries has initiated several projects under the common label the COD Project, which is carried out in three, consecutive steps. The results presented below are a compilation of the major achievements accomplished so far. The obtained results are based partly on field surveys in the coastal zone during 2000 and 2001, and partly on analyses of surveys and log book data as well as on unverified observations by fishermen along the Swedish west coast.

Surveys, log book data and unverified observations data revealed a persistent decline of the cod, pollack and plaice stocks in the Kattegat and Skagerrak. The offshore cod stock has declined continuously and almost simultaneously since the beginning of the 1980s in both the Skagerrak and Kattegat, ending at very low catch levels in the late 1990s (Fig. 2.3.6). Furthermore, the most conspicuous decline was noted during the spawning period during January-March (Fig. 2.3.7). Previous studies have shown that local spawning stocks are located along the Swedish Skagerrak coast and in the Kattegat. A spawning stock/aggregation is defined as a cohort of fish, which repeatedly spawn at a certain area/spot.

In order to obtain reliable estimates of abundance and structure of the present inshore demersal fish community, bottom trawls were made repeatedly on the Swedish Skagerrak coast in 2000-2001. Juvenile fish like dab, plaice, whiting and haddock dominated the demersal fish catches in 2000, as well as cod in 2001. The study (Fig. 2.3.8) showed an extremely low abundance of fish above 25-30 cm in total length for almost all long-lived fish species in relation to historical records for the Skagerrak coast from 1920s to 1970s.

The abundance of fish above 25-30 cm in total length did not increase during the study period, probably due to migration off the coast. The high abundance of juveniles, despite the absence of adult fish, may also indicate that the inshore demersal fish population dynamics is regulated by offshore recruitment. Hence, a major change of the inshore stock composition may have occurred during the last twenty years. Local stocks of demersal fish have been eradicated, and the inshore has become more and more dependent on transportation of recruits from offshore spawning areas in, predominantly, the North Sea.

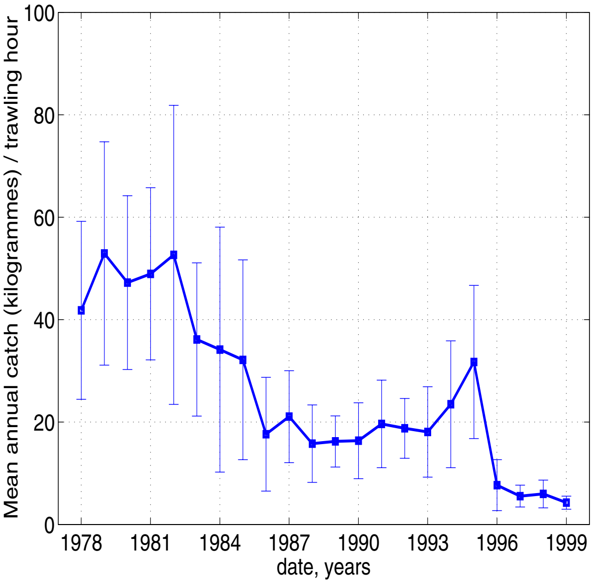

Fig. 2.3.6: A time series of mean annual catch per trawl hour in Skagerrak and Kattegat.

The effects of several biotic and abiotic variables on Atlantic cod recruitment and abundance in the Kattegat and eastern Skagerrak were explored by deploying the General Additive Models (GAM) type of modelling. It was recognised that fishing pressure dominated the abundance of cod stock, while annual cod recruitment changes were of low significance. In other words, if the fishing intensity

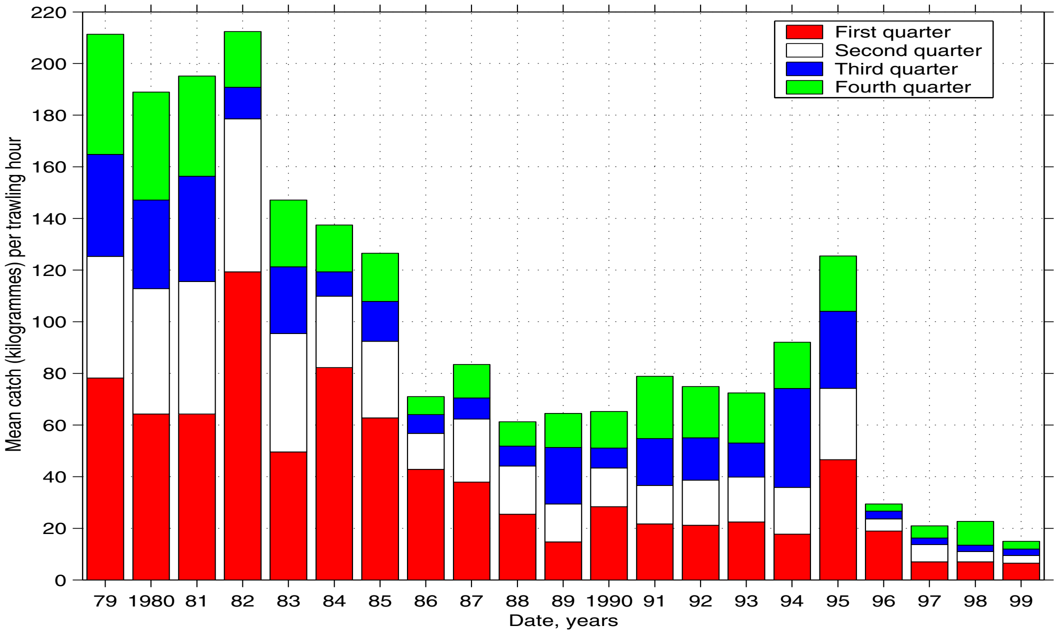

Fig.2.3.7: The same as in Fig. 2.3.8 but for different quarters of the year as stacked bars.

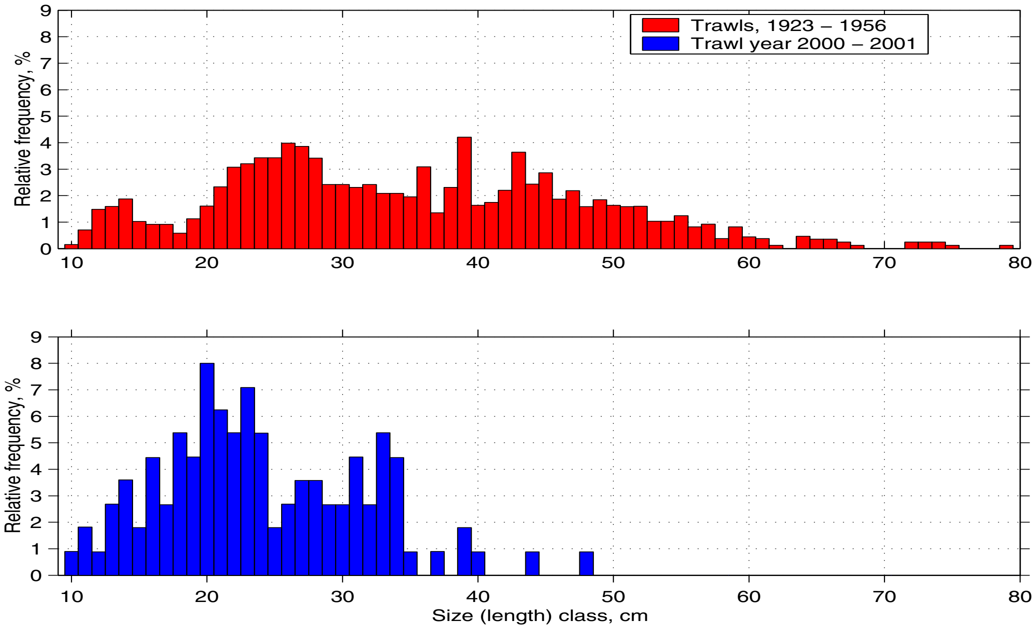

Fig.2.3.8: Histograms of cod size obtained from trawls in Brofjorden, Skagerrak from first part of the last century and from the period 2000 – 2001.

is not reduced substantially, cod stock abundance cannot be maintained even if the environmental conditions promote a high recruitment. It should be observed that no negative effects on cod abundance and recruitment could be attributed to climatological factors and the contents of oxygen, nitrogen and phosphorus in the model. In addition, no trend in recruitment of cod could be detected, which indicates that the recruitment may not be harmed by any unknown factor. To summarize, there is no evidence that the observed decline in cod abundance by studying recruitment sensitivity could be linked to a deteriorated environment in the Kattegat and Skagerrak.

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2.3.3 Organic carbon, nitrogen and phosphorous in sediment

– Ingemar Cato, Geological Survey of Sweden

Organic matter or marine humus forms a significant but often minor proportion of marine sediments, in generally between 0.5 and 10 % in the Skagerrak and Kattegat region. The amount of organic matter is best calculated from the organic carbon (and/or nitrogen) content, since loss on ignition (LOI) gives to approximate values. In general the organic carbon forms about 50 – 60 % of the organic matter. However, there is a variation in the carbon-to organic-matter ratio depending on the nature of the source material and the state of oxidation of the organic material.

The distribution of organic matter is depending on the prevailing bottom dynamic conditions. Both clay-sized particles and organic matter require quiet bottom waters for their deposition, as currents and waves will cause them to remain in suspension. Sediment deposition safeguard the enclosed organic matter against oxidation the better, the more fine-grained the sediment. The wider pores in coarse sediment allow water to circulate and to introduce a fresh supply of oxygen into the sediment, which will result in an increasing breakdown and in some cases a carrying away of deposited organic matter. Thus the distribution of organic matter (organic carbon, Fig. 2.3.9) has to be seen in the light of the distribution of different sediment types.

In the Kattegat and Skagerrak three main areas of bottom sediments can be distinguished, due to different bottom dynamic conditions. Sand and coarse silt, with an organic carbon content of less than 1 % dry matter, dominate the sediment surface of the shallow areas (<20-25 m) influenced by wave action (e.g. Floderus 1988). These sediments, poor in organic matter, are found within the main part of the western Kattegat, along the Swedish coast from the Sound in the south to about 30 km south of Gothenburg and in the north-western Skagerrak off of Jutland.

