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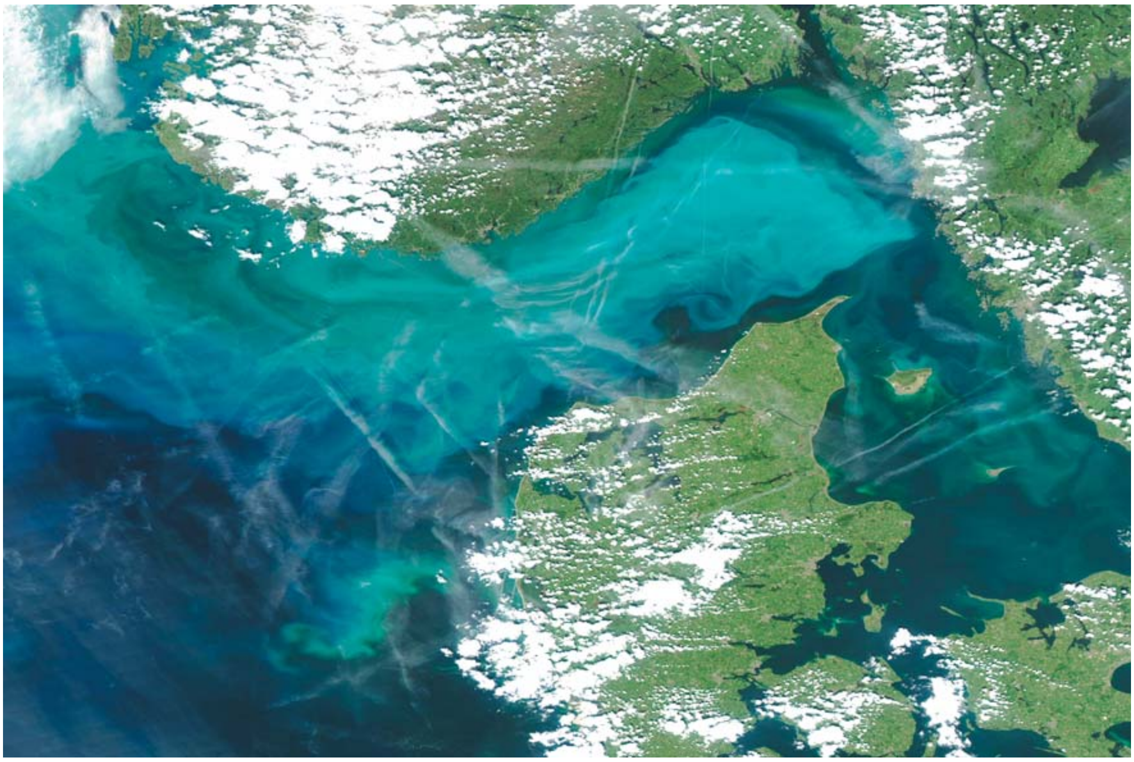

Swedish National Report on Eutrophication Status in the Kattegat and the Skagerrak

OSPAR ASSESSMENT 2007

Title: Swedish National Report on Eutrophication Status in the Kattegat and the Skagerrak
OSPAR ASSESSMENT 2007
Editor: Bertil Håkansson, SMHI, Oceanographic laboratory, Nya Varvet 31, Göteborg

Front Page: The Skagerrak and Kattegat can get a slight turquoise colouring of the ocean water in May-June. The satellite image shows the situation 27 June, 2003. The colour is caused by some phytoplankton species, in this case the harmless coccolithophoride *Emiliania huxleyi*. Data from NASA, TERRA MODIS, processed by Martin Hansson, SMHI.

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Swedish National Report on Eutrophication Status in the Kattegat and the Skagerrak

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OSPAR ASSESSMENT 2007

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Swedish National Report on Eutrophication Status in the Kattegat and the Skagerrak

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1 Summary

The surface area of the Kattegat and the Skagerrak, located in the eastern North Sea, is about 22 000 km^2 and 32 000 km^2, and the mean depth is about 23 m and 210 m, respectively. The Skagerrak and the Kattegat forms the inner end of the Norwegian trench, which has the characteristics of a deep (700 m) fjord connecting the Baltic Sea with the Norwegian Sea (e.g. Rodhe, 1987). The sill depth of the fjord is about 270 m.

The Kattegat offshore and inshore waters were identified as problem areas, whereas the Inshore Skagerrak waters the OSPAR categories I - IV indicate a slight incoherence in the assessment, although with an overall judgement to be identified as a problem area. The offshore Skagerrak was identified as a non problem area, according to the OSPAR Comprehensive Procedure. (OSPAR Commission, 2005).

The present assessment confirms the general results obtained from the 2002 OSPAR Comprehensive Procedure, covering the time period 1998 to 2000. The decreasing trends of dissolved nutrients continued also during 2001 to 2005 but were still above elevated levels in Kattegat and inshore Skagerrak areas, as defined by the Comprehensive procedure. The Chlorophyll concentrations remain high and above background concentration, while oxygen still decreased in most areas clearly below deficiency levels. Zoobenthos is still disturbed by low faunal diversity, abundance and biomass at many coastal sites. Phytoplankton indicator species are still present at elevated levels and algal toxins occur also during the present assessment period.

In comparison with the WFD procedure, OSPAR background and elevated levels for some parameters and sub-areas are generally higher compared to WFD reference and moderate levels. In addition, summer and winter total nitrogen and phosphorus are also assessed in the WFD but not in OSPAR. Nevertheless, these two parameters support the main results obtained for winter dissolved nutrients.

The Skagerrak and Kattegat area is influenced by transboundary fluxes to a great extent. Especially the inflow of nitrogen and phosphorus from the Baltic Sea is a major source for both nutrients, according to the budgets presented. Lowering the inputs to the area is best achieved by reduction of nitrogen from land but also from the Baltic Sea. For phosphorus the most effective meassure should be to lower the concentration in the southern Baltic Sea, i.e. to combat eutrophication in the Baltic. Nitrogen reduction is more important than phosphorus, taking into account the OSPAR and WFD classification schemes.

2 Introduction

OSPAR developed the *Common Procedure for the Identification of the Eutrophication Status of the OSPAR Maritime Area* in 1997 with updates in 2002 and 2005 (Ref. No. 2005-3). The last updates were done in harmonisation with the European Directives and to prepare for the second application of the guidance - the OSPAR 2008 Integrated Report.

The first Swedish application of the guidance for Skagerrak and Kattegat was published in 2002 (Håkansson, 2002). The assessment clearly indicates that the Swedish parts of the Kattegat and Skagerrak are affected by eutrophication.

Some signs of improvements were seen. Winter time dissolved phosphorus (DIP) concentrations decreased during 1998 - 2002. Also the oxygen conditions in the Kattegat bottom waters improved but were still below acceptable levels, while zoobenthos showed signs of negative indirect effects.

Finally, it was concluded that the anthropogenic nutrient load brought to the sub-basins has origin both from domestic and transboundary inflows. Swedish abatement measures will only affect Swedish coastal waters.

3 Description of the assessed area

Offshore areas of Kattegat and Skagerrak

The surface area of the Kattegat and the Skagerrak is about 22 000 km^2 and 32 000 km^2, and the mean depth is about 23 m and 210 m, respectively. The Skagerrak and the Kattegat forms the inner end of the Norwegian trench, which has the characteristics of a deep (700 m) fjord connecting the Baltic Sea with the Norwegian Sea (e.g. Rodhe, 1987). The sill depth of the fjord is about 270 m.

The average outflow of low-saline water from the Baltic Sea and the Kattegat transports nutrients from the Baltic along the Swedish (the Baltic current) and the Norwegian coasts (the Norwegian Coastal current) in the Skagerrak (Fig. 3.1). A deep-reaching high-saline inflow from the central and the northern North Sea circulates in a cyclonic direction and forms the bulk of the Skagerrak water. A weaker, less saline inflow from the southern North Sea transports nutrients to the surface layers of the Skagerrak along the northern Jutland off the Danish coast (the Jutland current). These currents may reach the Swedish coast and add to the northward flow below the less saline Baltic current. The inflows from the North Sea also contribute to the inflows to the northern Kattegat. About 65 % of the freshwater volume of the Skagerrak is contained in a band of about 30 km width along the western Sweden and southern Norway (Gustafsson and Stigebrandt, 1996). Shifting wind speed and direction on the Skagerrak area may modulate the general circulation pattern on short terms.

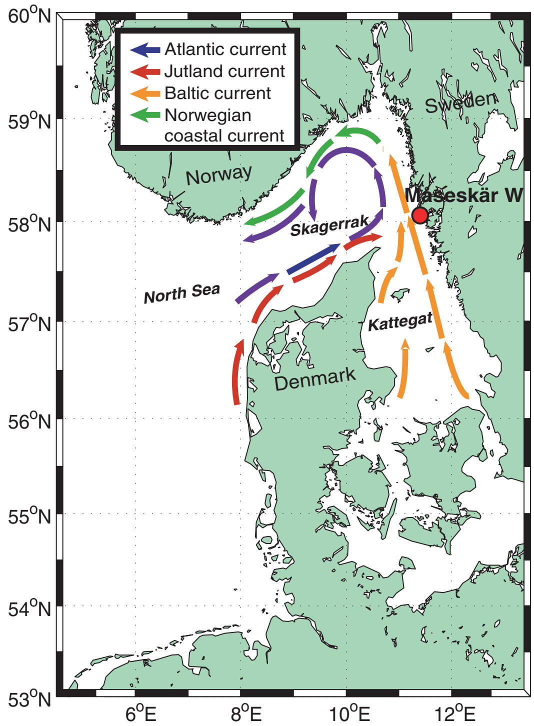


Fig. 3.1. Generalized current pattern in the Skagerrak and Kattegat area (B.Karlsson, SMHI).

Coastal waters of Kattegat and Skagerrak

Coastal waters are delimited from offshore waters making use of the Water Framework Directive methodology i.e. the border is set one nautical mile offshore a line connecting the outermost skerries off the coastline (NFS-2006:1). The border between Kattegat and Skagerrak is drawn from the north eastern tip of Jutland in Denmark to the City of Göteborg in Sweden following the HELCOM convention. The main river entering the assessed area is Göta älv just at the border between the two sub-basins. The general circulation along the west coast of Sweden is in the northward direction and hence most of the river water is mixed into the coastal water north of the mouth. Thus the area of coastal Skagerrak is mostly affected by this freshwater inflow.

The typology of the coastal waters is governed by a high salinity range, stratified with a shallow halocline and of relatively high influence of surface waves. The southernmost part of Kattegat coastal waters is shallow with characteristic bottom substrates interaction (NFS-2006:1).

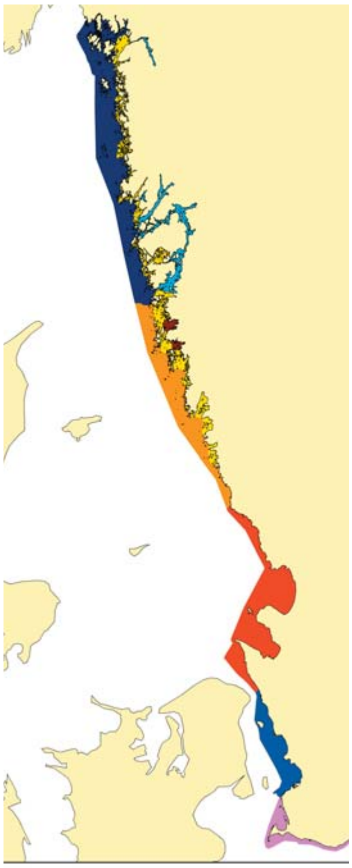


Fig. 3.2 WDF typologi of Swedish coastal waters.

4 Methods and data

4.1 Zoobenthos

Quality assessment of ecological changes in the sea can be provided most effectively by studying the sedimentary habitat and the benthic fauna, as most of the ecological impact and pollution load sooner of later will end up on the seabed. A marine benthic community in a fairly stable environment undergoes only minor qualitative and quantitative changes over time. Through evolution, benthic species have adjusted to cope with predicted environmental variations and interspecific competition. A significant disturbance will, however, introduce changes in the species composition, abundance and biomass.

This parameter is based on results from the Swedish National monitoring programme for benthic macrofauna during the years 2002 to 2005. Between these years, the same stations were sampled and analysed. 15 stations were selected for a comparison between the open sea areas and coastal areas (3 stations in the Kattegat open sea, 4 stations at the Kattegat coast, 4 stations in the Skagerrak open sea, and 4 stations at the Skagerrak coast). The mean of two replicate samples for each station was used in the analysis, in total 120 samples. The samples were collected annually in May, with a 0.1 m^2 Smith-McIntyre grab and the sediment was sieved through a 1 mm screen. The depth varied between 53 and 107 m in the open sea stations and between 28 and 62 m in the coastal stations.

4.2 Inputs from land

Nutrient loading to the Kattegat and Skagerrak from Sweden occurs by direct discharges through rivers, direct discharges from factories and water treatment works, by diffuse discharge through groundwater, and by atmospheric deposition.

To assess the nutrient loading from rivers, nutrient concentrations are monitored in the major water courses. These are then combined with an estimate of the diffuse discharge from smaller watercourses to calculate the total waterborne nutrient loading. These calculations are carried out by the Environmental Assessment Department at the Swedish Agricultural University (http://ma.slu.se).

Figure 4.1 shows annual total run-off between 1969 and 2005 from Sweden to the Skagerrak (upper) and the Kattegat (lower). Run-off to the Kattegat is considerably larger than to the Skagerrak, because of the influence of Göta Älv, the largest river in Sweden. This river drains into the north eastern corner of the Kattegat however, and so impacts most on the Skagerrak.

Inter-annual variability in run-off is large: Coefficients of variation (based on annual means) are 25% and 24% in the Skagerrak and Kattegat respectively. Day to day variability can also be large. The coefficient of variability of the daily mean flow is 47% in the Göta Älv. Despite the river being regulated, there remains some seasonality to the discharge (Figure 4.2). The spring flood peaks in March, with a mean discharge of around 800 m^3/s. Minimum run-off is in July, when discharge is just over 400 m^3/s.

This variability is reflected in the seasonal distribution of nutrient loading. Figure 4.3 shows Box plots of the nutrient loading based on daily observations of flow and nutrient concentrations at Alelyckan, on the southern branch of the Göta Älv (which takes approximately one third of the total Göta Älv discharge) between 1985 and 2002.