In the Skagerrak Deep (200-700 m deep) and the Deep Trench (50-150 m deep) that intersects the eastern Kattegat is dominated by recent postglacial clayey sediments with an organic carbon content of about 2-3 % dry matter (Cato et al. 1992, Kuijpers et al. 1992, Cato 1997a). These Deeps forms the

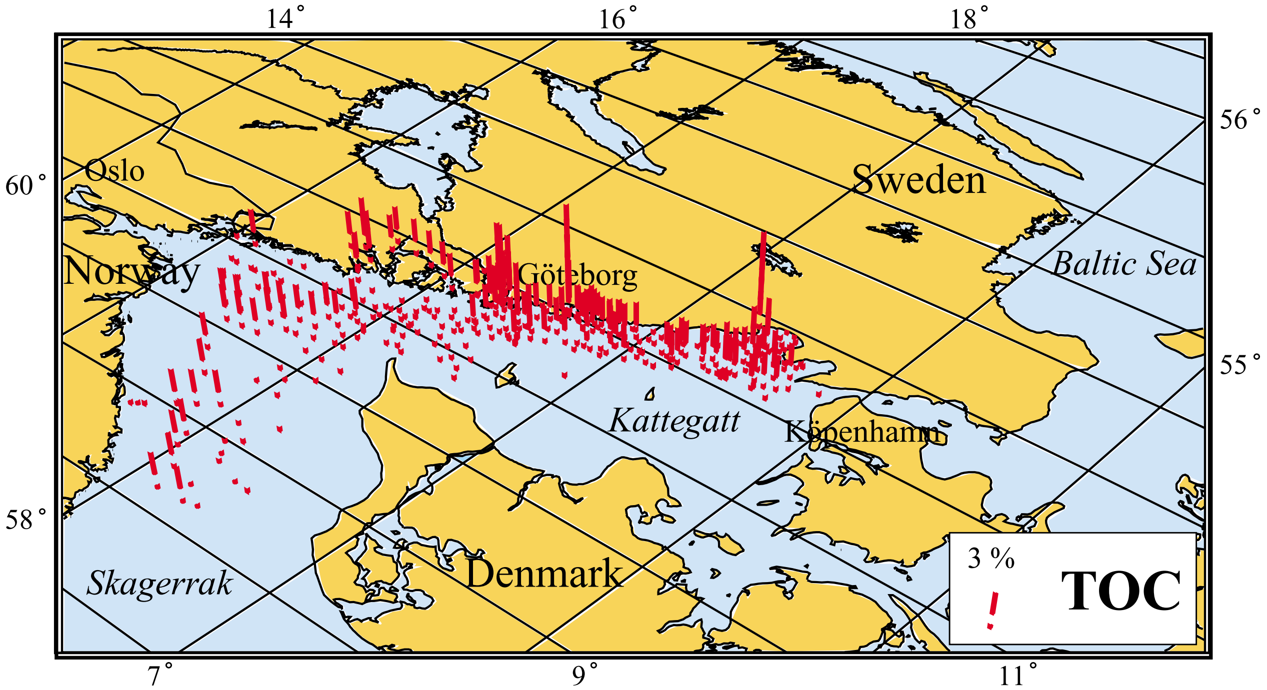

Figure 2.3.9: Geographical distibution of total organic carbon (%) in the superficial sediments (0-1 cm) of the Kattegat and Skagerrak.

Table 7. Mean, median and the range of variation of total organic carbon, total nitrogen and total phosphorous in the surfical (0-2 cm) fine-grained sediments of the Swedish EEZ in the Kattegat.

Element	Years of Sampling	Unit	No. of Samples	Range	Mean	Median	References
Org C	1970	%	66	0.4 – 2.5	1.1		Olausson 1975
	1986-90	%	108	0.28 – 7.5	2.1	2.2	Cato, unpubl.
	1987 – 91	%	32	0.37 – 3.7	1.8		Kuijpers *et al.* 1992
Tot. N	1970	%	16	0.08 – 0.37	0.23		Olausson 1975
	1986-90	%	28	0.032 – 0.32	0.22	0.24	Cato unpubl.
	1987-91	%	24	0.15 – 0.33	0.23		Kuijpers *et al.* 1992
Tot. P	1970	g/kg	39	0.37 – 1.19	0.79		Olausson 1975
	1986-90	g/kg	143	0.45 – 3.0	0.92	0.89	Cato 1997b

main sink of fine-grained sediments that are dominated by suspension deposition (Bengtsson & Stevens 1996). On both sides of the trench at depths between 25 and 50 m, the bottom sediments consists of postglacial silty clays which, depending on the depth, now and then are resuspended and oxygenated in its uppermost part. These conditions allow an increased breakdown of organic matter and in general the organic carbon content of the sediments in these areas are less than 2 % dry matter.

Areas dominated by fine-grained sediments rich in organic matter (organic carbon content between 3-6 % dry matter) are found in certain sheltered bottom areas along the rugged Norwegian and Swedish coastlines of the Skagerrak. In the northern Sound, Great Belt and especially Little Belt many small mud deposition basins, rich in organic matter, are also found.

The range, median and average concentrations of organic carbon, total nitrogen, total phosphorous of the Kattegat and Skagerrak fine-grained sediments at different periods are given in Table 7 and 8.

The majority of the nitrogen occuring in the sediment is organically bound and therefore displays a distribution pattern closely resembling that of organic carbon. The carbon-nitrogen (C/N) ratio is considerably higher in the sediment than in plankton organisms, due to the faster release of nitrogen than carbon during the decomposition of organic matter. In general the nitrogen content of the sediment is 10 % of the organic carbon content. However, the C/N ratio varies with the type of organic matter, the age of the organic matter and the redox situation (e.g. Cato 1977). Phosphorous on the other hand is more related to the inorganic sediment particles than to organic matter.

On average the organic carbon and phosphorous content of the surface sediment of Kattegat has increased between 1970 and the end of the 1980´s, while the nitrogen content seems to be unchanged (Table 7). On the other hand, in the Skagerrak the organic carbon content show no change during the same period. Instead both nitrogen (not significant) and phosphorous have increased in Skagerrak (Table 8).

Twelve sediment stations close to the Swedish Skagerrak coast have, on the request of the Bohus Coast Water Conservation Association, been sampled in 1990 and resampled in 1995 (Cato 1997b). On average the organic carbon content of the surficial sediments has remained unchanged during this period. Nitrogen, on the other hand, had increased by 15 % and the C/N ratio had decreased by 19 % during the same period (Fig. 2.3.10). The changes indicate an increase in the relative amount of deposited marine detritus (rich in nitrogen and poor in cellulose). This change in the ratio may be due to eutrophication, which favours the production of marine organic matter viz. the supply of organic matter from land. Corresponding changes have previously been reported in the Göteborg archi-

Table 8. Mean, median and the range of variation of total organic carbon, total nitrogen and total phosphorous in the surfical (0-2 cm) fine-grained sediments of the Swedish EEZ in the Skagerrak.

Element	Years of Sampling	Unit	No. of Samples	Range	Mean	Median	References
Org C	1970	%	49	0.2 – 2.7	1.7		Olausson 1975
	1986-90	%	81	0.5 – 3.2	1.6		Cato, unpubl.
Tot. N	1970	%	5	0.05 – 0.24	0.14		Olausson 1975
	1986-90	%	15	0.086 – 0.39	0.21		Cato unpubl.
Tot. P	1970	g/kg	26	0.3 – 1.1	0.69		Olausson 1975
	1986-90	g/kg	109	0.44 – 3.0	1.09	0.96	Cato 1997b

pelago between 1966 and 1982 (Cato 1986), in the Brofjorden between 1972 and 1995, and in the Stenungsund area between 1975 and 1995 (Cato 1997b).

On average the phosphorous content at the twelve sediment sites increased with more than 50 % between 1990 and 1995 (Fig. 2.3.11).¨

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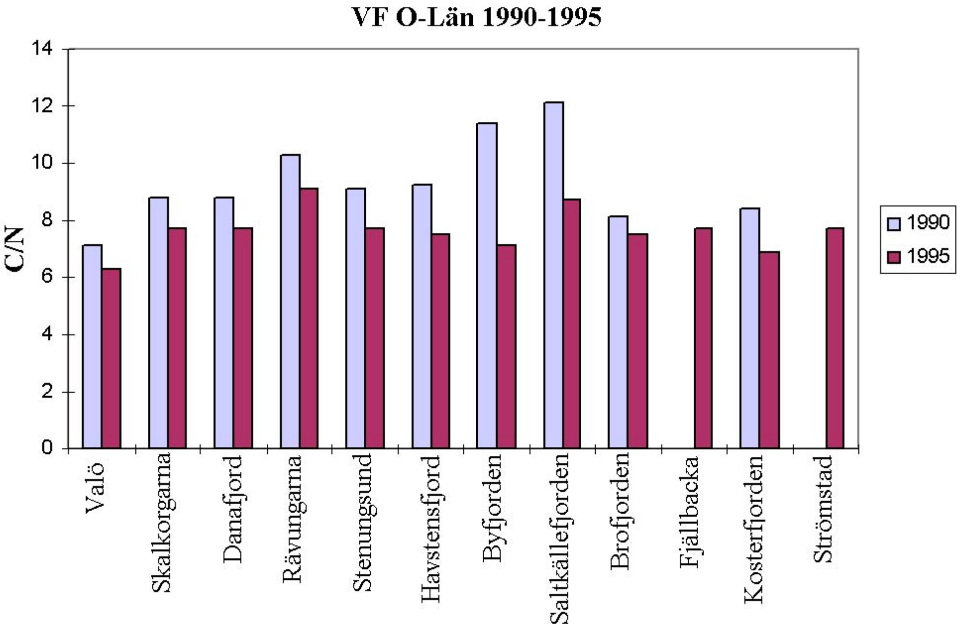

Fig. 2.3.10: The C/N ratio in the surficial sediment at 12 resampled stations along the Bohus Coast in 1990 and 1995 respectively (From Cato 1997).

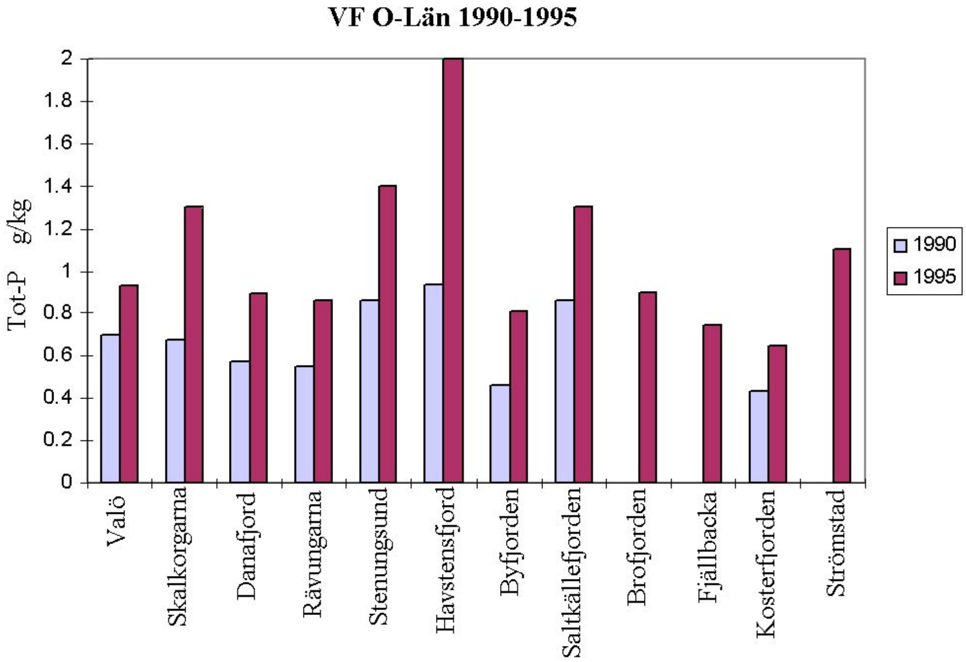

Fig. 2.3.11: The concentration of total phosphorous (g/kg dw) in the surficial sediment at 12 resampled stations along the Bohus Coast in 1990 and 1995, respectively (From Cato 1997b).

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2.4 Algal toxins (DSP/PSP Mussel Infection Events)

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Summary

The blue mussels (*Mytilus edulis*) along the Swedish west coast have contained DSP-toxins above the limit for consumption during part of the year every year since the monitoring programme started in 1988. Some areas that previously have been believed to be toxin free have experienced toxic events the last few years. PSP-toxins occur only rarely and usually below the limit for ban of consumption. However, e.g. in 2002, concentrations were higher than the limit for a short period in one fjord.