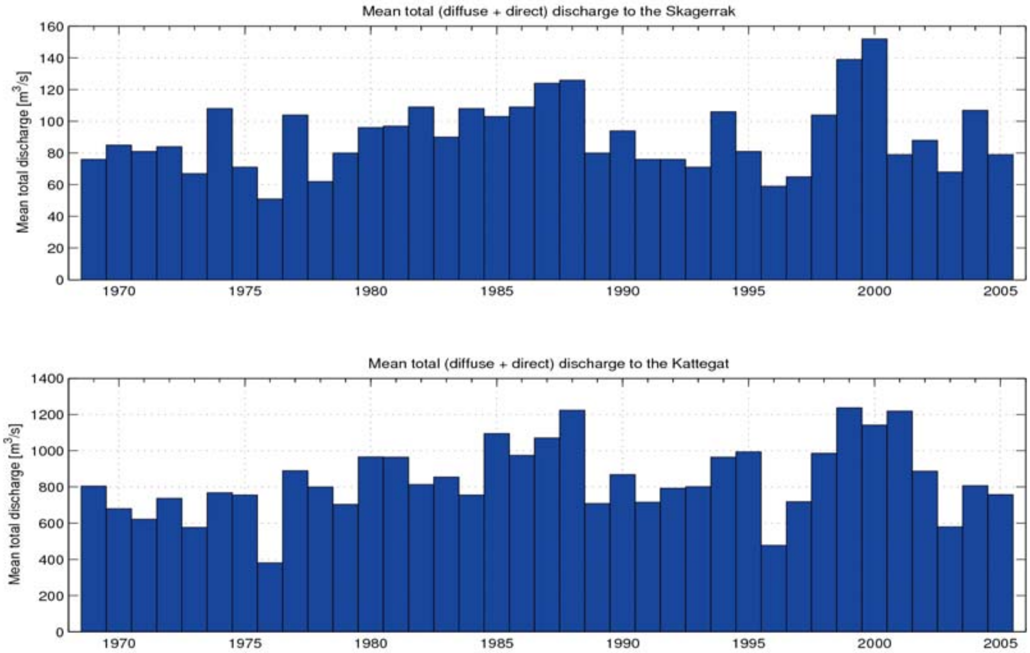


Fig. 4.1 Annual mean water discharge (sum of both direct and diffuse sources) to the Skagerrak and Kattegat

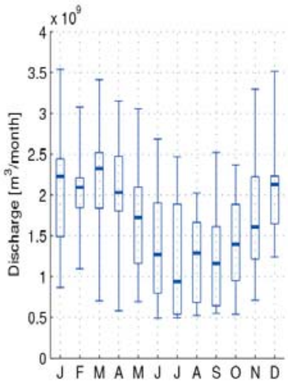


Fig.4.2 Box plot showing the annual discharge cycle of the Göta Älv

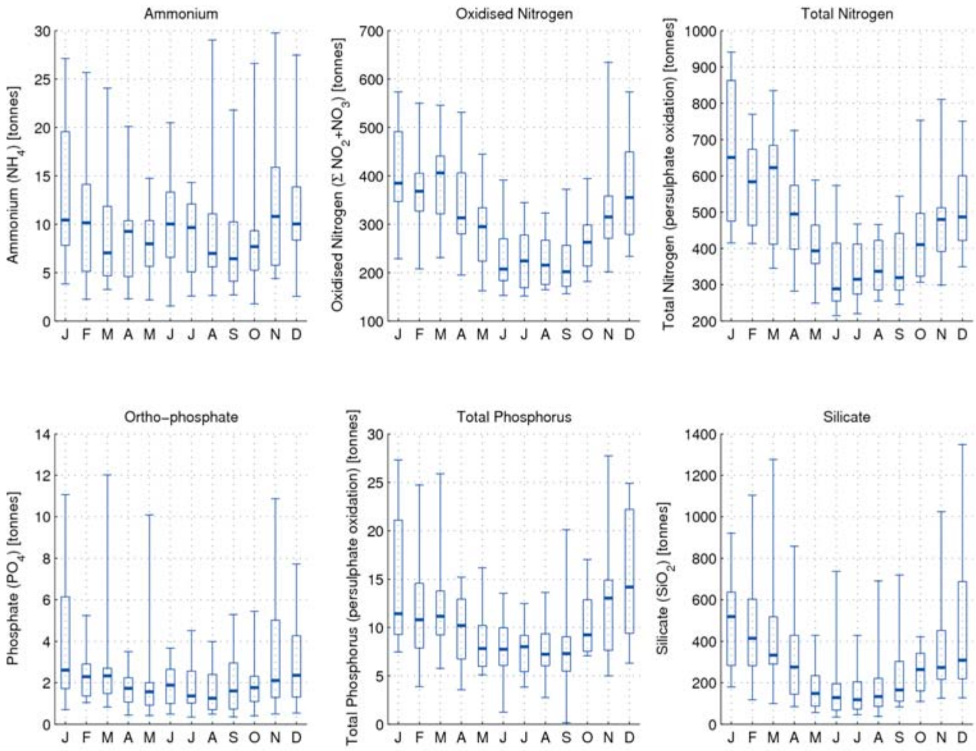


Fig. 4.3   Box plots of the annual mean cycle of nutrient loading (in tonnes/month) in the southern branch of the Göta Älv

The variability is almost all due to the flow variability. Nutrient concentrations measured show only weak seasonality. In the case of ammonium, the annual cycle is the reverse of the run-off, with highest concentrations in the summer months. Phosphorus (as total phosphorus and ortho-phosphate) shows a weak seasonality, while both nitrogen and silicate concentrations resemble the annual discharge cycle.
Figure 4.4 shows time series of the total nutrient load (including both diffuse and direct discharges) to the Kattegat and Skagerrak. The impact of the Göta Älv is clearly visible in the Kattegat data, which show loads five to ten times greater than to the Skagerrak. Trend analysis of these time series show a significant (at 95% confidence) increase in phosphate loading to the Skagerrak, and silicate loading to the Kattegat, for the period 1969 – 2005. All other nutrient trends were insignificant at this level.
Nutrient loads are significantly correlated with run-off (Appendix I). When nutrient loads are corrected for fluctuations in discharge, phosphate, total phosphorus and silicate all show changes greater than 5% over the period 1996– 2005 (Table 4.1). None of the changes observed however were statistically significant at a 95% level.

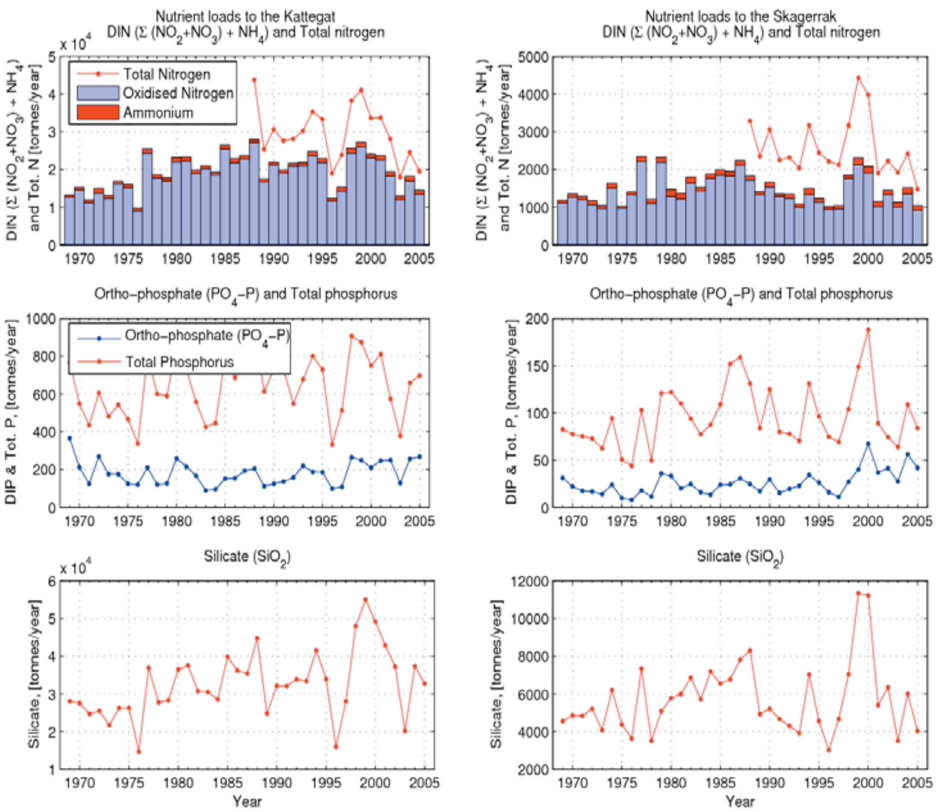


Fig. 4.4 Time series of nutrient loading from direct and diffuse sources to the Kattegat (left) and Skagerrak (right)

Substance	Kattegat				Skagerrak			
	Estimated nutrient loading		Loading corrected for discharge fluctuations		Estimated nutrient loading		Loading corrected for discharge fluctuations	
	% Change 1996 - 2005	Statistically significant (95% level)	% Change 1996 - 2005	Statistically significant (95% level)	% Change 1996 - 2005	Statistically significant (95% level)	% Change 1996 – 2005	Statistically significant (95% level)
Ammonium	9.4%	No	0.5%	No	45.8%	No	3.5%	No
Oxidised nitrogen	-16.4%	No	0.9%	No	-20.3%	No	3.6%	No
Total nitrogen	-27.6%	No	0.8%	No	-44.6%	No	4.0%	No
Ortho-phosphate	57.6%	No	0.6%	No	91.2%	No	5.1%	No
Total phosphorus	7.8%	No	0.8%	No	-9.8%	No	5.2%	No
Silicate	2.8%	No	1.0%	No	-19.0%	No	5.5%	No

Table 4.1 Changes in nutrient loading to the Kattegat and Skagerrak, 1996 – 2005, based on both raw data and data corrected for run-off fluctuations.

4.3 Trans-boundary transports

The Swedish Coastal and Ocean BIogeochemical model (SCOBI) (Marmefelt et. al., 1999; 2000; 2004; Eilola et al., 2006; Eilola and Sahlberg, 2006; Eilola and Meier, 2006) was used for the assessment of eutrophication status in the Skagerrak and the Kattegat, and of the following long-term effects on the ecosystem for the 50% nutrient reduction target (PARCOM Recommendation 88/2). The Swedish “OSPAR” model was validated by a comparison of a long time series (1985-2002) of the model results to data from a number of stations representing different parts of the model domain.
A quantitative examination of the model performance was done by a comparison between the seasonal and annual averages of the model results and in-situ data. The validation showed that the model produced good results especially in the surface layers of the modelled areas.
The model validation and the final reporting of the results using the OSPAR comprehensive procedure are presented by Eilola and Sahlberg (2006). A detailed description of the model system (Fig.4.5) and its forcing is also given in the report. The forcing and boundary conditions of the model are briefly described below.

At the North Sea boundary (the Hanstholm – Oksöy section) results from the hydrodynamical model HIROMB (High Resolution Operational Model for the Baltic Sea) were used for the transports. Transports obtained from the prognostic model for the estuarine circulation in the Baltic entrance area (Gustafsson, 2000) were used at the southern boundary (the narrowest cross section between the Samsö Belt and the southern Kattegat, and between the Sound and the southern Kattegat). Data of observed temperature, salinity, NO_3, NO_2, NH_4, TotN, PO_4, TotP and oxygen were extracted from ICES and from SHARK (**S**vensk **HA**vsa**RK**iv) SMHI´s data base and used as boundary conditions for the transports. The data set was divided into depth intervals and seasonally averaged in each year. Linear interpolation in time between years with observations was used to fill in gaps of lacking data. Extrapolation of data was done using a climatological mean value based on the average of available and interpolated data.

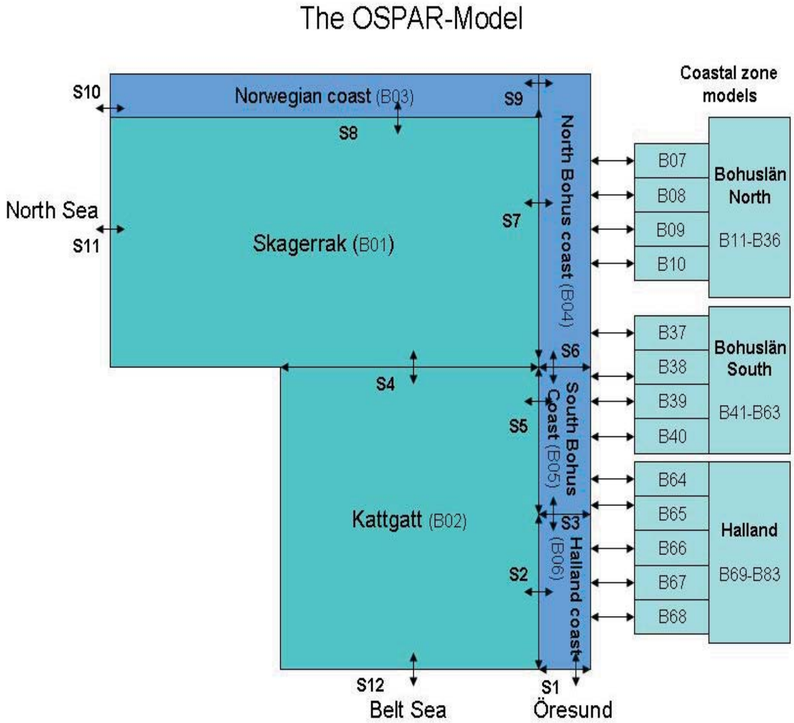


Figure 4.5. A schematic figure of the OSPAR model showing the location of the six main basins (marked with B) and the 12 sounds (marked with S) including the coupling to the Swedish coastal zone models.

Land runoff includes information of water discharge and the nutrient concentrations of total nitrogen, nitrate, ammonium, total phosphorus and phosphate. From Norway there were only measurements of water discharge and nutrients available from the Glomma River. Along other parts of the Norwegian Skagerrak coast daily mean values were taken from the hydrological HBV model. The monthly mean nutrient concentrations of the discharge were based on data from the two NIVA reports 674/96 and 715/97. The discharge data from Denmark were taken from the HBV model calculations and in the mean nutrient concentrations were taken from a study by Stålnacke (1996). Along the whole Swedish coast Eilola and Sahlberg (2006) used the same discharge data as was used in the three coastal zone models (e.g. Marmefelt et. al., 2004). These data consists of a mixture of measurements and HBV model calculations. For larger rivers there are normally daily measurements of the discharge. However in small rivers modelled discharge data was taken from the same HBV model used in the TRK-project (Brandt and Ejhed 2002). Measurements of nitrogen and phosphorus concentration were interpolated to daily values. In areas where measurements were missing the data were estimated from the nutrient information available from the surrounding areas with similar land type. Data from point sources were based on yearly values from some years during the whole period. A complete time series was constructed by interpolation between the measurements.

Monthly mean values of atmospheric nitrogen deposition were calculated with the MATCH model (**M**ultiscale **A**tmospheric **T**ransport and **CH**emistry Model). The study was based only on five years (1998-2002) of monthly deposition data which were extrapolated by using the monthly precipitation data. For the phosphorus deposition a constant value was used during the whole period (Areskoug 1993).