Background

Algal toxin content has been monitored in blue mussels (Mytilus edulis) along the Kattegat-Skagerrak coast since 1988. The “Water Quality Association of the Bohus Coast” as well as the aquaculture industry has funded the analyses. Starting in year 2001 there is a somewhat more comprehensive sampling program co-ordinated by the National food administration. The toxins analysed has almost exclusively been ocadaic acid (OA) and *Dinophysis* toxin 1 (DTX-1). Also, PSP-toxins have been measured in blue mussels when PSP-producing algae have been found in the water. Until year 2000 analyses was mainly performed at Clinical Bacteriology, Gothenburg University, by HPLC (High Performance Liquid Chromatography). Today most analyses are made using LC-MS (Liquid Chromatography Mass Spectrometry) at a private company, AnalyCen AB, in Linköping.

Temporal and spatial distribution of toxins Diarretic Shellfish toxins (DST)

DST produce Diarrhetic Shellfish Poisoning (DSP). The source of the toxins are mainly phytoplankton belonging to the dinoflagellate genus Dinophysis. DST has been detected from the Tjärnö archipelago in the North to Varberg in the South. There is a seasonal variation in the content of DST in blue mussels. Figure 2.4.2 shows the pattern from year 2001, which is typical. There is a period in June-August with concentrations below the limit

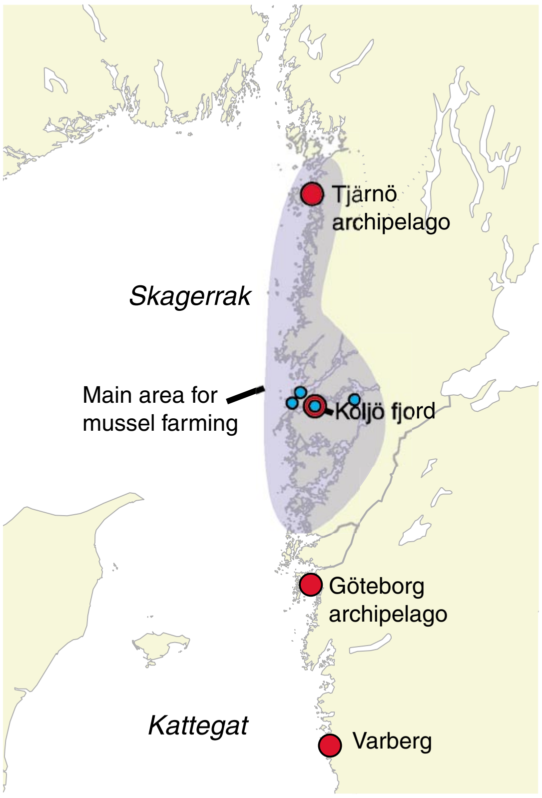

Figure 2.4.1. Map of with main area for the mussel farming sites. Locations for sites from which data is presented in Fig. 2.4.2-2.4.4 are indicated. Data from Varberg (not shown) is limited to the years 1994-95 when a maximum concentration of 2500 µg/kg was detected.

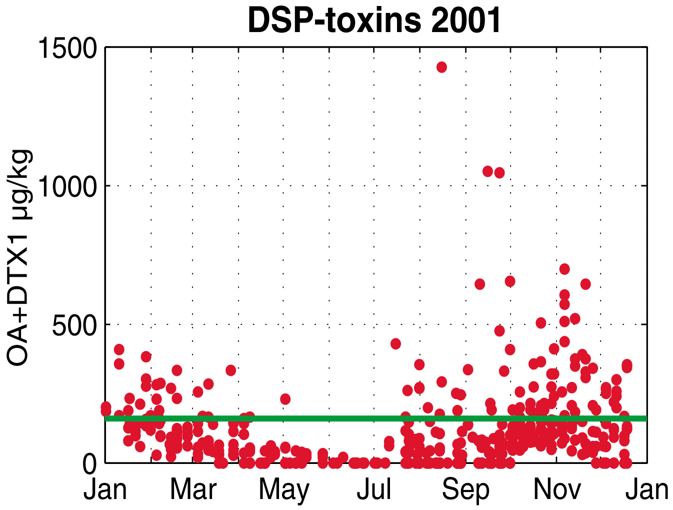

Figure 2.4.2 Concentrations of DST (sum of ocadaic acid and *Dinophysis* toxin -1) in blue mussels (*Mytilus edulis*) during year 2001. Data from all locations along the West Coast of Sweden is shown. The green line indicates limit for ban of consumption (160 µg/kg).

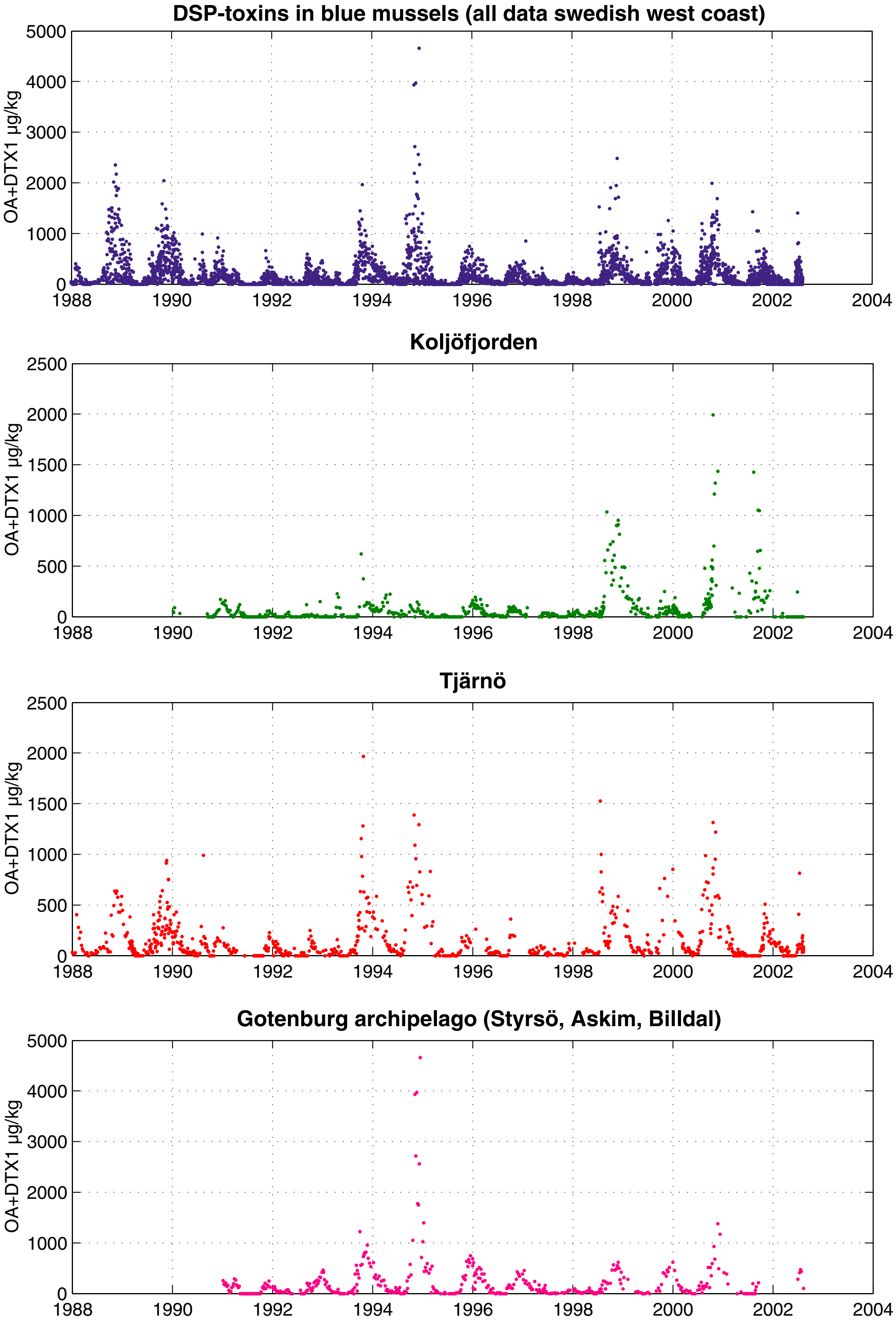

Figure 2.4.3. Concentrations of DST 1988 – Aug. 2002. All available data (A), Tjärnö archipelago (B), Koljöfjorden (C), Göteborg archipelago (D).

for consumption in the whole area. During the rest of the year toxin containing mussels are found at least somewhere in the area. However, there are usually some areas with concentrations below the limit for consumption at a any given time. The mussel farming industry manages to supply the market with toxin free mussels most of the time by harvesting at different locations.

The whole data set from 1988 to August 2002 shows no evident trend (Fig. 2.4.3). Since DST data from a period with less eutrophication are lacking, no conclusions can be made regarding the influence of eutrophication on concentrations of DST in shellfish. At one location, the Koljö fjord north of the island of Orust, shows a different pattern . A clear increase in the levels of DST was recorded starting in 1998. The reason for this is unknown.

The data set is not balanced regarding number of samples per year and location but if the whole set is used 30.4 % of the samples have DST-values above 160 µg/kg mussle meat, i.e. the limit for commercial distribution.

Paralytic Shellfish Toxins (PST)

PST cause Paralytic Shellfish Poisoning (PSP). The source of the toxins is phytoplankton belonging to the dinoflagellate genus *Alexandrium*. PST have not been and are not regularly monitored in Sweden. The toxins have usually been analysed only when *Alexandrium* spp. are expected to occur in the water, i.e. during April and May. Generally PST have been below the limit for ban of consumption (800 µg/kg). However, e.g. in 1997 concentrations as high as 1600 µg/kg was recorded. In addition, during 2001 PST levels above the limit for consumption was recorded during an experimental set-up (Fig. 2.4.4) The limited available data set makes no conclusions regarding the influence of eutrophication on PST content in shellfish possible.

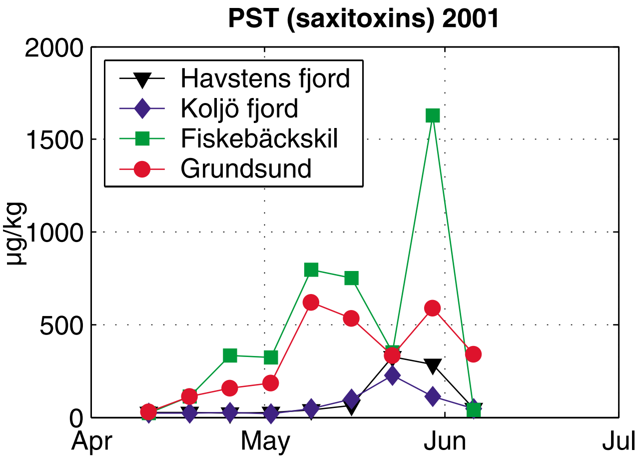

Figure 2.4.4. PST in blue mussels at four localities close to the island of Orust in May-June 2001.

Table 9. Detection of PST in blue mussels along the Swedish west coast. The number of samples analysed is low and analyses are usually restricted to April and May.

Year	PST above limit
1988	yes
1989	no
1990	no
1991	no data
1992	yes
1993	no
1994	no
1995	no
1996	no data
1997	yes
1998	no data
1999	no data
2000	no data
2001	yes
2002	yes

3. RESPONSES AND ADAPTIVE MANAGEMENT

3.1 Nutrient reduction strategies and measures

– Sverker Evans, Swedish EPA

In April 2001, the Swedish government launched a Bill "The Swedish Environmental Objectives – Interim Targets and Action Strategies". The proposals in this Bill will substantially strengthen the implementation of concrete environmental measures in the years to come with a view to achieving extensive environmental improvements and ecological renewal in Sweden in the next 10 years. The Bill refines the framework of environmental objectives that was approved by Parliament in April 1999.

The primary environmental objective is to hand over a society to the next generation in which the major environmental problems have been solved. Fifteen environmental quality objectives have been adopted by Parliament, which focus on the ecological dimension of sustainable development. The objectives are policy objectives and will form the basis of future environmental policy. They are formulated with regard to nature's capacity for absorbing environmental impacts and describe the environmental state, which the environmental measures seek to achieve. Proposals for interim targets, measures and strategies for achievement of the environmental quality objectives are presented, too. In most cases, the interim targets relate to the situation in 2010, although other time scales have been chosen in a few cases.

As regards the objective related to eutrophication of the marine environment, the outcome within a generation should include the following:

- Nutrient inputs do not cause adverse effects to human health and are not detrimental to biological diversity.
- Nutrient concentrations in coastal waters and seas are essentially the same as in the 1940s, and nutrient inputs into the sea do not cause eutrophication.
- The ecological status of Sweden's coastal waters, as defined by the Water Framework Directive, is good.

The interim targets related to marine eutrophication are as follows:

- By 2009 an action programme in accordance with the Water Framework Directive will be in place, specifying how to achieve a good ecological status in lakes and streams, as well as coastal waters.
- By 2010 waterborne anthropogenic emissions in Sweden of phosphorus compounds into lakes, streams and coastal waters will have diminished continuously from 1995 levels.
- By 2010 waterborne anthropogenic nitrogen emissions in Sweden into the sea south of Åland Sea will have been reduced by 30 % compared with 1995 levels, i.e. to 38,500 tonnes.
- By 2010 ammonia emissions in Sweden will have been reduced by at least 15 % compared with 1995 levels to 51,700 tonnes annualy.
- By 2010 atmospheric emissions in Sweden of nitrogen oxides will have been reduced to 148,000 tonnes per year.

It will be necessary to take a number of actions in order to achieve the interim targets. These include continued development of wastewater treatment plants along the coast from Stockholm to the Norwegian border, improved wastewater pipeline systems, improved individual sewage treatment systems, and increased supervision of such systems. In addition, wetlands may represent a complement to wastewater treatment plants in order to prevent nitrogen from entering lakes and seas. By 2005 a measurable time specified target for phosphorus will be presented. Provisions concerning livestock density in order to reduce nutrient inputs into the soil will be reviewed. The taxes on artificial fertilizer and pesticides will also be reviewed in order to improve their effect as environmental instruments.

The Swedish Environmental Code represents an adaptation of the legislation to environmental developments, and the Code will be one of the instruments used to achieve the environmental quality objectives.

3.2 International co-operation

– Sverker Evans, Swedish EPA

Marine environmental issues are transboundary by nature. International cooperation and international agreements are therefore essential if the Swedish environmental quality objectives are to be achieved. Swedish efforts to achieve environmental objectives are pursued in interaction with the EU's environmental policy. OSPAR and HELCOM constitute the two most important international organisations in order to reach agreements on necessary reductions of transboundary nutrient inputs to the Kattegatt and Skagerrak.

OSPAR Strategy to Combat Eutrophication

OSPAR's objective with regard to eutrophication 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 Common Procedure will identify areas where actions are needed. The Identification of the Eutrophication Status of the Maritime Area will be used to characterise areas as a problem area or a potential problem area or a non-problem area with regard to eutrophication. For further details see Appendices A and B.

In the case of problem areas measures shall be taken to reduce or to eliminate the anthropogenic causes of eutrophication. Reports shall be provided on the implementation of such measures, and assessments shall be made of the effectiveness of the implementation of the measures on the state of the marine ecosystem. Actions should comprise an integrated target-oriented and source-oriented approach. The main elements of the target-orientated approach are as follows:

- an evaluation of the situation in the maritime area that is expected following the implementation of agreed measures;
- the development, where possible, of an agreed procedure to derive ecological quality objectives and the adoption of such objectives, possibly in the form of region-specific ecological quality objectives, aimed at avoiding harm to marine ecosystems;
- the setting of intermediate targets, in order to work towards attaining such objectives. Such targets should be combined with an indication of the size of further nutrient reductions required, estimated on the basis of an evaluation of the situation that is expected following the implementation of agreed measures, and possible means to achieve these reductions.

The source-oriented approach has the following main elements:

- the implementation of any national or international measures as adopted by individual Contracting Parties for the reduction of nutrients in discharges/emissions from industry, sewage treatment plants, agriculture and other diffuse sources;
- the promotion of good housekeeping in indus try and sewage treatment and of good agricultural practice and ecological agriculture including proper use of the approach of aiming to strike a balance between the amounts of nutrients in the fertiliser applied and the requirements of the crop, and that proper attention is given to ammonia emissions;

In all areas from which nutrient inputs are likely to contribute to inputs into problem areas with regard to eutrophication the following Recommendations should be implemented:

- PARCOM Recommendation 88/2 on the Reduction in Inputs of Nutrients to the Paris Convention Area;
- PARCOM Recommendation 89/4 on a Coordinated Programme for the Reduction of Nutrients;

- PARCOM Recommendation 92/7 on the Reduction of Nutrients Inputs from Agriculture into Areas where these Inputs are likely, directly or indirectly, to cause Pollution;

- any future OSPAR instruments updating these Recommendations;

When and where it is established that problem areas and potential problem areas with regard to eutrophication have achieved the status of non-problem areas with regard to eutrophication, actions should be kept at a level that ensures that this improved status is maintained.

The Commission will implement this strategy progressively by making every effort to combat eutrophication in the maritime area, in order to achieve, by the year 2010, a healthy marine environment where eutrophication does not occur.

North Sea Conferences

The second North Sea Conference (NSC) agreed to aim to achieve, between 1985 and 1995, a substantial reduction of the order of 50 % in inputs of phosphorous and nitrogen, into areas where these inputs are likely, directly or indirectly, to cause pollution. The 1995 Progress Report for the fourth NSC indicates that for phosphorus an overall reduction of 50 % would be achieved by most countries, whilst for nitrogen the overall reduction was only about 25 % mainly due to rather little progress in the agricultural sector. Since 1985 there has been a significant reduction in the total inputs of phosphorus, but no clearly discernible reduction in riverine inputs of nitrogen to the North Sea. This is primarily due to the poor reduction of the input to the aquatic environment from agriculture. Riverine inputs showed big annual differences related to differences in river flow. No trends were detected over the period 1990–1996. However, over the same period the direct inputs of nitrogen decreased by about 30 % and those of phosphorus by about 20 %, which reflects improvement in sewage treatment. No general trends were noted for atmospheric inputs. Within the EC Council Directive 91/271/EEC concerning urban wastewater treatment and Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources are applicable. The 1998 Implementation Reports on the directives illustrated their rather poor implementation.

In view of the negative impacts of anthropogenic nutrient inputs over extended parts of the North Sea coastal zones, implementation of the OSPAR Strategy to Combat Eutrophication should be pursued vigorously. An important first step is to take the necessary action to achieve the agreed 50 % reduction target, in particular with regard to nitrogen. Efforts should be focused on emissions, discharges and losses from agricultural and urban sources, in particular through enforced application and compliance with the EC Directives 91/676/EEC and 91/271/EEC concerning nitrate and urban wastewater treatment. Further measures should aim at reducing mineral surpluses. In support of the Strategy, efforts should be made to complete the development and application of the classification criteria for establishing the eutrophication status and to evaluate the situation that will exist when the 50% reduction in the inputs of nutrients has been achieved. Research efforts should focus on qualitative and quantitative links between nutrient enrichment and environmental responses. Emphasis should be placed on the environmental effects of oxygen depletion, on changes in the community structure of plankton and benthic algae species.

Expected situation as result of 50 % reduction in N and P

Based on model calculations and mesocosm studies, as well as the environmental development in years of low run-off, an indication can be derived of the expected situation following the implementation of the 50 % reduction target for nitrogen and phosphorus.

Model predictions

A modeling workshop was organised by the Environmental Assessment and Monitoring Committee (ASMO) of OSPAR in 1996. The workshop focused on model validation and responsiveness of the models to nutrient input reduction.

With respect to the responsiveness of the models the following general conclusions were drawn:

- Nutrient load reduction of 50 % does not linearly translate into a 50 % reduction in nutrient concentrations and direct effect parameters such as chlorophyll a;
- The maximum response of nutrient concentrations to nutrient load reduction is ca. 35%, in chlorophyll a ca. 30 %, and in yearly primary production ca. 30 %;
- The calculated responses for the species com position varied considerably.

Environmental responses in years of low run-off

Within the Danish Marine Research Programme HAV-90 it has been calculated that if the targets of the Action Plan for the Aquatic Environment are met and similar reduction plans in other Baltic and North Sea countries are implemented, the deepwater oxygen conditions will be improved. In normal years of typical precipitation, runoff, wind conditions and water exchange, there would be no pronounced oxygen depletion (<2mg oxygen/l) in the open parts of inner Danish waters, with the exception of the Little Belt. The Sound and the Fehmarn Belt would maintain oxygen concentrations below 4 mg O_2/l.

The year of 1996 may be considered “nature’s own huge experiment”, which incidentally showed that a reduction of the nitrogen load to the level aimed at in the Action Plan for the Aquatic Environment will improve the environmental condition of Danish waters significantly under normal meteorological conditions. Due to low run off in 1996 but also in 1997 the inputs of nitrogen from land were approx. halved compared to the normal level. The effects were clear-cut, e.g. significantly higher values for Secchi depths and oxygen, as well as lower primary production and reduced concentrations of nutrient salts. The effects began to show already in 1996 in the fjords etc. and in 1997 the effects were significant in the more open stretches of the marine area. The improvements compared well to estimates generated by models.

Attempts have been made within the framework of HAV-90 to assess what effects the implementation of the Action Plan for the Aquatic Environment would have on the flora. Based on model calculations the Plan’s target of a 50 % reduction in nitrogen inputs to the aquatic environment would typically bring about a reduction of 40 % in nitrogen concentration in heavily polluted areas and of 20% in less polluted areas.

In conclusion, a reduction of N and P with 50 % will lead to positive environmental conditions for both coastal and offshore waters.

3.3 Marine monitoring and research

– Bertil Håkansson, SMHI

The very first national attempt to cover the physical status of marine waters was done in 1877, using a naval vessel. The driving force, except scientific interest, was the need to better understand fluctuations in fish resources. The expedition was initiated by F.L. Ekman but the main results were published many years later by O. Pettersson (Pettersson, 1893). Under the Hydrographic-Biological Commission established in 1901 (Fonselius, 2001), expeditions were organised in co-operation with other countries. Before World War I only temperature, salinity and oxygen was measured, whereas after the 1921 pH and alkalinity were added. No data collection at all was performed during the First and Second World War (Fonselius, 2001). The Hydrographic Department of the National Fishery Board was established in 1948. In 1960 the Hydrographic Department started with monitoring phosphate and some years later nitrite and nitrate, followed by silicate and ammonium. In the beginning hydrographic cruises was at best performed on an annual basis, but increased after 1950s to 4 - 6 cruises per year. Increasing awareness of environmental problems related to eutrophication and toxins in marine waters called for more detailed information. During the 1990s, efforts were made to cover the seasonal time scale in the sea. In 1996 monitoring cruises every month was initiated which cover physical, chemical and biological parameters in the water column.