4.4 Phytoplankton

4.4.1 Introduction

Phytoplankton is one of the designed quality elements in the Water Framework Directive. One reason is that phytoplankton constitutes the base of the marine food web. Benthic production is minor compared to pelagic production in most areas. Phytoplankton also has a large biodiversity. One hundred different species are often found in a teaspoon of water. Changes in the species composition may have effects at other levels in the food web. Another reason is the harmful algal blooms that sometimes plague the Skagerrak-Kattegat area. In 1988 the bloom of *Chrysochromulina polylepis* affected fish and benthic organisms strongly. Since then several blooms of harmful algae have occurred. The most prominent are the blooms of *Verrucophora spp*. (the name *Chattonella spp.* has been used previously) in 1988, 2000, 2001, 2004 and 2006 which has affected farmed and wild fish through gill damage. Blooms of species producing shellfish toxins are persistent problems in the area. The phytoplankton communities in the Kattegat and the Skagerrak are influenced by organisms transported to the area from the Baltic and the North Sea area. Phytoplankton from the brackish water in the Baltic have problems surviving in the higher salinities found in the Kattegat but some years (e.g. 2006) surface accumulations of cyanobacteria are transported into the Kattegat and may also be traced in the Norwegian Coastal Current. Oceanic species originating in the Atlantic are sometimes transported into the Skagerrak-Kattegat area by currents from the North Sea. One example is the coccolithophorid blooms (see cover of report). Phytoplankton species introduced to the area through ballast water is a threat that has become larger due to increased maritime traffic.

4.4.2 Phytoplankton monitoring

Regular phytoplankton monitoring in the Skagerrak and the Kattegat has been performed at about a dozen locations during the period 2001-2005 (see Fig. 4.6). Some of the data sets started in 1986 but most started in the early 1990:s. Sampling in 2001-2005 was mostly monthly except for station Släggö on the Skagerrak coast and station Anholt E in the central Kattegat where sampling was performed ca 24 times per year. At some locations where mussel farms are located phytoplankton sampling has been performed every week for shorter periods. Sampling is in general carried out from ships and the hose method is used for obtaining integrated samples from 0-10 m depth and at several stations also from 10-20 m depth. The Utermöhl method with sedimentation chambers and inverted microscopes are used for analysing Lugol-preserved samples for the total phytoplankton community except for autotrophic picoplankton for which this method is not suitable. In addition net samples are analysed. The quality of the data is in general rather good but sampling frequency is lower than the temporal variability in the sea. For a few of the stations the biomass of phytoplankton has been measured using the biovolume method, i.e. cells are measured and the cell volume is calculated using geometric shapes such as spheres and cylinders to approximate the cells shape.

4.4.3 Phytoplankton indicator species

Some of the indicator species indicated in the guidance for the Common procedure (OSPAR Commission 2005) are difficult to identify with the method used for routine analysis. One example is the haptophyte alga *Chrysochromulina polylepis* which is only identified to the genus level in routine analysis. Thus the data presented in Appendix I is at the genus level. It should also be noted that the limit for OSPAR elevated levels of the toxin producing genera *Dinophysis* and *Alexandrium* is 100 cells per Litre. The volume used for routine analysis is only ca 20 ml. One cell observed in this analysis translates into 50 cells per Litre. It is obvious that the data quality of cell numbers below 500 cells per Litre (10 cells identified) is uncertain.

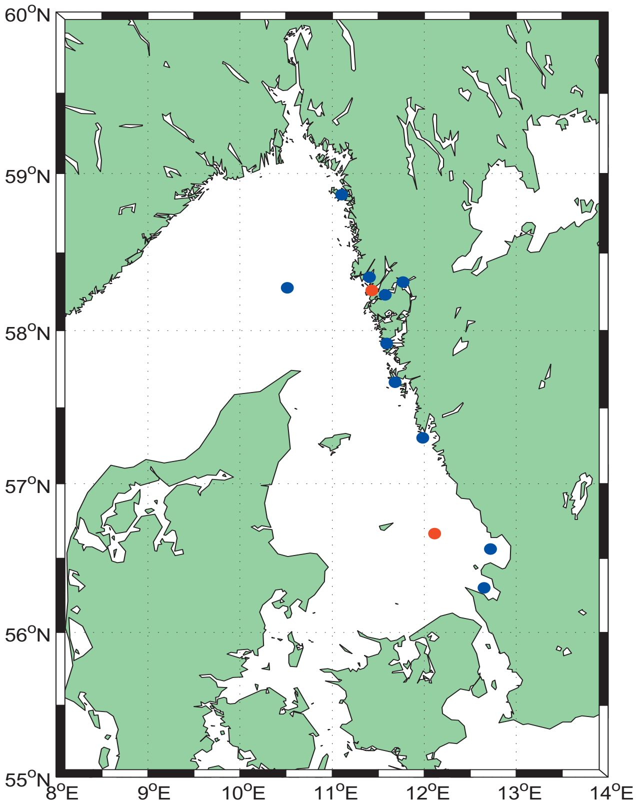


Fig. 4.6 Map showing the regular phytoplankton monitoring stations in the Skagerrak-Kattegat area. Stations with red markers are sampled ca 24 times per year whereas the blue markers indicate monthly sampling. In addition to these stations sampling is performed at some mussel farming locations, usually in connection with harvesting.

4.5 Algal toxins

4.5.1 Introduction

Some phytoplankton species produce toxins. The toxins may be accumulated by filter feeders that feed on phytoplankton. One example is blue mussels *Mytilus edulis* that is farmed mainly along the Skagerrak coast. Also wild populations of blue mussels are harvested in the area. In Sweden the dinoflagellate genus *Dinophysis* is the major producer of algal toxic. Some of the species in the genus produce DST (Diarrhetic Shellfish Toxins) which may cause illness in humans who eat mussels. Another problem is PST (Paralytic Shellfish Toxin) which in this area is produced by in the dinoflagellate genus *Alexandrium*. PST is not very common in the Swedish part of the Skagerrak and the Kattegat but since the toxin is lethal also relatively rare occurrences of *Alexandrium* could pose a risk. Other dinoflagellate genera and the diatom genus *Pseudo-nitzschia.*

4.5.2 Methods and data

Monitoring of algal toxins in mussels in the Skagerrak and the Kattegat started in the mid 1980's. The monitoring has been focused on Diarrhetic Shellfish Toxins (DST) although Paralytic Shellfish Toxins (PST) and also Amnesic Shellfish Toxins (AST) has been analysed but to a much smaller extent. Tests using mouse bioassays and chemical techniques have been used. Up until year 2000 the Sahlgrenska University Hospital performed most tests. Since year 2000 the Swedish National Food Administration administers the monitoring and private companies in Sweden and Denmark are commissioned for the tests and analyses. High Performance Liquid Chromatography (HPLC) has been used since 1988 for analysis of DST. HPLC-MS, i.e. HPLC with mass spectrometry detectors was introduced ca 2001. A comprehensive report on DST in blue mussels was published by Karlson et al. in 2007.

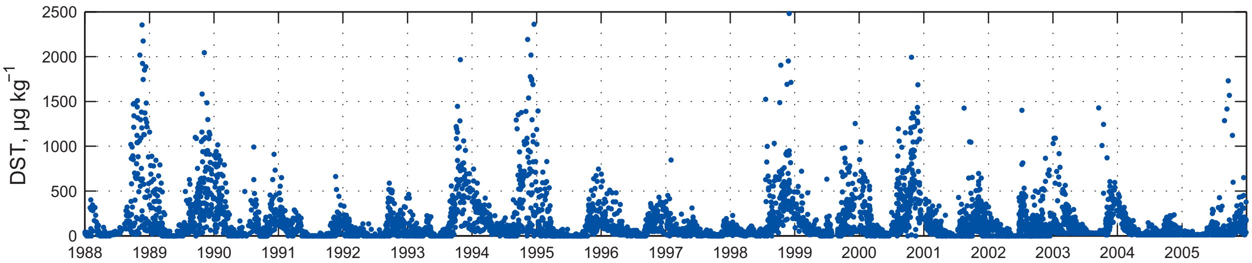


Figure 4.7   Diarrhetic Shellfish Toxins (µg kg-1) in blue mussels at locations from the Skagerrak and the Kattegat coast 1988 to 2005. Five data points from November-December 1994 are off scale. The highest value was 4659 in December 1994. (from Karlson et al. 2007).

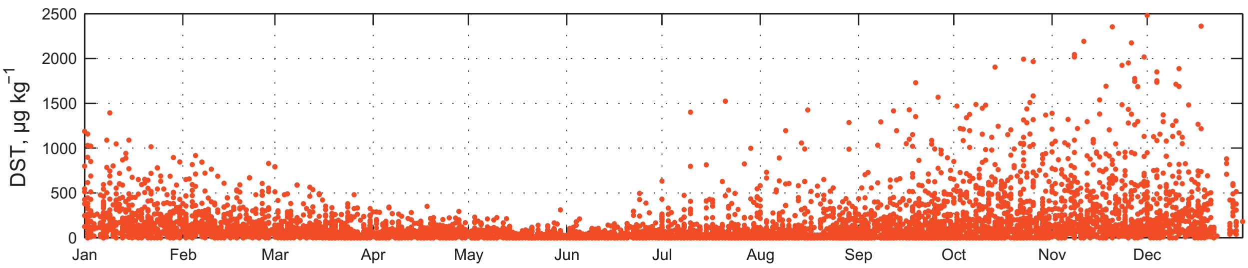


Figure 4.8 All measurements of DST (µg.kg-1) at all locations from 1988 to 2005. The seasonal variation is presented by plotting all data as a one year seasonal cycle. Five data points from November-December 1994 are off scale. The highest value was 4659 in December 1994. (from Karlson et al. 2007).

4.6 Nutrients, Chlorophyll and Oxygen

Nutrients, chlorophyll and oxygen data are reported from national and regional monitoring programmes in the Kattegat and Skagerrak areas. National monitoring data cover the period from 1970 up to 2006 with sampling rates from about 4 times a year to 12 to 24 times a year from 1996 and onwards. The monitoring guidelines follow strictly the HELCOM procedures. The monitoring is made by the SMHI Oceanographic Laboratory, who has an accredited (SWEDAC) monitoring, analysis and data handling work programme. Inshore observations are generally made under the auspice of County Boards of Halland and Bohuslän. In the latter county the Water Quality Association of the Bohus Coast (http://www.bvvf.com/english/default.html) is responsible for the monitoring and assessment work. All data in this assessment is taken from the national data host at SMHI (www.smhi.se//oceanografi/oce_info_data/oce_data_en.html).

5. Eutrophication assessment based on the period 2001 - 2005

5.1 Nutrient budgets

The annual average modelled transports of nutrients (DIN, DIP, TotN and TotP) and water through the open boundaries (Table 5.1) are discussed here. The corresponding figures from the Swedish OSPAR assessment 2002 (Håkansson, 2003), Rydberg & al. (1996) and Savchuk (2005) are also shown. The supply of water and nutrients from land runoff and the atmospheric deposition of reduced nitrogen NOx and NHx and of phosphate (PO4) to the Skagerrak and Kattegat model area are also presented.

The western boundary fluxes of the present model were computed for from 24 hour running mean based on snap shots every 6th hour from HIROMB. The results from Rydberg & al. (1996) were based on estimations from repeated measurements during 1990-1994 at a number of stations in the southern half of the Oksöy-Hanstholm section. The southern boundary fluxes of the present model are computed from daily mean values obtained from the Gustafsson (2000) model. Savchuk (2005) computed long-term mean (1991-1999) transports from Knudsen relations using long-term averages of salinity and net freshwater supply. The figures are difficult to compare directly but are shown in order to give examples of different transport estimates.

The average import of nitrogen and phosphorus at the western boundary is about 4279 kton N and 544 kton P per year. About 45% and 60% of this is in inorganic forms, DIN and DIP. There is a net export of both nitrogen (179 kton N per year) and phosphorus (15 kton P per year) to the North Sea.

The average import of nitrogen and phosphorus at the southern boundary is about 534 kton N and 49 kton P per year. About 20% and 50% of this is in inorganic forms, DIN and DIP. There is a net import at the southern boundary of both nitrogen (231 kton N per year) and phosphorus (16 kton P per year) to the Kattegat.

The average supply of nitrogen and phosphorus from land is about 120 kton N and 3 kton P per year. About 74% and 20% of this is in inorganic forms, DIN and DIP. The contribution of nitrogen and phosphorus from each country are 36 ktonN and 1 ktonP from Norway, 41 ktonN and 1 ktonP from Denmark and 43 ktonN and 1 ktonP from Sweden.

The average atmospheric supply of nitrogen and phosphorus is about 43 kton and 0.3 kton P per year.

Period 1985-2002

The average transports of water are in the range 20 000-21 000 km^3 per year at the western boundary and 1200-1800 km^3 per year at the southern boundary. The net inflow to the Kattegat from the Sound and the Belt Sea is in the model about 557 km^3 per year. The average freshwater supply from all three countries is 106 km^3 per year and the contribution from each country is 66 km^3, 6 km^3 and 34 km^3 from Norway, Denmark and Sweden, respectively. The net outflow to the North Sea from the Kattegat is about 663 km^3 per year.

Period 2001-2002

The modelled average transports of water in these years are rather similar to the long-term average discussed above. The difference between the long-term average nutrient supplies to the Kattegat-Skagerrak area and the situation in the years 2001-2002 is summarized in Table 5.2. The modelled pelagic and benthic mass change and the internal sinks of phosphorus and nitrogen are summarised in Table 5.3. Budgets for total nitrogen and phosphorus in the Skagerrak and Kattegat are shown in figure 5.1.

Annual average transport; 1985-2002	Water	Tot-N	Tot-P	DIN	DIP
	km³/yr	kton/yr	kton/yr	kton/yr	kton/yr
North Sea to the Skagerrak	20279	4279	544	1946	334
Skagerrak to the North Sea	20942	4458	559	2026	352
Belt Sea and the Sound to Kattegat	1786	534	49	117	25
Kattegatt to the Belt Sea and the Sound	1229	303	33	84	17

Annual average transport; 2001-2002	Water	Tot-N	Tot-P	DIN	DIP
	km³/yr	kton/yr	kton/yr	kton/yr	kton/yr
North Sea to the Skagerrak	20811	4376	509	2056	317
Skagerrak to the North Sea	21500	4601	538	2180	345
Belt Sea and the Sound to Kattegat	1716	463	42	101	21
Kattegatt to the Belt Sea and the Sound	1140	273	28	80	14

Annual average transport;	Water	Tot-N	Tot-P	DIN	DIP
	km³/yr	kton/yr	kton/yr	kton/yr	kton/yr
North Sea to the Skagerrak	25230(3)	3840(1)	n.d.	2040(1)	360(1)
Skagerrak to the North Sea	25230(3)	n.d.	n.d.	n.d.	n.d.
Belt Sea and the Sound to Kattegat	1212(2)	365(2)	33.4(2)	n.d.	n.d.
Kattegatt to the Belt Sea and the Sound	687(2)	174(2)	15.3(2)	n.d.	n.d.