Environmental problems related to eutrophication, environmental toxins and dwindling fish resources are at present the most important targets for monitoring. Traditional methods are being complemented or replaced with new methods and tools for monitoring and assessment procedures to meet new requirements and demands from stakeholders (OSPAR, HELCOM, EEA and national institutions). For example, ocean hind/now/scenario-casting models are becoming available. However, these calls for dedicated monitoring, since ocean models need data for calibration, validation and assimilation. There is also a need for improved assessment routines with faster updates and with reports focusing on specific themes or environmental targets.

To make these new methods, tools and procedures realistic and useful, modern measurement devices and techniques are necessary to take into account. For example, ferry box devices are becoming an established technique, which can survey surface waters frequently. The Finnish Algae Line is pioneering this type of monitoring in the Baltic (Kononen & Leppänen, 1997). Ocean buoys are another technique for operational monitoring, which can sample with high frequency the whole water column (Johnsen, Volent, Tangen & Sakshaug, 1997). Using modern telecommunications data can be provided in almost real time. A number of buoys are becoming available in the Baltic Sea, the Danish Straits and in Kattegat, where Germany, Denmark and Sweden are extending their capacity to monitor physical, biological and chemical ocean states. Furthermore, remote sensing is becoming an important complement to open sea monitoring (Håkansson, 2000; Kahru, 1997).

Major research projects in Skagerrak and Kattegat during the 1990s, related to environmental problems are the Skagerrak Experiment (Dybern et al., 1994 and Danielssen et al., 1997), the Swedish multidisciplinary research project Large-scale environmental effects and ecological processes in the Skagerrak-Kattegat (JSR, 35, 1-3, 1996) and the Danish Marine Research Programme (Jörgensen & Richardson, 1996). Along with many other research initiatives these have contributed to the understanding of processes, environmental impacts and system analysis.

Parameters and Data holders

The environmental monitoring programmes cover many parameters but only the most important ones related to eutrophication issues are mentioned here. Nutrients in the water column are of strategic importance to monitor during the winter months, whereas oxygen conditions, especially in deep waters, are measured during early autumn in order to observe the nutrient status and eutrophication effects. Plankton and chlorophyll a are monitored at monthly intervals, but with higher frequency during spring bloom periods. Scientists at the request of regional and national stakeholders perform monitoring of community structure, depth distribution, abundance and biomass of benthic flora and fauna. The Swedish Food Administration monitors mussel toxins, which has a direct impact on human health. Regional laboratories are monitoring benthic fauna and flora at representative sites along the coast. The National Fishery Board monitors fish recruitment and stocks.

In order to provide better accessibility to national monitoring data, there are a number of Swedish National Data Hosts, which are to receive and archive data from specific subject areas. As regards marine eutrophication issues, the Swedish Meteorological and Hydrological Institute keeps hydrographical and hydrochemical data, the Stockholm Marine Science Centre archives marine biological data and the National Fishery Board keeps data about fish and shellfish stocks. The data hosts are responsible for quality control, banking, and delivery of monitoring data to international conventions and other organisations. The Swedish national monitoring data are delivered by routine to the International Council for the Exploration of the Sea (ICES), which serves as data centre for both HELCOM and OSPAR.

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4. SUMMARY AND CONCLUSIONS

4.1 National marine eutrophication assessment

Degree of Nutrient Enrichment(I)

Nutrient load

The Swedish runoff covers both diffuse and river runoff. Generally, the DIN to DIP ratio is larger than 10 times higher than what is found in the receiving open sea. For example, the river Göta älv holds DIP, DIN and SiO_3 concentrations of about 0.2, 40 and 40 µmol/l, respectively, which can be compared with the corresponding DIP, DIN and SiO_3 concentrations presented in Figs. 2.1.6b-2.1.7b. A special study on source apportionment has been done to evaluate the share of the waterborne nutrient input that is anthropogenically produced. It was concluded that about 70 % of the total nitrogen and 40 % of the total phosphorus was due to human activities. These figures are related solely to the runoff from the Swedish West Coast catchment and do not take into account the outflow from the Baltic Sea. While the waterborne runoff of nutrients is small compared to the nutrient transport in the sea, it still affects the coastal area as well as the open sea. The nitrogen input to the Laholm Bay has increased from nearly 4000 tonnes per year in 1975 to about 5800 tonnes per year in 2000 (Stibe, 2002). The nitrogen and phosphorus input from land to Kattegat has increased with 40 and 50 % respectively, since 1970.

The atmospheric load of nitrogen to the Skagerrak and Kattegat surface waters is estimated using model calculations, whereas the import of TP and TN from adjacent seas is merely broad estimates. Nevertheless, in Table 9 figures of the nutrient load is given, showing that rivers, adjacent seas and atmospheric load is of the same order of magnitude for TN, while TP imported from the Baltic Sea and from Swedish rivers is of equal magnitude.

It is concluded that at least the riverine nutrient input to the Skagerrak and Kattegat is much above pristine conditions, and that no declining trends could be observed during the time period 1970 to 2000.

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Nutrient levels

Winter DIN and DIP salinity corrected concentrations show, in generall small variations over decadal time scales. Here we choose 1990s nutrient levels for assessment. In the inshore and offshore parts of Skagerrak, the average DIP concentrations are 0.6 and 0.6 µM, respectively. The corresponding DIN concentration is 8 µM. In inshore and offshore Kattegat the average DIP concentrations are similar and close to 0,65 µM, while the corresponding DIN concentration is 7 µM i both areas.

Thus, in Kattegat both the inshore and offshore levels of DIN and DIP are above 150 % of background levels (4-5 and 0.4 µM). In Skagerrak the DIP levels are close to background (0.6 µM), whereas DIN is close to background (10 µM) in inshore waters while below background in offshore waters.

Table 10: Estimated load of TP and TN on the Skagerrak-Kattegat as a whole. Figures is in tonnes per year for TP and 10^3 tonnes/year for TN. Atmospheric load is based on MATCH data from 1998 and 1999, whereas data from adjacent areas is taken from Table 3.

	Rivers	Atmosphere	From Baltic	From North Sea
TP	675	-	450	-
TN	30	53	8.5	24

Table 11: Summary of nutrient status and assessment during the 1990s. The different water bodies are shown as Coastal Kattegat/ Offshore Kattegat/Coastal Skagerrak/Offshore Skagerrak. Background and critical data only exists for offshore waters.

Parameters	Background	Critical	Observed	Evaluation
DIN	4.5 / 10	> 6 / >15	7 / 7 / 8 / 8	+ / + / - / -
DIP	0.4 / 0.6	> 0.6 / > 0.9	0.65 / 0.65 / 0.6 / 0.6	+ / + / - / -
DIN/DIP	16	> 25	< 16 / 16 / >16 / 16	- / - / - / -
DIN/SiO_3	1	> 2	1 / 1 / 1.3 / 1.7	- / - / - / -
DIP/SiO_3	0.083	> 0.125	0.1 / 0.1 / 0.1 / 0.125	- / - / - / -
Chlorophyll *a*	1.5	>2.25	2.5 / 2 / 3 / 2	+ / - / + / -

Nutrient ratios

The Redfield ratios in Kattegat inshore and offshore waters are lower than background (16). Inshore waters have generally higher ratios than offshore waters, mainly due to the high nitrogen transport from land. Only occasionally the Redfield ratio reaches above 16 during wintertime. The DIN/SiO_3 ratio is close to background level (1) in inshore Kattegat waters, while the DIP/SiO_3 ratio is lower than the critical level (0.125) but above background. In offshore Kattegat these ratios are slightly higher than in inshore waters. In Skagerrak the inshore waters have a Redfield ratio above 16 but below the critical assessment level of 25. In offshore waters the Redfield is at or below 16 on average. For DIN/SiO_3 the ratio is above background level (1) and occasionally above 2 in inshore Skagerrak waters, while DIP/SiO_3 is lower than the critical level (0.125) but above background. In offshore Skagerrak these ratios are slightly higher than in inshore waters.

It can be concluded that on average the DIN and DIP concentrations in Kattegat is clearly above critical levels, while normal in Skagerrak. Nutrient ratios are above background in Skagerrak but below critical levels. In Kattegat nutrient ratios are close to background except for DIP/SiO_3 which is above background but below critical level. In both areas there is a tendency for the Redfield ratio to increase and approach normal value.

Direct Effects (II)

Chlorophyll *a*

During the 1990s the average Chlorophyll a values during the growing season in both offshore Skagerrak and Kattegat are higher than the background level (1.5 µg/l), but below the critical assessment level of 2.25 µg/l. Only occasionally is the Chlorophyll a content above the critical value. However, in inshore waters of Kattegat and Skagerrak the Chlorophyll a content is above the critical value. Hence, in terms of phytoplankton biomass during the growing season both Kattegat and Skagerrak can be classified as eutrophicated, particularly the inshore waters.

Phytoplankton Indicators Species

Harmful algal blooms are still a serious environmental problem for the Kattegat-Skagerrak area. The fishery, the aquaculture industry and the tourism suffer. The blooms of *Chattonella* spp. in the Kattegat-Skagerrak area in May-June 1998 and in March 2002 are new phenomena that may be eutrophication related. Blooms of *Dinophysis* spp. occur yearly along the Kattegat-Skagerrak coast. The periods of high DSP-toxin content in blue mussels have increased. Also new areas now have mussels containing DSP-toxins. Events of PSP with Alexandrium spp. occur occasionally. Strong blooms of Pseudo-nitzscia have been observed, but no effects of ASP (Amnesic Shellfish Poisoning) are indicated so far. The 2,5 fold increase in primary production, comparing the 1990s with the 1950s, is clearly driven by increased nutrient supplies.

Macrophytes including Macroalgae

There are no long times series of macrophytes in Swedish waters. Nevertheless, large changes in macroalgae species composition and depth distribution ranges were found during the 1980s in inshore Kattegat compared to historic data. In inshore Skagerrak, the lower level of their depth distributions have been shifted upwards in some algal species, while their upper limits are lowered. These changes are considered to be effects of eutrophication although cause and effects are not fully understood.

Indirect Effects (III)

Deepwater Oxygen

The degree of oxygen depletion (hypoxia) is generally high in the Kattegat and inshore Skagerrak waters. In Kattegat hypoxia is seasonal and most pronounced in autumn. The autumn spatial average oxygen concentration levels are below 6 mg/l most of the time and in south Kattegat between 4 and 2 mg/l. More than 50 % of all measurements have values below 6 mg/l and ca 36 % below 4 mg/l in offshore Kattegat. Inshore waters show about the same conditions. In offshore Skagerrak the situation is normal and hypoxia is absent. However, there is a decreasing trend in oxygen content which, if it continues, will lead to seasonal hypoxia around 2010. In inshore Skagerrak waters we find hypoxia and even anoxic waters, 43 % of all bottom water measurements fall below 6 mg/l, on the average. Also here we find a decreasing trend in oxygen concentration on average, however in some fjords the deepwater oxygen concentration improve. We conclude that seasonal hypoxia is evident in both Kattegat and inshore Skagerrak.

Zoobenthos and fish kills

Since the early 1980s, the benthic fauna has been negatively affected by seasonal hypoxia in the southern Kattegat and in many Danish and Swedish coastal areas. This has also caused negative effects for the demersal fishery. The severity of the effects has varied between years, possibly because of climatic variations. Many shallow coastal areas at the Swedish Skagerrak coast are clearly disturbed, as demonstrated by low benthic faunal diversity, abundance and biomass. Some of these areas are enclosed and stratified with a temporal decrease in oxygen concentrations. In other coastal areas, the reason for the impoverished benthic fauna is unknown. Some offshore stations showed enhanced benthic faunal biomass, probably due to organic enrichment.

It is a well-known fact that the Norwegian Lobster is substantially sensitive to deepwater hypoxia and kills were reported during the late 1980s when severe hypoxia prevailed in the south of Kattegat. The cod stock has decreased dramatically during several decades and is now at its limit of survival. It appears, however, that the overriding problem is over-fishing, one of the reasons being that cod recruitment shows no signs to decline.

Organic Carbon/organic Matter

Sediment investigations indicate that the eutrophication indicator C/N ratio decreases in inshore Skagerrak waters as well as in Kattegat. This supporting evidence of eutrophication has been observed in inshore Skagerrak waters since late 1960s.

Other Possible Effects (IV)

Algal toxins

The blue mussels (*Mytilus edulis*) have contained DSP toxins during parts of the year in every year. During 1999-2002 the periods with toxin content in mussels above the limit for sale of farmed mussels have been longer than before. Also in areas that previously have been believed to be toxin free, toxic events now occur. PSP-toxins occur only rarely and are usually below the limit for ban for sale

4.2 Conclusions

Long time series covering the last 30 years show that with few exceptions the environmental conditions has not improved in Skagerrak and Kattegat since the 1970s. One exception is that the levels of DIP decreased during the 1990s and reached the same level as in the 1970s. However, it is difficult to evaluate the statistical significance of this trend. A general point of view which supports the conclusion about a decrease in DIP is that even though the river runoff during the period 1998 to 2000 approached the runoff found during 1985 to 1988, the DIP concentrations is not as high during 1998-2000 as compared to 1985-1988. Another parameter, which indicates a reversal of the inferior environmental conditions, is the deepwater oxygen concentration in Kattegat during the 1990s. However, the situation is far from acceptable, since this area is still severely affected by seasonal hypoxia.

The monitoring data show that concentrations of DIP, DIN, deepwater oxygen and to some extent chlorophyll *a* co-vary with the variations in runoff from adjacent land areas, which in turn are related to the nutrient load. Periods of high runoff to the Swedish West Coast and the Baltic Sea rise the levels of the above mentioned parameters, whereas the concentrations decrease during dry periods. Typically, these periods are lasting for some years forcing the DIP, DIN, deepwater oxygen and Chlorophyll a to vary with an amplitude of approximately with 0.1 µM, 1 µM, 1 mg/l and 1 µg/l, respectively.

The assessment clearly indicates that the Swedish parts of the Kattegat and Skagerrak are affected by eutrophication. Several of the investigated parameters in this assessment points towards eutrophication, such as for zoobenthos, organic carbon and nitrogen in sediments, some macroalgae, plankton, nutrients, oxygen, chlorophyll and algae toxins.

The anthropogenically-derived nutrients brought to the two sea areas have origin both from domestic and transboundary sources. Due to the complex hydrographic situation in the Kattegat and Skagerrak with huge exchanges of water masses from the North Sea and the Baltic Sea as well as high atmospheric nitrogen deposition (cf. Table 7), Swedish abatement measures will only affect the Swedish coastal area.

At present there are no clear signs that the eutrophication status in the two sea areas will improve in the near future.

Acknowledgement

We thank the Swedish Environmental Agency for supporting the assessment work. Philip Axe, Pia Andersson, Phil Graham, Thomas Klein and Martin Hansson at SMHI are acknowledged for producing figures, tables, data and layout of the report. We are also greatful to Odd Lindahl at KMB for providing information on primary production from Fjord Gullmaren.

APPENDIX A

Checklist for a holistic assessment

The qualitative assessment parameters are as follows:

a. the causative factors

the degree of nutrient enrichment

- 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)

APPENDIX B

Description of assessment categories and procedures

Category I - Degree of nutrient enrichment
Nutrient Inputs
Riverine Inputs and Direct Discharges

Assessment procedures should:

- consider the pattern of change in inputs and flows over the maximum period possible;

- where possible, consider seasonal variations;

- take into account the level of the (yearly) riverine discharge ("wet" and "dry" years) related to the respective riverine N- and P-inputs;

- consider, if possible, current elevated Total N- and Total P-inputs compared to respective "reference" (background) levels and/or increased trends compared with previous years. Levels and years need to be defined. In respect of establishing whether there is an increasing trend in inputs, any increase of more than 5 % over a ten year period should be considered an increasing trend. In respect of the analysis of trends, flow adjustment of riverine inputs should be made.

Winter nutrient concentrations

Widely used in comparable assessments are total dissolved inorganic nitrogen compounds (NO_3 + NO_2 + NH_4 (DIN)) and ortho-P (DIP) for winter time when algal activity is lowest.

The widely used uniform assessment procedure with respect to yearly trends and elevated levels in DIN and DIP winter concentrations in salinity gradient (riverine influenced) waters is as follows:

- Mixing diagrams and salinity specific background concentrations:

In marine coastal waters with salinity gradients yearly trends in winter nutrient concentrations are assessed by plotting the winter nutrient concentrations of each year in relation to the respective measured salinity values. In winter, defined as period when algal activity is lowest, DIN and DIP show a more or less conservative behaviour and a good linear relationship with salinity (decreasing concentration with increasing salinity from coast to offshore).

- Trends and elevated levels compared with salinity specific background concentrations.

In order to compensate for differences in salinity at the various locations and during the various years, nutrient concentrations are normalised for salinity. This is done by calculating the winter nutrient concentration at a given salinity (e.g. 30) from the mixing diagram of a particular year. The salinity normalised nutrient concentration (with 95 % confidence interval) is plotted in relation to the respective year in order to establish trends in the winter nutrient concentrations and the level of elevation compared with background concentration.

In areas where there is no relationship between salinity and nutrient concentrations, nutrient levels can be simply assessed by calculating mean values for the winter period and compared to region specific background concentrations.

The assessment level of elevation in DIN and DIP can be roughly set at > 50 % above a salinity related and/or region specific background concentration.

Winter N/P ratios; N/Si ratios, P/Si ratios
Increased winter N/P ratios (compared to Redfield ratio = 16) and absolute excess of nitrate may increase the risk of nuisance and toxic algal species, while increased ratios of N/Si (> 2) and P/Si (> 0.125) may cause shifts in species composition from diatoms to flagellates, some of which are toxic.
Elevated levels of winter N/P ratio > 25; (i.e. >50% above Redfield ratio) are used.

Category II - Direct effects of nutrient enrichment

Chlorophyll *a*

Maximum and mean chlorophyll a concentrations during the growing season, are is considered to be a useful direct effect assessment parameter of nutrient enrichment.

In determining the maximum and mean chlorophyll levels in estuaries, chlorophyll concentrations should be averaged over the estuarine salinity range during the growing season.

There is a large fluctuation in chl.a concentrations between years and seasons as well as spatial differences. Elevated levels of chl a of > 50 % above historical and/or region specific background concentrations are used as harmonised assessment level.

Phytoplankton Indicator Species

Region/area-specific phytoplankton indicator species, such as noxious species (*Phaeocystis, Noctiluca*) and potentially toxic (dinoflagellates) species (e.g. *Chrysochromulina polylepis*, *Gymnodinium mikimotoi*, *Alexandrium* spp., *Dinophysis* spp., *Prorocentrum* spp.) are important assessment parameters. The species show elevated concentrations/toxic levels and increased duration of blooms compared with pristine conditions.

Macrophytes including Macroalgae

Shifts in species from long-lived species like *Zostera* to nuisance short-lived species like *Ulva* form an important region-specific indicator/assessment parameter in shallow waters, estuaries and embayments. In some of these areas, reduced depth distribution is used as specific assessment levels.

Category III - Indirect effects of nutrient enrichment

Oxygen Depletion

The degree of oxygen depletion is widely used as an indirect assessment parameter for nutrient enrichment.

The various degrees of oxygen depletion show ranges for the various regions/areas: < 2 mg/l: acute toxic (ca. 75 % depletion); 4 - 5 mg/l (ca. 50 % depletion) and < 5 - 6 mg/l: deficient. Oxygen concentrations above 6 mg/l are considered to cause no problems.

Changes/kills in zoobenthos and fish kills

This parameter is indirect related to nutrient enrichment. A distinction can be made between acute toxicity directly related to oxygen depletion and/or toxic blooms, and long term changes in zoobenthos species composition as result of long term eutrophication.

Category IV - Other Possible Effects of Nutrient Enrichment

Algal Toxins (DSP/PSP Mussel Infection Events)

This is a relevant assessment parameter in relation to potential toxic algal species in areas with mussel cultures.

The harmonised assessment criteria are compiled in Table 1.

Classification of the eutrophication status on the basis of the harmonised assessment criteria and their respective assessment levels

To carry out the classification of the eutrophication status of areas of the maritime region each contracting party should undertake a number of steps which are outlined in sections below. The first step is to provide a score for each of the harmonised assessment criteria being applied according to the guidance in Table 1. The second step will bring these scores together according to the format in Table 2 to provide a classification of the area. The third step is to make an appraisal of all relevant information concerning the harmonised assessment criteria their respective assessment levels and the supporting environmental factors, to provide a transparent and sound account of the reasons for establishing a particular status for the area and to ensure that the status is clearly linked to relevant causative factors i.e. anthropogenic nutrient enrichment.

Table 1. The agreed Harmonised Assessment Criteria of the Comprehensive Procedure

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

Finally this process should enable the classification of the maritime area in terms of problem areas, potential problem areas, and non-problem areas.

Integration of Categorised Assessment Parameters for Classification

The assessment levels of the agreed harmonised assessment criteria form the basis of the first step of the classification.

The next step is the integration of the categorised assessment parameters mentioned in Table 1 to obtain a more coherent classification. For each assessment parameter of Categories I, II III and IV mentioned in Table 1 it can be indicated whether its measured concentration relates to a problem area, a potential problem area or a non-problem area. The results of this step are summarised in Table 2 and explained below:

- Areas showing an increased degree of nutrient enrichment accompanied by direct and/or indirect/ other possible effects are regarded as 'problem areas';

Table 2. Integration of Categorised Assessment Parameters (see Table 1) for Classification.

Category I Causative factors	Category II Direct effects	Category III and IV Indirect effects/ other possible effects	Classification
+	+	and/or +	problem area
-	+	and/or +	problem area (caused by transboundary transport)
+	-	-	potential problem area
-	-	-	non-problem area

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

(-) = Neither increased trends or elevated levels or shifts or 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.

- Areas may show direct effects and/or indirect or other possible effects when there is no evident increased nutrient enrichment, e.g. as a result of transboundary transport of (toxic) algae and/or organic matter arising from adjacent/remote areas. These areas could be classified as 'problem areas';

- Areas with an increased degree of nutrient enrichment, but without showing direct, indirect/ other possible effects, are regarded as 'potential problem areas';

- Areas without nutrient enrichment and related (in)direct/ other possible effects are considered to be 'non-problem areas'.