Annual average freshwater supply to all 83 basins of the model area	Water	Tot-N	Tot-P	DIN	DIP
	km³/yr	kton/yr	kton/yr	kton/yr	kton/yr
1985-2002	106	119610	3366	88943	720
2001-2002	113	122051	3678	91517	721

Annual average atmospheric supply to all 83 basins of the model area	Nox	NHx	PO4
	ton/yr	ton/yr	ton/yr
1985-2002	21781	20772	315
2001-2002	21781	20772	315

Table 5.1. The annual average open boundary transports of nutrients and water, and the supply of water and nutrients from land and atmosphere to the Skagerrak and Kattegat area are shown for the periods 1985-2002 and 2001-2002. Figures from the [1]OSPAR assessment 2002 (CP 2002), [3] Rydberg & al. (1996) and [2] Savchuk (2005) are also presented. The nutrient supplies to Skagerrak from the North Sea reported by CP 2002 are based on the results from Rydberg & al. (1996).

		Tot-N	Tot-P	DIN	DIP
		kton/yr	kton/yr	kton/yr	kton/yr
1985-2002	Net supply	393	20	164	9
	Net export	178	15	80	18
	Change	-214	-5	-84	9
2001-2002	Net supply	355	19	155	8
	Net export	225	29	124	28
	Change	-130	11	-31	20

Table 5.2. The annual average net supply of nutrients to the Kattegat-Skagerrak area, and the net export from the area to the North Sea is shown. The difference between the supply and the export is shown by Change.

	Nitrogen	**Phosphorus**
	ktonN/yr	*ktonP/yr*
Mass change	-71.7	-11.8
Sink	137.7	0.6

Table 5.3. Total mass change (water + sediment) and permanent internal sink in basin number 1 to 6 in the period 2001-2002 (see Fig. 4.5). The internal sink is mainly denitrification for nitrogen and permanent burial in sediments for phosphorus.

The net supply of nitrogen and phosphorus from land, atmosphere and the Baltic Sea to the Skagerrak and Kattegat area is about 10% lower in 2001-2002, and the net export of nutrients to the North Sea is about 26% (Tot-N), 93% (Tot-P), 55% (DIN) and 56% (DIP), higher in 2001-2002 compared to the long-term average. The reduced supply is mainly due to lower nutrient inputs from the Belt Sea and the Sound. Loading from land increased slightly in this period.

In 2001-2002 the net supply of nitrogen from land, atmosphere and the Baltic Sea to the Skagerrak and Kattegat area was 355 ktonN/yr. From this, about 225 ktonN/yr was exported to the North Sea while the rest 130 ktonN/yr was removed by denitrification in the six major basins (Fig.5.1). There is also a negative nitrogen mass change (about 72 ktonN/yr) in the six major basins. The modelled denitrification in these basins may explain about 8 ktonN/yr of this change while the rest (64 ktonN/yr) is retained in the coastal areas. The net supply of phosphorus from land, atmosphere and the Baltic Sea to the Skagerrak and Kattegat area was 18 ktonP/yr while about 29 ktonP/yr was exported to the North Sea. The net export of 11 ktonP/yr and the internal sink of 0.6 ktonP/yr mainly explains the negative mass change (-11.8 ktonP/yr) in the six major basins. About 0.2 ktonP/yr was retained in the coastal areas. Retention in the coastal areas has not yet been explicitly investigated. The net export of phosphorus to the North Sea is mainly in the form of DIP.

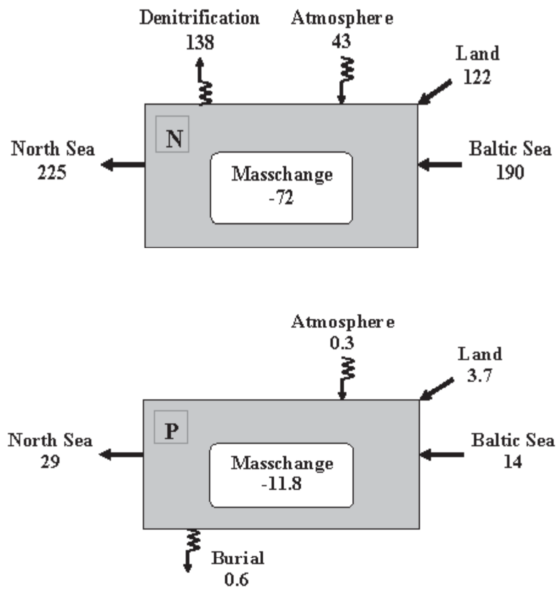


Fig. 5.1 Nutrient budgets for Skagerrak-Kattegatt basins in kton/yr.

5.2 Parameter-related assessment based on background concentrations and assessment levels

5.2.1 Category I - Nutrient Enrichment

Land input from Sweden

Nutrient supply to the Kattegat and Skagerrak from land is dominated by the contribution of the Göta Älv. As the river drains into the north eastern Kattegat, it's effect is felt most along the inshore Skagerrak. Despite regulation, the run-off has a seasonal signature, with peak flows in the winter months, peaking in March. This results in the maximum nutrient supply from land coinciding with the spring bloom. Fluctuations in the supply of nutrients are large, which precludes a meaningful trend analysis of the time series.

Winter Nutrient Concentrations: DIN, DIP and Si

Concentrations of winter inorganic nutrients indicate nutrient availability for the spring bloom. At the end of the summer, nutrients are depleted. During autumn and winter, concentrations increase as nutrients are supplied while biological activity is at a minimum.

To assess the winter nutrient concentrations, it is necessary to identify the winter period. Fig. 5.2 shows the annual mean cycles of nitrogen (DIN and total nitrogen) phosphorus (DIP and total phosphorus) and silicate for the offshore Kattegat and offshore Skagerrak. From the figure, it is seen that maximum DIN, DIP and silicate concentrations occur during January. Total nitrogen and phosphorus appear to peak during February. In the Skagerrak the spring bloom does not occur until the end of February at the earliest.

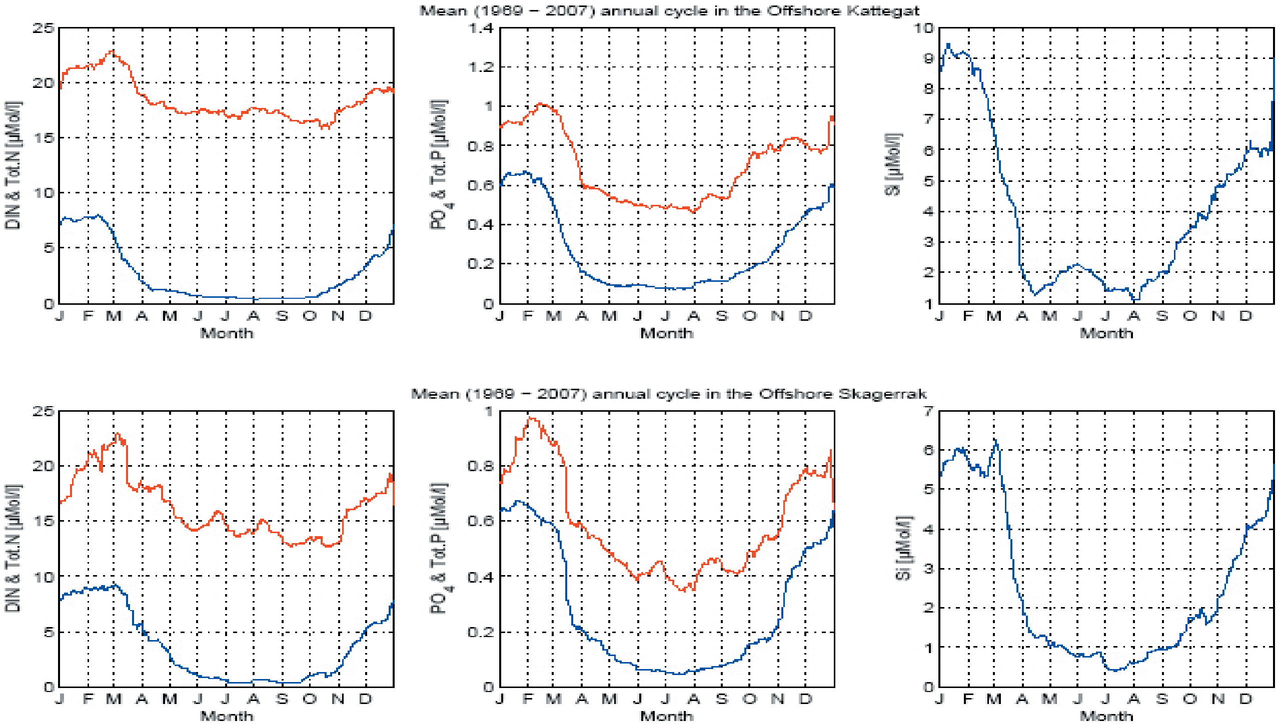


Fig. 5.2 Annual mean cycles of nitrogen (DIN and total nitrogen), phosphorus (DIP and total phosphorus) and silicate for the offshote Kattegat (upper) and offshore Skagerrak (lower) based on data from 1969 to 2007, filtered with a 14 day running mean.

Within the Kattegat and Skagerrak, salinity gradients are large. The Baltic surface outflow is brackish, while the deep water of the Skagerrak is oceanic. In addition, the coastal zone is influenced by fresh water run-off. To reduce the variability introduced by these salinity variations, the region was divided into four sub regions. The inshore Kattegat and inshore Skagerrak regions are those areas where water quality status objectives are set by the EU Water Framework Directive – that is, within and area bounded by the Baseline plus one nautical mile. The offshore Kattegat and offshore Skagerrak lie outside of these boundaries. Sampling positions from the respective sub regions are shown i Fig. 5.3.

While the division into sub-regions reduces the impact of salinity variations, data within each sub region still showed dependence on salinity. Appendix I shows the mixing diagrams for winter surface DIN, DIP & silicate for each of the four sub-regions. All parameters and regions have significant trends with salinity, with the exception of DIN in the offshore Skagerrak. Across all areas, DIP increases with increasing salinity while silicate decreases with increasing salinity. DIN decreases with increasing salinity in the inshore Kattegat and Skagerrak. In the offshore Kattegat, DIN increases with increasing salinity, because the brackish water flowing out from the Baltic is low in DIN. In the offshore Skagerrak, the relation between DIN and salinity was not significant at a 95% level.

Data were plotted as time series of median and 90th percentile concentration, corrected to a reference salinity of 30 psu. These time series were compared with reference values published in OSPAR 2005, and those produced for the Water Framework Directive. Results for 2001 – 2005 are tabulated in the following three tables. Graphs of the results are in Appendix I.

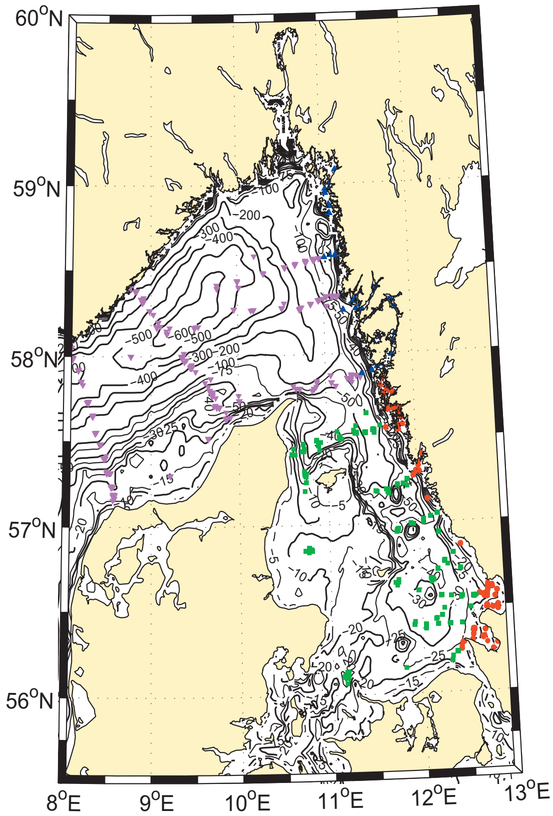


Fig. 5.3 Sampling positions and topography in the Kattegat and Skagerrak. The different coloured points indicate sampling locations in each of the subregions.

	Kattegat				Skagerrak			
	Inshore		Offshore		Inshore		Offshore	
OSPAR background	4 – 5 µMol/l				10 µMol/l			
OSPAR elevated	> 6 – 7 µMol/l				> 15 µMol/l			
WFD Reference	4.5 µMol/l		N.A.		6 µMol/l		N.A.	
WFD Moderate status	≥6.75 µMol/l		N.A.		≥9 µMol/l		N.A.	
Observed	Median	90%	Median	90%	Median	90%	Median	90%
2001	5.43	16.39	7.86	8.80	11.29	18.40	8.05	18.99
2002	6.68	14.56	7.54	8.82	10.91	14.29	6.97	13.74
2003	3.72	12.56	7.15	8.08	6.69	12.57	5.93	10.74
2004	6.66	10.53	8.11	12.87	10.57	13.45	8.30	12.92
2005	<0*	5.27	6.29	9.13	1.44	9.54	4.95	6.94

Table 5.4 Winter surface DIN at 30 psu

	Kattegat				Skagerrak			
	Inshore		Offshore		Inshore		Offshore	
OSPAR background	0.4 µMol/l				0.6 µMol/l			
OSPAR elevated	> 0.5 – 0.6 µMol/l				> 0.9 µMol/l			
WFD High status	0.4 µMol/l		N.A.		0.5 µMol/l		N.A.	
WFD Moderate status	≥0.6 µMol/l		N.A.		≥0.75 µMol/l		N.A.	
Observed	Median	90%	Median	90%	Median	90%	Median	90%
2001	0.54	0.65	0.55	0.64	0.59	0.82	0.51	0.67
2002	0.55	0.64	0.57	0.64	0.66	0.89	0.52	0.69
2003	0.54	0.60	0.58	0.64	0.59	0.65	0.56	0.71
2004	0.71	0.79	0.64	0.69	0.61	0.83	0.54	0.66
2005	0.48	0.69	0.72	0.95	0.50	0.92	0.46	0.59

Table 5.5 Winter surface DIP at 30 psu

	Kattegat				Skagerrak			
	Inshore		Offshore		Inshore		Offshore	
Observed	Median	90%	Median	90%	Median	90%	Median	90%
2001	3.09	6.78	8.37	10.48	6.79	17.10	6.67	13.43
2002	5.39	11.41	7.61	10.78	8.11	20.20	5.76	11.39
2003	4.87	9.72	9.47	10.91	6.81	13.89	6.92	10.48
2004	7.81	14.93	8.44	11.98	10.33	19.64	7.05	11.08
2005	<0*	6.27	7.98	13.04	0.04	15.73	4.19	6.85

Table 5.6 Winter surface silicate at 30 psu. No status guidelines available.
** The correction to a reference salinity resulted in a negative concentration*

Winter N/P, N/Si and P/Si ratios

Winter nutrient ratios were assessed for offshore regions only (Appendix I). Elevated nitrogen levels inshore mean that use of standard 'Redfield'-type ratios may not be appropriate (OSPAR, 2005). In both the offshore Kattegat and Skagerrak, the median and mean DIN:DIP ratios lie below the 'standard' value of 16, and only very rarely exceed the assessment level. Elevated values in 1998 in the Skagerrak were due to unusually high DIN concentrations.