APPENDIX C

Reporting format on the results of the OSPAR Comprehensive Procedure

Area

Skagerrak and Kattegat in the eastern part of the North Sea.

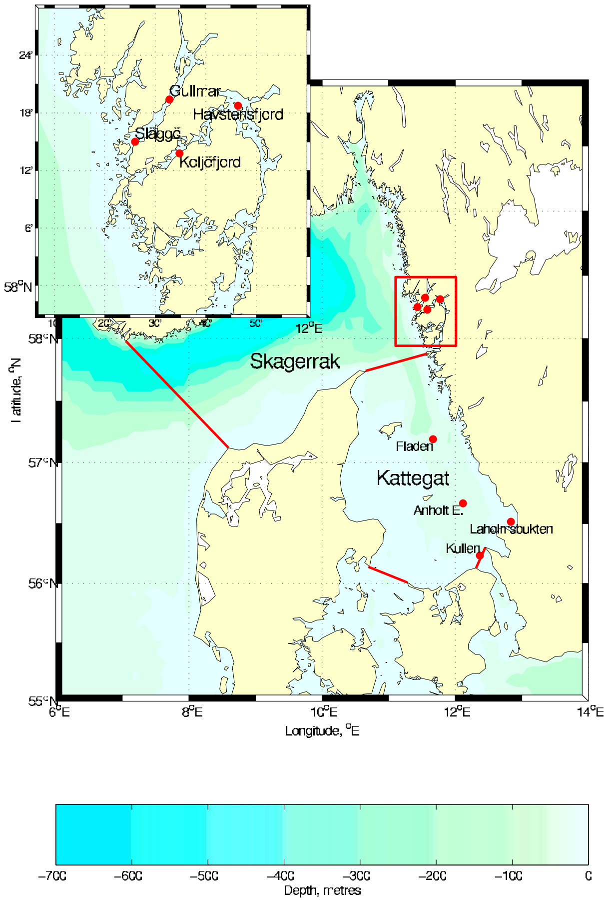

Fig. 2.1: Overview map of the eastern North Sea, covering the Skagerrak and Kattegat areas. Single specific sites from where time series are being used in this report are marked.

Description of the area

The Kattegat and the Skagerrak with surface areas of about 22 000 and 32 000 km^2 and mean depths of 23 m and 210 m, respectively, connect the brackish Baltic Sea with the North Sea, where the salinity is almost oceanic. Water of Baltic origin forms a surface layer in the Kattegat with a salinity increasing from 15 PSU in the southeast to 25 PSU in the northwest. Water originating from the North Sea is found below a pronounced halocline at a depth of about 15 m. The salinity in the deep water ranges from 32 to 34 PSU. The Kattegat surface water is bounded to the north by a sharp surface front, on average directed from Skagen towards the northeast. From here on the low-saline water of Baltic origin follows the Swedish and Norwegian coasts in the Skagerrak as a low-saline current.

The anthropogenic input of nutrients from land and changed nutrient ratios primarily affect the coastal zone. Nutrient related problems are widespread in the Kattegat and the eastern Skagerrak. Negative impacts include periodic disturbances of the ecosystem such as oxygen depletion and the subsequent increased mortality of benthic organisms, as well as changes in the abundance and diversity of the different animal and plant communities, e.g. increased phytoplankton blooms including, occasionally, harmful species. As a result of periodic oxygen depletion in the Kattegat bottom water, fishing for Norwegian Lobster has almost ceased in this area. In view of the storage of nutrients in the sediments, recovery times may be of the order of decades.

Discussion

Long time series covering the last 30 years show that with few exceptions the environmental conditions has not improved in Skagerrak and Kattegat since the 1970s. One exception is that the levels of DIP decreased during the 1990s and reached the same level as in the 1970s. However, it is difficult to evaluate the statistical significance of this trend. A general point of view which supports the conclusion about a decrease in DIP is that even though the river runoff during the period 1998 to 2000 approached the runoff found during 1985 to 1988, the DIP concentrations is not as high during

Table 3. Assessment

Category	Assessment Parameters	Description of Results	Score
Degree of Nutrient Enrichment (I)	Riverine total N and total P inputs and direct discharges (RID)	The load has substantially increased since 1930s. TP increased with 50 % and TN with 40 % between 1970s and 1990s.	+
	Winter DIN- and/or DIP concentrations	In both inshore and offshore Kattegat the winter concentrations are above critical levels, while Skagerrak is close to background.	+
	Increased winter N/P ratio (Redfield N/P = 16)_	The ratio is close to background in both Skagerrak and Kattegat.	-
Direct Effects (II)	Maximum and mean Chlorophyll a concentration	Both inshore Kattegat and Skagerrak is above critical level.	+
	Region/area specific phytoplankton indicator species	Chattonella and Dinophysis occur frequently and DSP-toxin is spreading into new areas and affects mussel farms.	+
	Macrophytes including macroalgae (region specific)	The lower limit of penetration has decreased especially during 1980s.	+
Indirect Effects (III)	Degree of oxygen deficiency	In Kattegat and inshore Skagerrak seasonal hypoxia is a severe problem in deep water. Anoxic conditions can occur during autumn periods. However, the decreasing trend in Kattegat has stopped during 1990s but still the conditions are far from acceptable.	+
	Changes/kills in Zoobenthos and fish mortality	Benthic fauna and demersal fishery has declined due to hypoxia. The cod stock has almost disappeared in inshore areas but this is mostly due to fishing pressure.	+
	Organic Carbon/Organic Matter	Sediment data indicate eutrophicated waters in inshore Skagerrak and in Kattegat since late 1960s.	+
Other Possible Effects (IV)	Algal toxins (DSP/PSP mussel infection events)	DSP in mussels are observed every year and the time periods for ban is increasing.	+

1998-2000 as compared to 1985-1988. Another parameter, which indicates a reversal of the inferior environmental conditions, is the deepwater oxygen concentration in Kattegat during the 1990s. However, the situation is far from acceptable, since this area is still severely affected by seasonal hypoxia.

Our monitoring data show that concentrations of DIP, DIN, deepwater oxygen and to some extent chlorophyll a co-vary with the variations in runoff from adjacent land areas, which in turn are related to the nutrient load. Periods of high runoff to the Swedish West Coast and the Baltic Sea rise the levels of the above mentioned parameters, whereas the concentrations decrease during dry periods. Typi-

Table 4. Classification

Category I Causative factors	Category II Direct effects	Category III and IV Indirect effects/ Other possible effects	Classification
+	+	+	Skagerrak is classified as a problem area
+	+	+	Kattegat is classified as a problem area

cally, these periods are lasting for some years forcing the DIP, DIN, deepwater oxygen and Chlorophyll a to vary with an amplitude of approximately with 0.1 µM, 1 µM, 1 mg/l and 1 µg/l, respectively

The assessment clearly indicates that the Swedish parts of the Kattegat and Skagerrak are affected by eutrophication. Several of the investigated parameters in this assessment points towards eutrophication, such as for zoobenthos, organic carbon and nitrogen in sediments, some macroalgae, plankton, nutrients, oxygen, chlorophyll and algae toxins.

The anthropogenically-derived nutrients brought to the two sea areas have origin both from domestic and transboundary sources. Due to the complex hydrographic situation in the Kattegat and Skagerrak with huge exchanges of water masses from the North Sea and the Baltic Sea as well as high atmospheric nitrogen deposition, Swedish abatement measures will only affect the Swedish coastal area.

At present there are no clear signs that the eutrophication status in the two sea areas will improve in the near future.

APPENDIX D

General and physiological information of various phytoplankton indicator species

Source: ANNEX 5(Ref. § 3.14a) OSPAR convention for the protection of the marine environment of the North-East Atlantic meeting of the eutrophication task group (ETG) london (secretariat): 9-11 october 2001

Appendix 3. Draft Common Assessment Criteria their Assessment Levels and Area Classification within the Comprehensive Procedure of the Common Procedure.

Phaeocystis spp

- foam-forming nuisance species in colonial form; occurrence during spring-summer;
- increased concentrations of more than 10^6 cells/l and increased bloom duration per year are an indication of increased eutrophication;
- occurrence of colony-formation depends on the physiological state and is related to the excess of nitrate as N-source during N-limiting under certain conditions by light;
- Phaeocystis outcompites other species under N-limitation at low N/P ratios; it has a lower P demand than diatoms and needs a minimum temperature of 7°C; Topt is 15°C;
- relatively high abundance, increased frequency and duration of blooms in Continental waters are strongly linked with increased eutrophication;
- Phaeocystis free-living cells (but not colonies) are grazed by tintinnids, and not grazed by copepods; it therefore has a poor food value, is a bad food source for bivalves and has a negative effect on young oysters, probably due to its mucilage.

Noctiluca scintillans

- this large (0,3 mm) non-toxic heterotropic (hence oxygen consuming) dinoflagellate forms regular tomato soup coloured surface accumulations in spring under calm weather conditions (<3-5 Bft) (nuisance species);
- its high abundance (above 10^3 cells/l) leads to low oxygen concentrations below the top layer and to high ammonium concentrations which may be harmful to fish. Oxygen deficiency induced by *Noctiluca* blooms caused a mass kill of cockles in the Dutch Wadden Sea;
- its high abundance may be due to its increased food resources as result of increased eutrophication.

Chrysochromulina polylepis

- fish and benthos killing species; toxic above 10^6 cells/l; bloom occurrence in spring;
- the exceptional bloom in May 1988 in Kattegat, Skagerrak and Danish waters is likely to be linked to eutrophication with other factors (climate, hydrography) involved; its toxicity may be related to N/P ratios (more toxic under P-limitation);
- it seems to prefer nutrient rich water and high light intensities; the combination of a mild winter with high precipitation, followed by a warm spring with very stable water masses was probably the most important cause of its massive, toxic bloom in May 1988.

Gymnodinium mikimotoi

(former name is *Gyrodinium aureolum*)

- fish-killing species when cell density exceeds 10^3 - 10^6 cells/l; in the Channel, West UK, Danish, Norwegian and Swedish waters these blooms have caused fish kills;

- bloom occurrence: late summer-autumn; first observation in 1966 along south-west Norwegian coast; optimal growth at 20 ^{0}C;
- it shows a preference for deeper water layers;
- blooms develop mainly in dynamic light environments (fronts, stratified water layers, turbid waters) where they have ecological advantage due to their ability to adapt at different light intensities, to migrate and to assimilate N at low light intensities;
- *Gymnodinium mikimotoi* is believed to be an introduced species which has spread its occurrence in the Skagerrak, Kattegat and North Sea waters since first recorded in autumn 1966 in Norwegian Skagerrak and off south West UK. Some authors have suggested that its occurring blooms nowadays are linked to and a consequence of long-term increases in nutrient levels; direct links between increased eutrophication and toxic dinoflagellate blooms may well be obscured by other factors as meteorology and hydrography. There is a need for further ecophysiological research.

Alexandrium spp.

- several species of *Alexandrium* (e.g. *A. tamarense. A. minutum/lusitanicum, A. ostenfeldii*) may be toxic (above 10^2 cells/l), depending on duration and cell concentration, and cause PSP;
- toxicity months: May-June;
- its appearance may be associated with a flux of water rich in nutrients, crossing fronts;
- it has been suggested that PSP-producing dinoflagellates may have spread geographically; summer blooms are recruited from resting stages which spend winter on the sea bottom.