High silicate concentrations in the offshore Kattegat result in a low DIN:Silicate ratio, despite high DIN concentrations. In the Skagerrak, decreasing DIN concentrations have caused the DIN:Silicate ratio to approach 'non-problem' levels in the last five years.

Ratios of DIP:Silicate have been stable in both the Kattegat and Skagerrak since the second half of the 1990s. This is despite the increasing DIP concentrations in the offshore Kattegat since 2001.

5.2.2 Category II - Direct Effects of Nutrient Enrichment

Maximum and minimum chlorrophyll a concentration

Table 5.7 contains means and 90-percentiles for chlorophyll-a, based on time series of the growing season (February - October) . These appear to show a decreasing trend between 1984 and 2005 in the Kattegat and inshore Skagerrak, though these are not significant at a 95% confidence level. Absolute levels remain higher than the OSPAR assessment level for problem areas (2 µg/l).

Secchi disk measurements support the results of the chlorophyll-a trend analyses. In the Kattegat (both inshore and offshore) and in the inshore Skagerrak, between 1969 and 2005 there was a significant increasing trend in Secchi depth of 5 – 10 cm per year. In the offshore Skagerrak, Secchi depth has decreased over the same time period, though this trend is not significant at a 95% level.

	Kattegat				Skagerrak			
	Inshore		Offshore		Inshore		Offshore	
	Median	90%	Median	90%	Median	90%	Median	90%
2001	2.50	6.38	1.90	4.40	3.30	10.05	2.20	4.84
2002	2.10	5.20	1.40	3.62	2.40	6.20	1.30	5.90
2003	1.80	7.20	1.00	5.68	2.30	7.14	1.40	3.57
2004	2.00	9.60	1.50	3.18	2.10	6.16	1.10	3.62
2005	1.75	5.30	1.40	3.45	1.90	5.70	1.30	2.80

Table 5.7 Median and 90th percentiles of growing season (February – October) chlorophyll-a (µg/l) for the period 2001 – 2005

Overview of phytoplankton indicator species 2001-2005

Graphs of the data set on the phytoplankton Graphs of the data set on the phytoplankton indicator species are presented in Appendix I. The new problem genus in the Skagerrak-Kattegat is *Verrucophora*. It was formerly known as *Chattonella* sp. or *Chattonella* cf. *verruculosa* in the Scandinavia but it has now been shown that the "Scandinavian *Chattonella* species" belong to a new genus in the Raphidophyceae. Two separate species have been blooming in the area. In 1988 and 2000 *V. verruculosa* blooms occurred with fish deaths while in 2001, 2004 and 2006 *V. farscima* bloomed. Fish deaths due to gill damage did occur in 2001 and 2006 in the area but was not observed in Sweden.

The dinoflagellate genus *Dinophysis* is the "indicator species" that most frequently occur above the OSPAR-elevated levels in the Skagerrak and the Kattegat. Only the outer Skagerrak has abundances of *Dinophysis* that in general is below the OSPAR assessment value. The genus contains species that are mixotrophic, i.e. they can use sunlight for photosynthesis but may also feed on other plankton organisms. It is questionable if the high abundances of *Dinophysis* is an indication of eutrophication in the area. One reason that the genus is common is probably the stratified water that is normal in this area. The brackish water from the Baltic causes a pyconocline at ca 15-20 m in summertime and organisms that have a good swimming capacity and mixotrophic mode may be favoured by such conditions.

The other “indicator species” that regularly occur with abundances above the OSPAR assessment value are *Alexandrium* spp. and *Prorocentrum* spp. The former is a problem for the mussel industry but is probably not an indicator of eutrophication since cell numbers and biomass are quite low. The most common species are *A. ostenfeldii, A. minutum*, *A. tamarense* and *A. pseudogonyalax*. The *Prorocentrum* species that are common are *P. micans* and *P. minutum*.

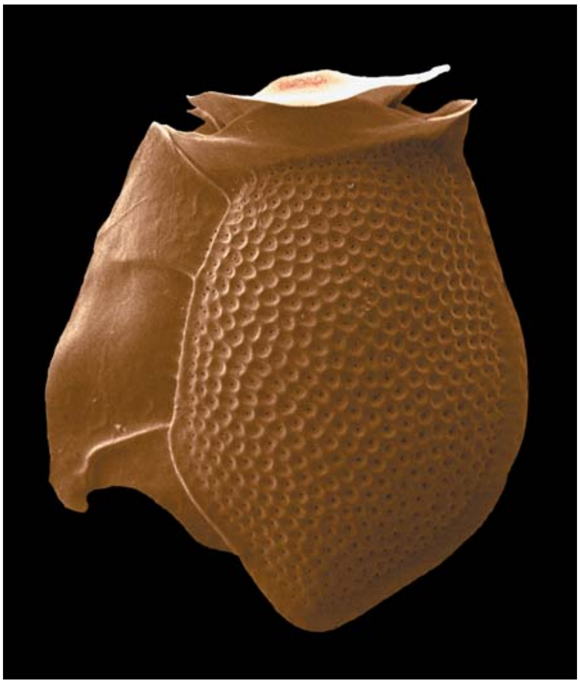


Fig. 5.4 Dinophysis acuta, one of the species that produce diarrhetic shellfish toxins. Artificial colouring has been added to the scanning electron micrograph Photo: Bengt Karlson.

Phaeocystis spp. was only observed on a few occasions in the Skagerrak-Kattegat area in 2001-2005 and always below the OSPAR assessmnet value. In other areas, e.g. parts of the English channel, the genus may form blooms that is a nuisance on beaches because large amounts of foam is produced.

Noctiluca scintillans does occur regularly in the area but abundances above the OSPAR assessment value was not observed in the monitoring samples 2001-2005. However, in summer 2002 dense accumulations of *Noctiluca* sp. was observed off Lysekil on the Skagerrak coast. The organism is heterotrophic and feed on other plankton.

Chrysochromulina polylepis is one of the OSPAR indicator species. The monitoring data show no occurrences above the OSPAR assessment value. In routine monitoring it is difficult to identify this organism to the species level. It is usually identified as *Chrysochromulina* spp. or as “unidentified flagellate”. Thus the data shown in Appendix I might be misleading, *C. polylepis* might be more common than the graph indicates.

Karenia mikimotoi (synonym *Gymnodinium mikimotoi* which has been called the European *Gyrodinium aureolum*) is an OSPAR-indicator species that used to form blooms in the Skagerrak. The last major bloom was in 1988 according to the authors knowledge. Since then a few occasions with abundances above the OSPAR assessment value has been noted. One event was in 2001.

Pseudo-nitzschia spp. is not an OSPAR-indicator species. The data is shown since several species from this diatom genus may produce amnesic shellfish toxins (AST). The limit used is the one the Swedish National Food Administration uses in connection with controls of shellfish. In Denmark and Norway AST (domoic acid) has been observed in shellfish in the 21st millennium but so far not in Sweden.

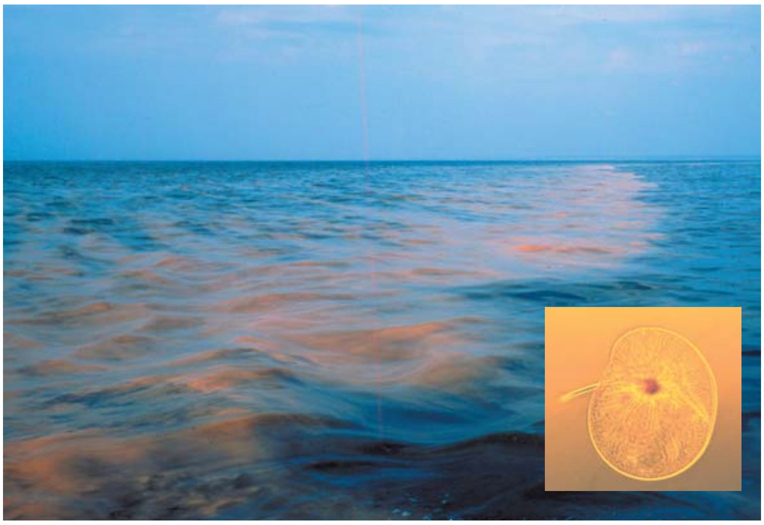


Fig. 5.5 An accumulation of the heterotrophic dinoflagellate Noctiluca sp. *observed in the Baltic current off Lysekil in 2002. Photo: Mattias Sköld.*
The small image shows Noctiluca scintillans *as seen in the microscope. Photo: Bengt Karlson*

5.2.3 Category III – Indirect Effects

Oxygen Deficiency

Analysis of oxygen data is based on the deepest oxygen sample from each profile. This is a reasonable descriptor of oxygen conditions just above the bottom, which directly impact sessile marine life.

Appendix I shows the distribution of bottom oxygen observations (as concentration and saturation) in each region. These time series appear to show decreasing trends. Analysis of the 5th percentile (the level of the lowest 5% of each year's data), showed significant, decreasing trends in concentration in all areas. The rate of decrease is greater inshore, about 0.1 mg/l per year. The offshore rate is about half this. The fifth percentile saturation also decreased, apart from the inshore Skagerrak. The decrease was just over 1% per year in the inshore Kattegat (Table 5.8).

The ninety fifth percentile exhibited similar behaviour to the fifth percentile, though trends were only significant offshore. The rate of decrease was similar to the fifth percentile. This suggests that the decrease is consistent across all offshore areas, both those areas which have historically had low bottom oxygen levels and those that have not been affected by hypoxia. As the change is also apparent in the oxygen saturation, this change cannot be explained by changes in water temperature.

Appendix I shows the proportion of each year's autumn bottom oxygen measurements in each hypoxia class. With the exception of 2000 and 2002, more than 50% of the bottom oxygen samples in the inshore Kattegat show no problems with hypoxia, even in the autumn. In the offshore Kattegat, the situation appears worse, with only 30% of bottom samples indicating no stress on bottom animals. The frequency of observations of acutely hypoxic water (< 2 mg/l) is however very low. 2002 stands out. This was a particularly bad year for hypoxia and anoxia in the southern Kattegat and Danish Straits, caused by several weeks of extremely calm weather, which prevented the horizontal advection of oxygen across the seafloor.

The situation appears even worse in the inshore Skagerrak, where 20% of samples regularly show acutely toxic conditions. This is because most sampling is concentrated in the west Swedish fjord system, which has very poor water exchange with the offshore and suffers from both seasonal, and in some fjords, permanent anoxia (Table 5.9a).

In the open Skagerrak, any form of hypoxia is extremely rare, although expressing the data in terms of oxygen saturation shows that oxygen saturation falls below 80% at around half the sampling sites (Table 5.9b).

	Bottom oxygen concentration		Bottom oxygen saturation	
	5 percentile	95 percentile	5 percentile	95 percentile
Inshore Kattegat	-0.10 mg/l/yr		-1.1% /yr	
Offshore Kattegat	-0.05 mg/l/yr	-0.03 mg/l/yr	-0.5%/yr	-0.4%/yr
Inshore Skagerrak	-0.13 mg/l/yr			
Offshore Skagerrak	-0.03 mg/l/yr	-0.03 mg/l/yr	-0.3%/yr	-0.3%/yr

Table 5.8 Significant trends in bottom oxygen concentration and saturation

	Kattegat				Skagerrak			
	Inshore		Offshore		Inshore		Offshore	
	5%	Median	5%	Median	5%	Median	5%	Median
2001	2.74	6.98	3.34	5.46	-3.58	5.18	6.84	7.58
2002	0.75	4.55	1.17	2.52	-10.88	4.15	6.76	7.24
2003	1.41	5.28	2.04	3.74	0.18	4.46	6.99	7.45
2004	1.87	6.06	4.00	5.40	-10.52	4.73	6.11	7.43
2005	1.70	5.96	3.86	5.42	-14.04	5.23	6.54	7.76

Table 5.9 a 5th percentile and median of autumn (August – October) bottom oxygen concentration (ml/l) for the period 2001 – 2005

	Kattegat				Skagerrak			
	Inshore		Offshore		Inshore		Offshore	
	5%	Median	5%	Median	5%	Median	5%	Median
2001	33.60	80.00	38.00	61.00	0.00	55.00	73.00	81.00
2002	8.50	52.00	13.00	28.00	0.00	47.50	72.00	77.00
2003	15.85	63.50	22.00	40.50	2.00	50.50	76.00	80.00
2004	20.60	68.00	44.00	61.50	0.00	51.00	70.00	81.50
2005	19.00	70.00	41.00	58.50	0.00	52.00	73.00	83.50

Table 5.9 b 5th percentile and median of autumn (August – October) bottom oxygen saturation (%) for the period 2001 – 2005

Benthic macrofauna in the open sea and coastal areas of Kattegat and Skagerrak

Neither the redox measurements nor the oxygen measurements, performed within the benthos monitoring programme (Agrenius 2002-2005) indicate that there had been any periods with severe oxygen deficiency at these Kattegat and Skagerrak stations during the sampling periods.

The mean number of species per 0.1 m^2 at the open sea stations in the Kattegat and Skagerrak was between 30 and 41, whereas it was lower for the coastal stations, as a mean between 23 and 28 species (Fig. 5.5). Mean abundance for the same areas was generally higher in the Skagerrak compared to the Kattegat, with the highest mean abundance in the open sea stations in Skagerrak (370-410 ind./0.1 m^2) and the lowest at the coastal stations in the Kattegat (174-217 ind./ 0.1 m^2). The mean biomass was similar between the areas with a peak for the Skagerrak open sea in 2002. This peak was mainly caused by a few large sea urchins, *Brissopsis lyrifera*, and at one station an increase in abundance of the brittle stars *Amphiura filiformis* (which can be explained by a local increase of organic enrichment).

Overall, there could be no significant temporal trends detected for the number of species, abundance and biomass within or between the four areas over the period 2002 to 2005.

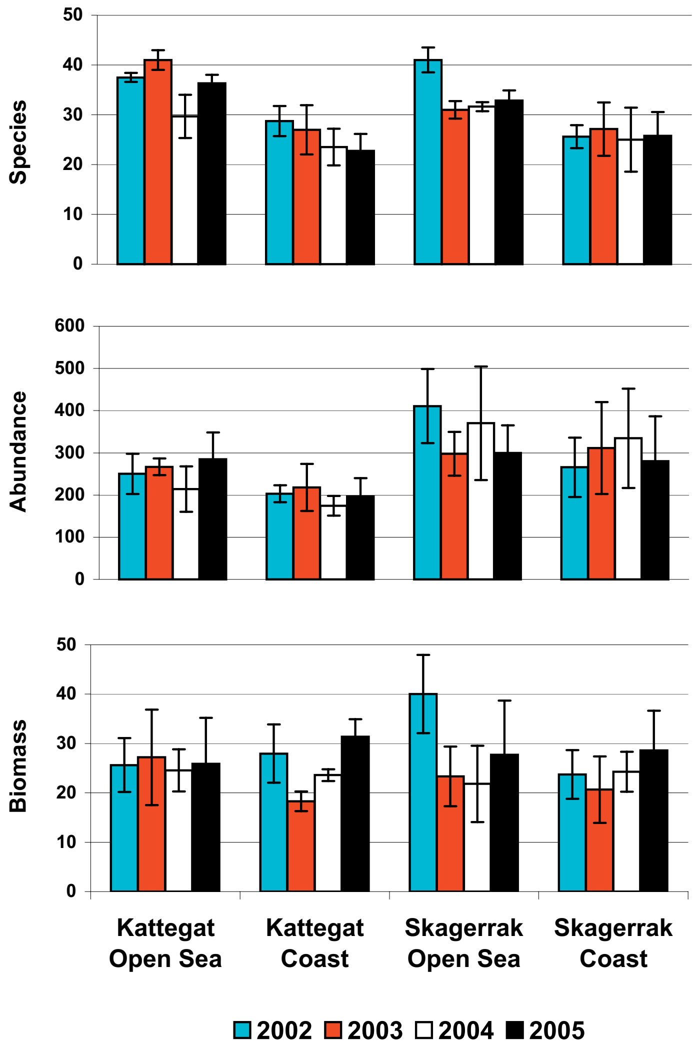


Fig. 5.5. Mean (with SD, n=3 and 4) number of species, abundance and biomass (wet weight) per 0.1 m^2 of the benthic infauna at 15 stations in the open sea areas and the coastal areas of the Kattegat and Skagerrak.