Dinophysis spp.

- *Dinophysis acuminata*, *D. acuta*, *D. norvegica*, *D. caudata*, *D. fortii*, *D. sacculus*, *D. rotundata*, *D. skagii* and *D. tripos* are considered as DSP mussel-infecting species;
- occurrence: late summer-autumn;
- more than 10^2 cells/l may give rise to DSP, depending on duration of occurrence;
- its occurrence is associated with low salinity coastal waters and calm weather (wind < 2 Bft during 1 week) rather than with temperature.

Other species

The raphidophycean species *Fibrocapsa japonica* and *Chatonella* spp. are increasingly occurring in coastal European waters. Massive toxicity has been reported for the small sized *F. japonica* when cell concentration is exceeding 4 x 10^6cells/l. This species may also directly affect marine mammals, whereas toxicity of *Chatonnella* spp. is mainly related to fish kills.

APPENDIX E

Number of stations and data points where DIN, DIP and SiO_3 have been mesaured

Table 5. Kattegat

Year	Inshore				Offshore			
	Number of Stations	Number of data points			Number of Stations	Number of data points		
		DIN	DIP	SiO_3		DIN	DIP	SiO_3
1950	0	0	0	0	0	0	0	0
1951	0	0	0	0	2	0	0	0
1952	2	0	0	0	1	0	0	0
1953	0	0	0	0	1	0	0	0
1954	2	0	0	0	0	0	0	0
1955	0	0	0	0	0	0	0	0
1956	0	0	0	0	0	0	0	0
1957	6	0	0	0	9	0	0	0
1958	0	0	0	0	0	0	0	0
1959	1	0	0	0	3	0	0	0
1960	8	0	0	0	2	0	0	0
1961	0	0	0	0	0	0	0	0
1962	3	0	0	0	6	0	0	0
1963	0	0	0	0	0	0	0	0
1964	0	0	0	0	0	0	0	0
1965	2	0	0	0	9	0	9	0
1966	0	0	0	0	0	0	0	0
1967	1	0	0	0	9	0	17	0
1968	0	0	0	0	3	0	9	6
1969	0	0	0	0	4	0	9	6
1970	3	0	4	0	6	2	14	0
1971	3	0	3	4	6	0	19	0
1972	8	0	10	11	24	17	47	14
1973	6	0	9	3	22	7	37	21
1974	7	0	30	0	18	4	45	0
1975	10	0	48	0	19	6	82	9
1976	8	10	51	0	28	12	104	8
1977	9	39	60	0	20	53	72	9
1978	7	3	18	3	19	18	62	12
1979	2	4	4	4	6	11	17	8

1980	4	10	10	4	9	24	30	18
1981	5	8	5	5	8	25	17	17
1982	2	2	2	2	4	4	9	5
1983	9	24	24	0	13	61	78	51
1984	7	0	6	0	28	26	53	24
1985	6	9	9	0	28	44	48	17
1986	10	12	12	0	35	26	34	12
1987	11	15	15	2	37	39	54	29
1988	16	40	43	2	46	140	161	12
1989	16	40	45	27	49	97	133	116
1990	18	71	76	76	45	163	192	186
1991	13	45	84	45	31	130	185	68
1992	8	38	45	45	36	140	163	152
1993	15	41	61	61	33	84	139	132
1994	21	65	99	115	32	82	88	155
1995	18	95	122	122	15	78	103	107
1996	22	106	118	118	28	95	102	104
1997	15	27	68	68	28	78	119	119
1998	15	26	73	73	28	78	108	108
1999	16	24	84	84	29	55	83	83
2000	15	28	91	91	28	60	99	99
2001	13	30	93	94	23	66	93	93
2002	14	31	52	52	27	54	66	66

Table 6. Skagerrak

Year	Inshore				Offshore			
	Number of Stations	Number of data points			Number of Stations	Number of data points		
		DIN	DIP	SiO_3		DIN	DIP	SiO_3
1950	5	0	0	0	10	0	0	0
1951	4	0	0	0	25	0	0	0
1952	3	0	0	0	26	0	0	0
1953	7	0	0	0	38	0	0	0
1954	2	0	0	0	19	0	0	0
1955	3	0	0	0	37	0	0	0
1956	2	0	0	0	15	0	0	0
1957	3	0	0	0	13	0	0	0
1958	7	0	7	0	17	0	12	0
1959	9	0	14	0	27	0	23	0
1960	12	0	13	0	37	0	20	0
1961	6	0	2	0	31	0	16	0

1962	13	0	18	0	34	0	4	0
1963	9	0	9	0	49	0	31	0
1964	18	0	68	0	33	0	30	0
1965	19	0	36	0	56	0	51	21
1966	22	0	54	0	53	0	103	0
1967	15	0	33	0	20	0	24	0
1968	34	23	74	0	25	0	48	0
1969	18	21	34	21	33	0	3	0
1970	3	0	0	0	19	0	0	0
1971	22	0	63	0	19	0	54	0
1972	22	0	129	60	28	6	36	0
1973	31	15	119	0	19	4	4	0
1974	27	78	157	0	10	3	10	0
1975	20	0	60	0	24	0	62	0
1976	5	0	8	0	30	0	48	0
1977	16	0	6	3	20	0	14	14
1978	22	27	102	12	30	21	93	15
1979	2	0	0	0	9	18	18	10
1980	13	26	35	0	17	18	43	10
1981	17	60	80	3	11	27	59	12
1982	2	0	0	0	1	0	2	2
1983	17	27	48	3	8	6	25	5
1984	17	0	39	0	30	0	6	4
1985	19	33	48	3	30	18	42	15
1986	14	37	46	0	42	82	96	13
1987	15	42	49	2	33	17	19	21
1988	17	42	50	2	25	36	77	18
1989	19	80	101	9	40	22	75	49
1990	28	300	324	292	44	174	224	172
1991	19	135	155	149	32	110	117	95
1992	17	148	162	146	36	63	85	85
1993	24	175	216	195	25	36	138	139
1994	18	167	197	189	46	80	154	209
1995	20	114	132	132	24	33	106	109
1996	14	104	104	104	20	90	90	90
1997	13	90	91	91	23	82	84	84
1998	9	74	75	74	19	61	64	65
1999	6	72	72	72	25	72	72	72
2000	8	85	85	85	23	60	60	60
2001	7	93	94	94	21	74	74	75
2002	8	61	61	61	21	67	69	69

Table 7. Oxygen

Year	Kattegat				Skagerrak			
	Inshore		Offshore		Inshore		Offshore	
	No. Of Stations	No. Of samples	No. Of Stations	No. Of samples	No. Of Stations	No. Of samples	No. Of Stations	No. Of samples
1950	0	0	0	0	0	0	0	0
1951	0	0	0	0	0	0	0	0
1952	0	0	0	0	0	0	0	0
1953	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	8	13
1955	0	0	0	0	0	0	12	12
1956	2	2	0	0	0	0	18	25
1957	0	0	0	0	4	4	9	9
1958	0	0	0	0	2	2	1	1
1959	0	0	0	0	4	4	5	5
1960	0	0	0	0	0	0	2	2
1961	0	0	0	0	0	0	6	6
1962	0	0	0	0	0	0	2	2
1963	0	0	0	0	0	0	1	1
1964	0	0	0	0	6	6	2	2
1965	1	2	4	8	10	17	1	1
1966	2	3	11	18	0	0	10	10
1967	3	9	7	23	15	19	8	18
1968	3	5	14	19	17	21	25	38
1969	11	13	23	24	17	19	18	25
1970	8	9	12	22	19	30	15	17
1971	8	8	22	25	18	18	20	25
1972	13	14	34	56	25	27	25	32
1973	12	15	24	35	38	79	23	37
1974	6	41	14	54	30	56	23	56
1975	7	27	19	48	20	25	32	60
1976	40	68	19	51	18	22	19	45
1977	5	25	10	57	16	30	9	46
1978	7	9	17	26	17	27	12	16
1979	5	6	11	15	20	31	13	13
1980	2	2	4	8	12	17	2	6
1981	12	14	17	24	15	18	5	9
1982	8	8	11	23	17	32	8	13
1983	5	5	21	39	18	32	13	19
1984	5	5	12	55	19	22	19	33
1985	12	15	21	44	19	23	22	39

1986	11	16	19	37	28	61	16	34
1987	21	27	36	70	28	64	24	36
1988	21	29	78	109	18	52	26	32
1989	25	44	52	92	21	58	28	43
1990	19	48	37	97	22	114	29	133
1991	15	30	36	66	17	56	20	37
1992	15	33	46	111	18	59	31	51
1993	17	41	34	74	35	75	39	66
1994	17	44	32	56	30	69	36	55
1995	16	46	21	46	36	73	26	53
1996	12	27	11	25	16	46	11	23
1997	13	34	13	32	8	20	11	21
1998	13	34	11	29	9	23	13	23
1999	10	28	11	35	9	21	15	32
2000	14	34	16	33	8	28	6	18
2001	14	31	17	34	8	23	16	23
2002	0	0	0	0	0	0	0	0

Table 8. Chlorophyll a:

Year	Kattegat				Skagerrak			
	Inshore		Offshore		Inshore		Offshore	
	No. Of Stations	No. Of samples	No. Of Stations	No. Of samples	No. Of Stations	No. Of samples	No. Of Stations	No. Of samples
1950	0	0	0	0	0	0	0	0
1951	0	0	0	0	0	0	0	0
1952	0	0	0	0	0	0	0	0
1953	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	0	0
1955	0	0	0	0	0	0	0	0
1956	0	0	0	0	0	0	0	0
1957	0	0	0	0	0	0	0	0
1958	0	0	0	0	0	0	0	0
1959	0	0	0	0	0	0	0	0
1960	0	0	0	0	0	0	0	0
1961	0	0	0	0	0	0	0	0
1962	0	0	0	0	0	0	0	0
1963	0	0	0	0	0	0	0	0
1964	0	0	0	0	0	0	0	0
1965	0	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	0	0
1967	0	0	0	0	0	0	0	0

1968	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0
1974	0	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	0	0
1977	0	0	0	0	0	0	0	0
1978	0	0	0	0	0	0	0	0
1979	0	0	2	12	0	0	0	0
1980	0	0	3	36	0	0	0	0
1981	0	0	3	32	0	0	0	0
1982	0	0	5	40	0	0	0	0
1983	0	0	3	36	0	0	0	0
1984	0	0	6	55	0	0	0	0
1985	0	0	6	70	0	0	0	0
1986	1	27	6	69	10	252	0	0
1987	1	30	6	79	9	263	1	4
1988	1	33	6	67	10	338	1	3
1989	5	92	18	113	15	378	26	54
1990	4	204	15	214	23	1174	11	116
1991	9	261	35	522	26	680	77	272
1992	7	137	25	363	15	608	9	27
1993	13	297	40	610	20	800	73	576
1994	9	353	27	329	20	743	83	685
1995	13	385	30	363	34	744	75	888
1996	11	243	7	221	14	589	4	203
1997	10	282	7	270	10	330	6	198
1998	9	297	7	269	6	280	5	154
1999	10	325	6	245	6	283	6	139
2000	9	321	5	221	7	360	4	117
2001	9	324	6	240	7	409	6	121
2002	9	99	3	45	7	118	3	39

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