A multi-dimensional statistical analysis (MDS) was made to analyse the species-abundance similarities between the 15 selected stations (Fig. 5.6). The MDS ordination separated the faunal composition into two groups: the open sea stations (A) and the coastal stations (B).

This shows that the structure of the benthic communities at the coastal stations and the open stations was different. The difference between the faunal composition at the coast and the open sea could be caused by a greater impact of human influence in the coastal areas. Another possibility could be that the environmental conditions at the open sea stations were more stable.

Based on a combination of the species tolerance values (ES50), and the abundance and diversity, a benthic quality index (BQI) was calculated for assessing the environmental status of the selected stations in the Kattegat and Skagerrak according to the EU Water Framework Directive (WFD) as presented by Rosenberg et al. (2004) (Fig. 5.7). Mean BQI at all stations varied between 16.6 and 11.3 at depths >20 m (Fig. 5.8). This shows that the benthic communities at most stations during the 2002-2005 period were in *good* or *high* conditions according to the five stages of classification within the WFD. In comparison between the open sea and the coastal areas, the BQI values were higher at all the open sea stations over all years. In 2004 at the Skagerrak coastal stations, the BQI showed that the benthic stations were only *moderate*. This was probably caused by the sediment being mechanically impacted by fishing activities (Agrenius 2005).

Benthic habitat quality assessment along the coast

To assess the benthic habitat quality, 12 stations were randomly stratified into four depth strata in each of three fjord areas in the Skagerrak (Gullmarsfjord, Koljefjord and Havstensfjord) and three coastal areas in the southern Kattegat (Skälderviken and Laholm Bay) and the northern Öresund. The assessment was based on digital analysis of images of sediment profiles obtained *in situ* by a sediment profile camera (SPI). The technique resemble an up-side-down periscope that penetrates about 25 cm into the sediment with a width of the prism of about 15 cm. Samplings were made in May in the years 2002 to 2005. The assessment was made by using a Benthic Habitat Quality (BHQ) index, where (1) structures on the sediment surface, (2) structures in the sediment, and (3) the mean depth of the redox potential discontinuity are scored and summarised (Nilsson and Rosenberg 1997; Rosenberg et al. 2002). The index values vary between 0 and 15, where low values are indicative of a bad environment and high values of a good environment. The BHQ indices have been preliminary classified according to the WFD (Rosenberg et al. 2004), see Fig. 5.7.

No overall significant difference was observed in benthic habitat quality between the years 2002 to 2005 (Magnusson and Rosenberg 2005). However, significant temporal reductions in BHQ were observed within the areas Koljöfjord and Laholm Bay (Fig. 5.9). For the Koljöfjord the conditions in 2005 were classified as *bad* and for the Laholm Bay as *moderate* according to the WFD. The classification of the individual stations according to the WFD in 2005 is presented in Fig. 5.9 and 5.10. The status of all stations in the Gullmarsfjord was *good* or *high*, whereas some stations in the Havstensfjord and several in the Koljefjord had a *bad* or *poor* status. Most stations in Skälderviken (Kattegat) and Öresund had a *good* status, whereas the benthic conditions were worse at some stations in the Laholm Bay. The reasons for the impact on the benthic habitats are suggested to be eutrophication in combination with poor water exchange in enclosed fjordic areas and restricted water exchange below the halocline in the Laholm Bay (Rosenberg et al.1996).

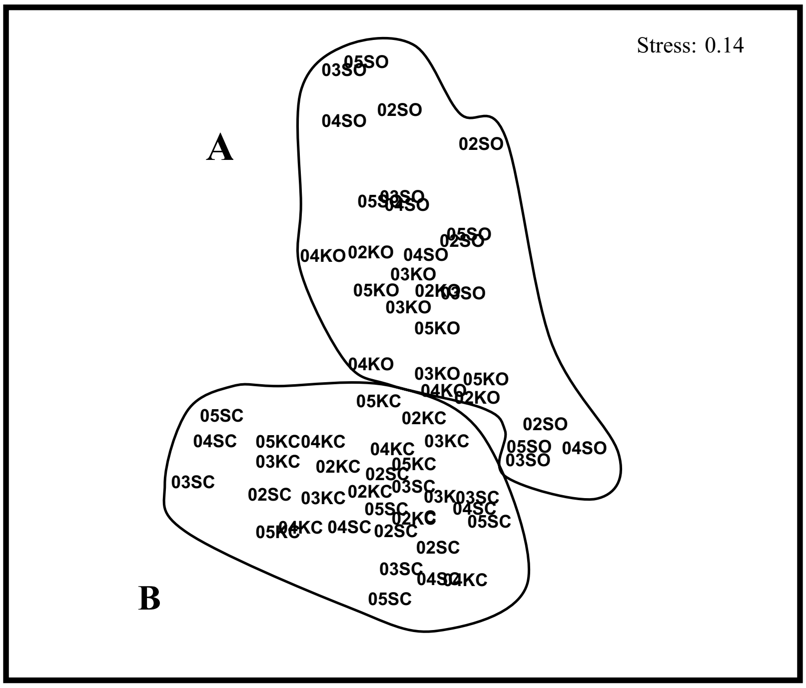


Fig. 5.6 Multi dimensional scaling (MDS) plot for the faunal composition at the open sea stations (A) and coastal stations (B) in the Kattegat and Skagerrak during the years 2002 to 2005.

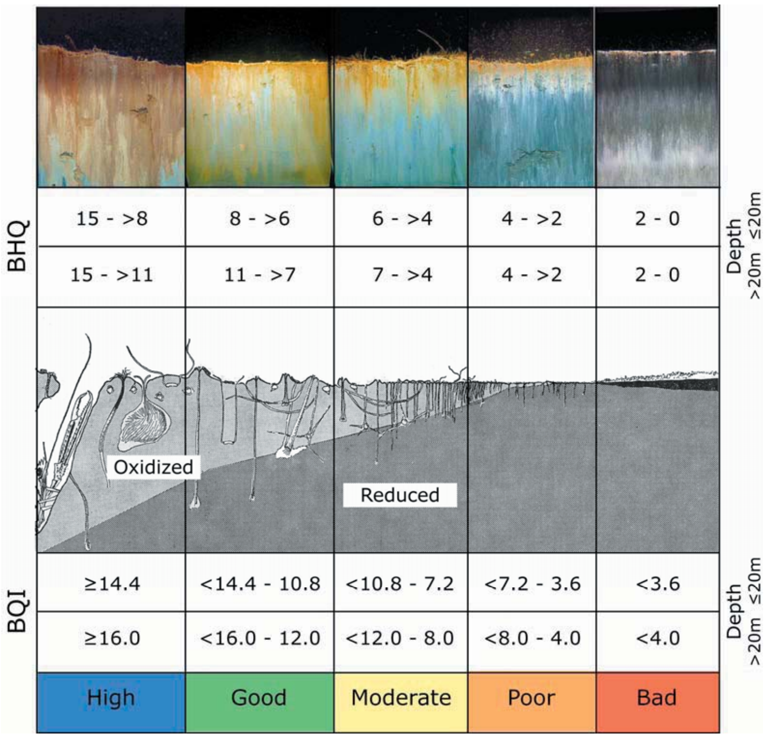


Fig. 5.7 Model of the faunal successional stages along a gradient of increasing disturbance from left to right (after Pearson and Rosenberg 1978). Sediment profile images (colours enhanced) are shown at the top, where brownish colour indicate oxidised conditions and black reduced conditions, and the benthic habitat quality (BHQ) index values (Nilsson and Rosenberg 1997) are presented for depths >20 m and ≥ 20 m (shown at the top of the figure). The benthic quality index (BQI) values for the different environmental status according to the Water Framework Directive (WFD), based on faunal composition analysis, are represented for depths >20 m and ≥ 20 m (at the bottom of the figure).

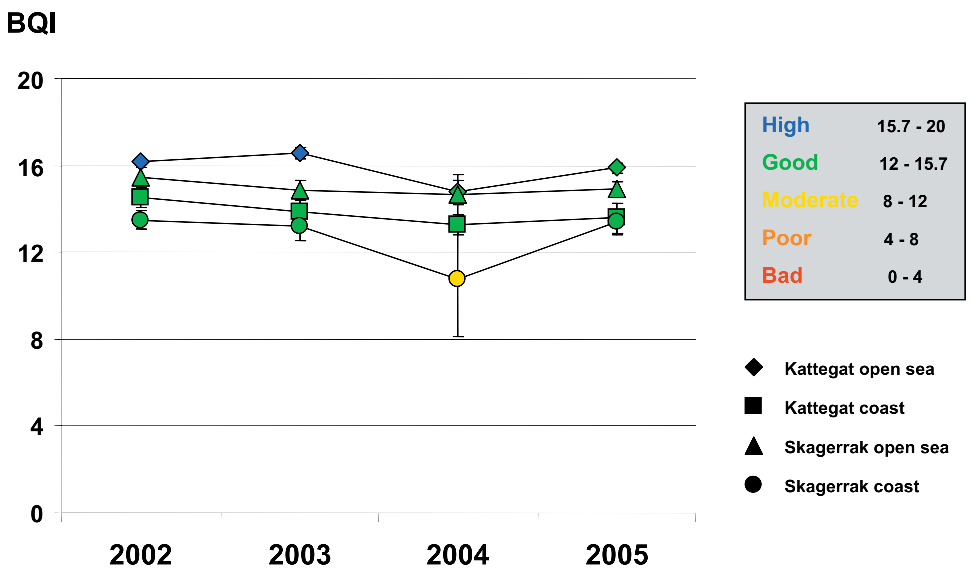


Fig. 5.8 Benthic quality indices (BQIs) and the environmental status according to the Water Framework Directive (WFD) classification according to Rosenberg et al. (2004) presented for the Kattegat and Skagerrak areas during the years 2002 to 2005.

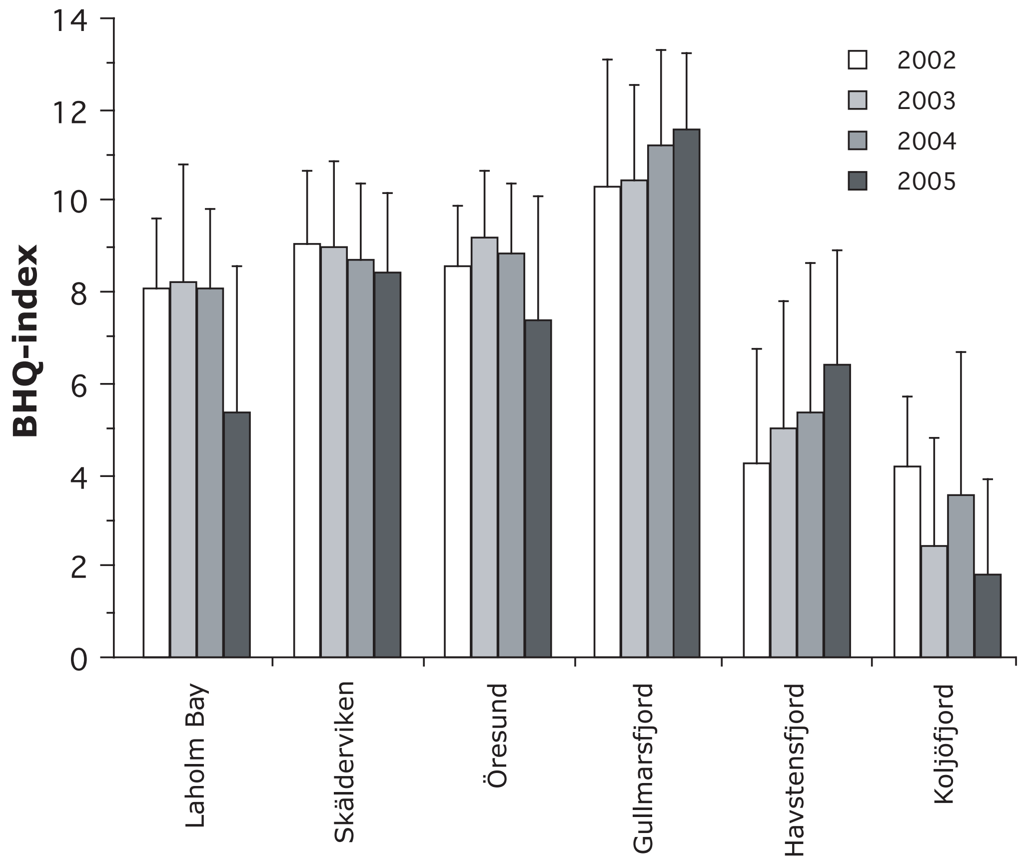


Fig. 5.9 Analysis of the benthic habitat quality (BHQ) during 2002 to 2005 by using a sediment profile camera in three coastal areas in the Kattegat and three fjords in the Skagerrak.

Long term changes in benthic communities in som coastal areas in the Skagerrak

Benthic fauna was sampled at 14 stations in three Swedish fjords and at 12 stations along the Swedish Skagerrak archipelago at depths between 7 and 34 m. The sampling was made at irregular intervals between 1976 and 1998. The benthic fauna showed general temporal declines during this period. Benthic animals were lacking at some sampling sites, and low number of species and low abundances were found at some other sites. More details are presented in Rosenberg and Nilsson (2005). This is the first time large-scale reductions in benthic communities have been observed in some of these rather shallow areas. The cause for these reductions was suggested to be low oxygen concentrations in the bottom-near water in association with detached vegetation, leading to organic enrichment and locally even to anoxic conditions.

Conclusions

The environmental status of the marine bottom areas of the open and outer coastal areas of the Skagerrak and Kattegat is classified as *good* or *high* according to the WFD. The benthic habitat was classified from SPI analysis to be generally *good* or *high* in the Gullmarsfjord, Skälderviken and Öresund, whereas the status was generally *bad* or *poor* in the Koljöfjord and variable from *bad/poor* to *high* in the Havstensfjord and Laholm Bay. The benthic fauna was found to be eliminated or poor at some inner coastal stations along the Swedish Skagerrak coast sampled irregularly during the period 1976 to 2001. The fauna showed a general decline during the sampling period, but the situation subsequent to 2001 is not known.

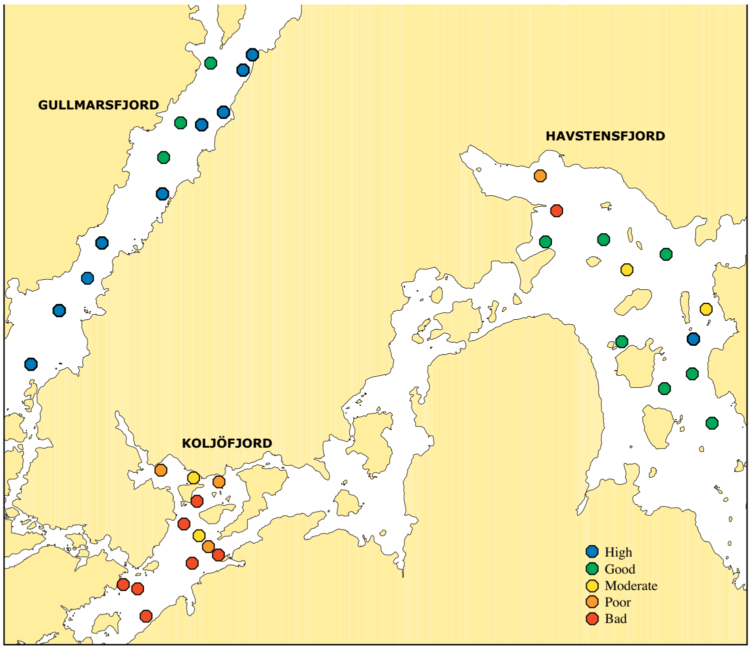


Fig. 5.10 Status of the benthic habitats assessed by using a sediment profile camera and their classification according to the EU Water Framework Directive according to Rosenberg et al. (2004) for the Gullmarsfjord, Koljöfjord and Havstensfjord in 2005 (from Magnusson and Rosenberg 2005).

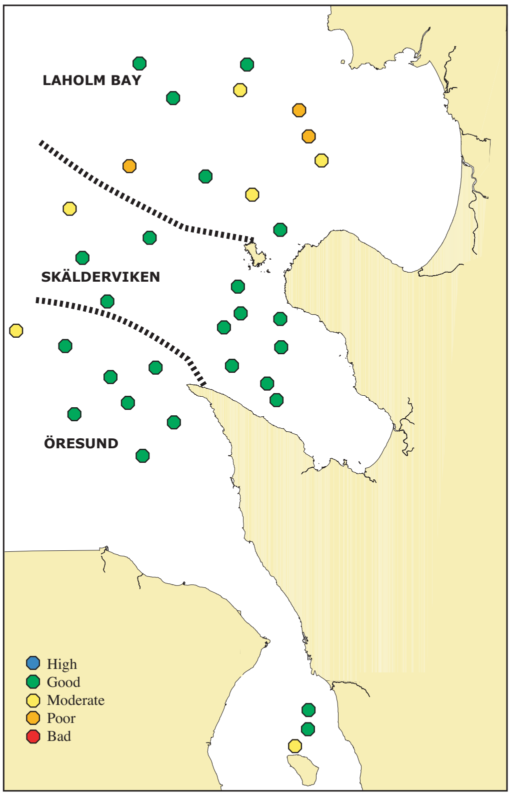


Fig. 5.11 Status of the benthic habitats according to the EU Water Framework Directive assessed by using a sediment profile camera and classification according to Rosenberg et al. (2004) for the Laholm Bay, Skälderviken and Öresund in 2005 (from Magnusson and Rosenberg 2005).

5.2.4 Category IV – Other Possible Effects of Nutrient Enrichment

Algal toxins 2001-2005

The Swedish National Food Administration administers monitoring of algal toxins in shellfish in Sweden. The major problem is diarrhetic shellfish toxins (DST) from the dinoflagellate genus *Dinophysis*. Figure 5.13 illustrates that this is a very common problem along the Swedish Skagerrak coast. The data set from the Kattegat coast is much smaller, especially from 2000 and onwards, but in 1994-1995 when a more comprehensive sampling program was carried out near Varberg high DST-concentrations were found there too.

DST above the regulatory limit of 160 µg/100 g mussel meat is common from early autumn to early spring. To interpret this as an indicator of eutrophication is probably wrong or at least unlikely. A more probably hypothesis is that the stratified water column in the area may promote the occurance of *Dinophysis*.

Other toxins does occur in the area. Paralytic Shellfish Toxins (PST) probably originating from the dinoflagellate genus *Alexandrium,* is found occasionally along the Skagerrak coast or in the fjords (data not shown). Only a few observations of PST above the regulatory limit has been made in 2001-2005. This may partly be due to low frequency of PST-analysis.

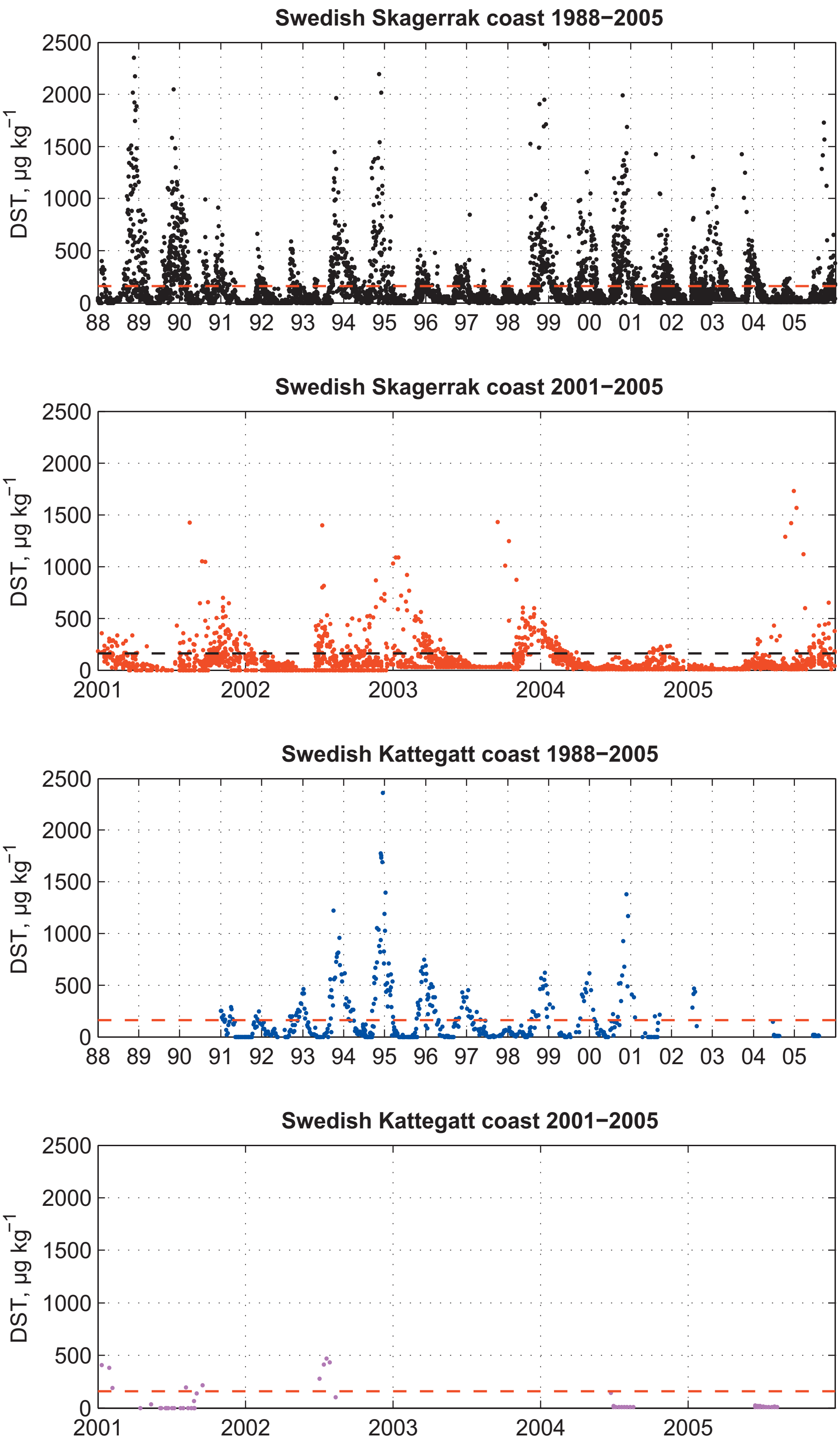


Fig. 12 The dataset presented shows concentrations of DST in blue mussels (Mytulis edulis) along the Kattegat and the Skagerrak coast 2001-2005. DST is defined as the sum of ocadaic acid and Dinophysis toxin 1 (DTX1).

5.3 Overall Assessment

5.3.1 Inshore Kattegat area

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

Table 5.10 Integrated Assessment of the Inshore Kattegat area.

The input from land and atmosphere shows elevated levels without any significant trends during the 2001 to 2005 period. The levels of input were much about the same as during the last 10 years.

DIN median concentrations where generally above elevated levels reported in the Comprehensice Procedure and for the 90 percentile about double the elevated level during the assessment period. DIP median concentrations on the other hand was clearly above background but at or close to the elevated concentrations, while the 90 percentile was just above elevated concentrations.
Chlorophyll median concentrations were above elevated concentrations, while oxygen concentrations show deficiency. Both oxygen concentrations and saturation has a negative trend in the area. Only in Laholm Bay the benthic fauna showed bad to poor conditions (according to the WFD classifications scheme).
The dinoflagellate genus Dinophysis frequently occurs above assessment levels.
The monitoring and modelling data indicate that the inshore Kattegat is eutrophicated area with increased levels of nutrients coming from both local land sources but also from transboundary influx of nutrients i.e. from the Baltic Sea.
The overall classification shows Inshore Katttegat to be a problem area. The Comprehensive Procedure is transparent, reliable and verifiable enough for the judgement. However, data or information on bottom flora and algal toxins is to some extent missing in the Swedish national monitoring programme of Kattegat Inshore waters. Nevertheless, improvements are expected to take place during the ongoing implementation of the WFD.

5.3.2 Offshore Kattegat area

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

Table 5.11 Integrated Assessment of the Offshore Kattegat area.

The input from land and atmosphere shows elevated levels without any significant trends during the 2001 to 2005 period. The levels of input were much about the same as during the last 10 years.

The monitoring and modelling data indicate that the offshore Kattegat is influenced by increased levels of nutrients coming from both local land sources and atmospheric deposition but also to a large extent from transboundary influx of nutrients i.e. from the Baltic Sea, while deep waters are influenced by a transboundary flow from Skagerrak in the north.

DIN median concentrations where generally above elevated levels during the assessment period. DIP median concentrations on the other hand was clearly above background but at or close to the elevated concentrations, while the 90 percentile was just above elevated concentrations.

Chlorophyll median concentrations were below elevated concentrations, while oxygen concentrations show elevated deficiency and for 2002 even acute toxicity. Both oxygen concentrations and saturation show a declining trend in the area. Benthic fauna showed good to high conditions (according to the WFD classifications scheme).

The monitoring and modelling data indicate that the offshore Kattegat is eutrophicated area with increased levels of nutrients mostly coming from transboundary influx from the Baltic Sea.
The overall classification shows Offshore Katttegat to be a problem area. The Comprehensive Procedure is transparent, reliable and verifiable enough for the judgement. However, it is important to note that a recent performed inventory of offshore bank areas in Kattegat indicated that bottom flora and fauna in general was found to be in a much better condition than corresponding inshore bottom areas. There is only minor information available on the ecological status prior to the inventory made during 2004 and 2005.

5.3.3 Inshore Skagerrak area

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

Table 5.12 Integrated Assessment of the Inshore Skagerrak area.

The input from land and atmosphere shows elevated levels without any significant trends during the 2001 to 2005 period. The levels of input were much about the same as during the last 10 years.

DIN and DIP median concentrations where generally close to background levels during the assessment period, while the DIP 90 percentile was close to elevated concentrations.

Chlorophyll median concentrations were above elevated concentrations and oxygen concentrations and saturation show deficiency. The negative trend in oxygen concentration was weak and there was no trend in the oxygen saturation. Only in some fjords with limited water exchange and perennial oxygen deficiency the benthic fauna was in a poor or bad state (according to the WFD classifications scheme). The inshore Skagerrak is also often subjected to harmful algae monitored at mussel farms.

Whether these are caused by natural variability in the ecosystem or by eutrophication is by now means clearly shown.

The overall classification shows Inshore Skagerrak to be a problem area. The Comprehensive Procedure is however not fully transparent, reliable and verifiable enough for the judgement. Different Categories in the procedure point towards different directions. It is also worth mentioning that data or information on long time series of bottom flora is missing in the Swedish national monitoring programme in this area. There is also a question mark to what extent the perennial oxygen deficits in the fjords are governed by limited water exchange or by too large inputs of nutrients compared to the fjord capacity. The primary production is about 200 gC $m^{-2}year^{-1}$ in the Gullmar fjord, clearly below the critical primary production of around 300 gC $m^{-2}year^{-1}$ set by Nixon (1995).

5.3.4 Offshore Skagerrak

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

Table 5.13 Integrated Assessment of the Offshore Skagerrak area.

The monitoring and modelling data indicate that the offshore Skagerrak is governed by atmospheric deposition and by transboundary influx of nutrients i.e. from the Kattegat and the North Sea. Especially can high nutrients (DIN) inflows emerges from the German Bight. This inflow is intermittent and occurs only now and then.

DIN median concentrations where generally at or below background levels. Only once during the assessment period was the 90 percentile DIN concentrations above elevated concentrations. DIP median concentrations were also below background concentrations and the 90 percentile never passed elevated concentrations.

Chlorophyll median concentrations were below or close to background concentrations. Oxygen concentrations and saturation levels showed no deficiency at all during the assessment period. Nevertheless, both oxygen concentrations and saturation showed a negative trend. Benthic fauna showed good to high conditions (according to the WFD classifications scheme).

The overall classification shows Offshore Skagerrak to be a non-problem area. The Comprehensive Procedure is transparent, reliable and verifiable enough for the judgement. However, it is important to note that a recent performed inventory of offshore bank areas in eastern Skagerrak indicated that bottom flora and fauna in general was found to be in a much better condition than corresponding inshore bottom areas. There is only minor information available on the ecological status prior to the inventory made during 2004 and 2005.

5.4 Comparison with preceding assessment

The present assessment confirms the general results obtained from the 2002 OSPAR Comprehensive Procedure, covering the time period 1998 to 2000. The decreasing trends of dissolved nutrients continued also during 2001 to 2005 but were still above elevated levels in Kattegat and inshore Skagerrak areas. The chlorophyll levels remains high and above elevated levels, while oxygen still decreased in most areas clearly below deficiency levels. Zoobenthos is still disturbed by low faunal diversity, abundance and biomass at many coastal sites. Phytoplankton indicator species are still present at elevated levels and algal toxins occur also during the present assessment period.

The main difference between the former and latter assessment is related to the technical procedure. In the latter assessment the quantification of background and elevated levels are more precise in terms of statistical measures and new methodologies to evaluate the status (i.e. zoobenthos). We can also compare the OSPAR procedure to the WFD procedure, where background and elevated levels for some parameters and sub-areas generally are higher compared to WFD reference and moderate levels. In addition, summer and winter total nitrogen and phosphorus are also assessed in the WFD but not in OSPAR. Nevertheless, these two parameters support the main results obtained for winter dissolved nutrients.

5.5 Voluntary parameters

5.5.1 Primary Production in the Gullmar fjord

Basic facts of the time-series

Primary phytoplankton productivity monitoring has been carried out since 1985 in the mouth area of the Gullmar Fjord, situated on the Swedish Skagerrak coast (Figure 5.14). This site is expected to be representative for the water quality and conditions of the outer coastal zone.

In short, the following method was used:
• ^{14}C-technique *in situ* at 9 or 10 depths; from surface to 15 or 20 m
• 4-hour incubation around noon
• Light factor method was used to calculate the daily production.
• No change of measuring protocol during the time-series.
• 421 measurements were performed 1985 – 2005 with an annual mean of 20.
• For a more comprehensive description of the measuring protocol and method used, see Lindahl (1995).

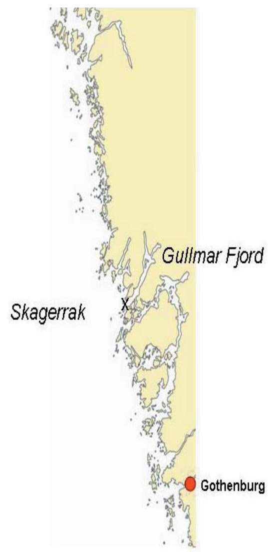


Figure5.13: Map showing the Swedish Skagerrak coast and the Gullmar Fjord. The primary production site was situated at "x".

Development the primary production over time

An analysis of the time-series data set of primary production 1985 - 1999 revealed an increase over time in the measured productivity ($p<0.001$) (Lindahl et al., 2003). The mean annual production increased during this period of time from around 230 gC m^{-2} $year^{-1}$ 1985-86 to almost 250 gC m^{-2} $year^{-1}$ at the end of the 1990's. The 10-year means of 1985 – 1994 was 240 gC m^{-2} year and of 1991 – 2000 257 gC m^{-2} $year^{-1}$ respectively. The lowest and highest annual value during the whole period was 182 gC m^{-2} $year^{-1}$ (1986 and 1991) and 339 gC m^{-2} $year^{-1}$ (1994) respectively. The mean annual increase in production was 1.2%, or approximately 3 gC m^{-2} $year^{-1}$.

The calculated annual production from 2000 to 2005 was significantly lower compared to the previous period. The mean annual production was only 220 gC m^{-2} $year^{-1}$, which was at the same level of production as the first five years of the time-series (Figure 5.15). The lowest and highest value during this period was 184 gC m^{-2} $year^{-1}$ (2005) and 253 gC m^{-2} $year^{-1}$ (2003) respectively. Thus, including the production from after the millennium shift, it was obvious that the trend of increasing annual primary production from 1985 to the end of the 1990's was broken.

A first attempt to analyze the development of the complete time-series from 1985 to 2005 has been made by calculating 5-year running means (Figure 5.16). A polynomial function of second order gave the best fit describing the overall trend ($r^2 = 0.78$) and revealed that the primary production in the Gullmar Fjord peaked during the 5-year period 1992 – 1996. Thus, the earlier linear increase in production up to 1999 was no longer to be the best fit and it could be concluded the production has dropped after the mid 1990's.

Possible factors affecting the observed trend

Attempts have been made to study the effect of weather/climatic forcing on the physical-chemical processes related to the primary productivity as well as long-term environmental changes of antrophogenic origin. In general, the phosphate supply to the Kattegat/Skagerrak area has been reported to decrease, while the nitrate supply has been unchanged or decreased since 1985 (Forum Skagerrak, 2001). Consequently, the nutrient supply trend has more or less decreased and not co-varied with the observed increase in primary production from 1985 and to the mid 1990's. A study on climate forcing suggested the presence of 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 months time-lag (Lindahl et al., 1998). Further, a direct correlation between the winter (December – March) NAO index and measured productivity in May was found (Belgrano et al., 1999).

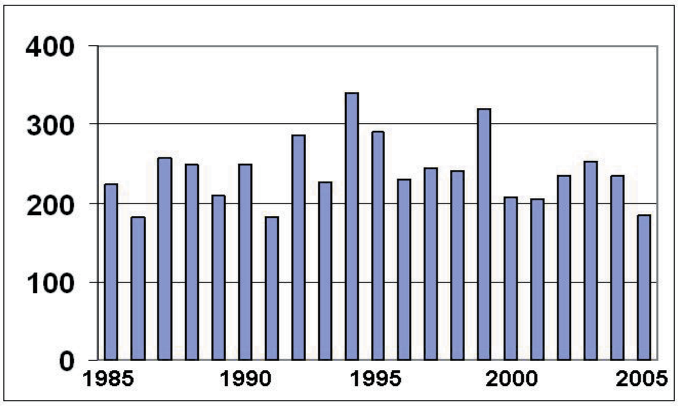


Figure 5.14: The annual primary production 1985 - 2005 in gC m^{-2} $year^{-1}$.

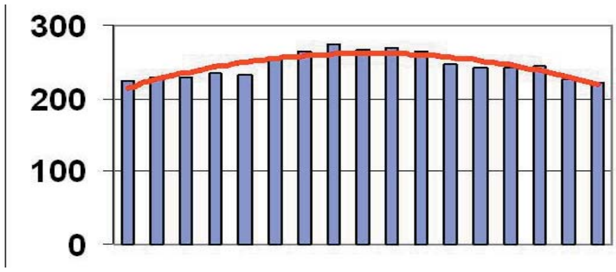


Figure 5.15: 5-years running means of the annual primary production 1985 – 2005. Red curve is trend line (r^2 = 0.78).

So far no extensive analyse of a possible explanation of the change from increasing to decreasing trend of the production has been carried out. According to an evaluation of trends from the period from 1990 to 2006 of hydrographical and nutrient data along the Swedish Skagerrak coast, statistical significant decreases in the concentrations of phosphate and all nitrogen parameters have been observed at the station Släggö situated very close to the primary production station (SMHI, 2007). At the same time an increase in water temperature was observed. It was also reported that the trend in oxygen concentration in the central deep part of the Gullmar Fjord had increased. Finally, it was striking that the period of highest primary production was coincident with the abundance of periods of low oxygen concentrations (Fig. 5.17). This co-variation may be a result of increased sedimentation during periods if high production as well as of large scale hydro-meteorological processes. Further analyse and evaluation will focus on the influence from anthropogenic effects as well as the climatic trend and variability.

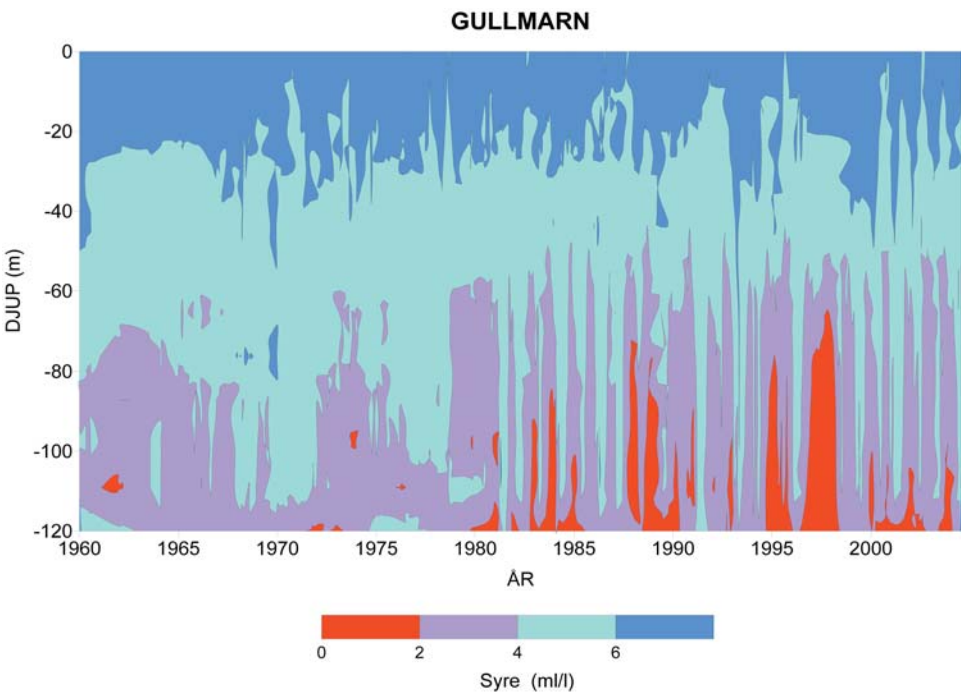


Figure 5.16: The oxygen concentration from 1960 to 2005 at the central and deepest part of the Gullmar Fjord. Red (< 2 ml·l^{-1}) means oxygen concentrations so low that fish leaves the area and damage to the benthic ecosystem may occur.

5.5.2 *Total nitrogen, total phosphorus and organic matter*

Time series of total nitrogen, total phosphorus and particulate organic carbon and nitrogen were examined, without correction for salinity. Data from the whole year were used to produce Box plots and annual means (Appendix I). Concentrations of total nitrogen and phosphorus have decreased since peaking in the late 1980s. Implementation of the Water Framework Directive has indicated levels of total nitrogen and phosphorus for 'High' status. Since 1992, annual mean and median total nutrient levels have been this threshold in both the inshore Kattegat and Skagerrak.

Particulate organic nitrogen and carbon measurements have been made in the Kattegat and inshore Skagerrak since the start of the 1990s. They are considered to be useful indicators of production. In the Kattegat, median POC levels vary between 10 – 30 µMol/l, with little observable difference between offshore and inshore during the period that measurements from both areas were available. Concentrations appeared to peak between 1998 and 2000.

PON concentrations in the Kattegat show a similar peak between 1998 and 2000. In the inshore Skagerrak, mean POC concentrations decreased from around 30 µMol/l at the start of the measurement period to around 20 µMol/l in 2005.

6 Comparison with Water Framework Directive in the Skagerrak and Kattegat

During the implementation of the WFD it was found that the reference values and the border between good and moderate for DIN (6 & 9 µmol/l, respectively) and DIP (0,5 & 0,75 µmol/l, respectively) has to be lower compared to the OSPAR (10 & 15 and 0,6 & 0,9, respectively) corresponding limits for background and elevated concentrations in the Skagerrak area at 30 psu. This difference was found to be related to the oceanographic regimes offshore the Swedish part of the Skagerrak coastal water bodies, which is characterised by the outflow of brackish Kattegat water along this coastal strip.

Another difference is that the winter reference nutrients concentrations are salinity dependent and in this way connected to freshwater input reference concentrations. Hence, in the coastal and transitional water bodies the status concentrations are always related to reference values at the same salinity. Hence, there is no need to make salinity corrections as is suggested in the OSPAR Comprehensive Procedure. In addition to dissolved nutrients also classification of total nitrogen (TP) and phosphorus (TP) is developed in the WFD, both for winter and summer.

For Zoobenthos methods are developed for status classification based in indexes as presented in chapter 4.1.1, which is not based on kills but on the abundance and distribution of tolerant and sensitive species.

Chlorophyll a has been inter-calibrated in the area and the reference values are set accordingly. The reference values are slightly below the OSPAR background values as is the case also with the border between good and moderate and the corresponding elevated level. This is the case both in Kattegat and Skagerrak.

7 Perspectives

7.1 Implemented and further planned measures

Worth to mention is the HELCOM Action Plan to be realised in 2007, which will have implications for the Kattegat as part of HELCOM. In Sweden a new Action Plan for the health of the Baltic, Kattegat and Skagerrak has recently been adopted. Especially, reduction of nitrogen emissions from ship traffic is at stake. Also reduction of household point sources of phosphorus in coastal areas is regarded as an important action to reduce emissions in comparison to what is already done in Sweden. Local tests are ongoing using mussel farms to harvest nitrogen from the coastal waters as a way to compensate diffusive emissions from farming in Bohuslän at the Skagerrak coast.

However, it should be reminded that the eutrophication problem in Kattegat and inshore Skagerrak is a complicated matter with several different sources of emissions transported to the area. Eilola & Sahlberg (2006), showed the eutrophication status to be dependent on transboundary fluxes from the Baltic Sea, the German Bight and emissions and sources from Denmark, Norway and Sweden. By reducing nutrient inputs from Sweden to Kattegat, according to the goals set by OSPAR, the Swedish inshore areas of Kattegat can obtain a water quality status of a no problem area. Similarly, the offshore area of Kattegat can only reach a healthy status if all riparian countries reduce their inputs, according to OSPAR goals, and if the interconnected Baltic Sea and the German Bight also achieve a healthy status.

Hence, the work for a healthy marine environment is indeed an international affair even at regional scales.

7.2 Outlook

Expected trends

Long-term trends in dissolved nitrogen (DIN) in Kattegat and Skagerrak offshore areas indicate decreasing winter concentrations compared to mid 1980:ties but with large annual variations. For total nitrogen (TN) similar trends are not visually noticeable.
Long-term trends in dissolved phosphorus (DIP) in Kattegat and Skagerrak offshore areas also indicate decreasing winter concentrations compared to mid 1980:ties but with large annual variations. These tendencies are also valid for total phosphorus (TP) in the offshore areas. During later years DIP and TP winter concentrations in the southern Baltic Sea has reached exceptionally high values, probably due to release of phosphorus from sediments under anoxic conditions and increased vertical exchange. Storm events might have been the driving force. These high concentrations of winter phosphorus are transported from the southern Baltic Proper to the Kattegat offshore areas. Here we can notice increasing winter concentrations during the last 2 years of the assessment period. This is a good example on the transboundary exchange sensitivity of Kattegat surface waters, but also points toward the dependency of the present and future water quality status on historical emissions of nutrients buried in sediments.

Improvements of assessments

The inter-relations of the past and the present on the future water quality need special care in assessments, especially the slow change to be expected from mitigations and measures of eutrophication. Model hindcasting and scenarios has to be involved to fully grasp the complexity and support judgement on measures and abatements. A model approach is needed to understand the effects of climate change on ecosystems. In this respect the monitoring data is by all means indispensable for model verification and assimilation as well as to improve knowledge on ecosystem processes, in addition to traditional assessment procedures.

Another factor to take into account is higher trophic levels in ecosystem models. Overexploitation of fish and subsequent alteration in the pelagic food web structure may to some extent influence the level of eutrophication.

There is a need to harmonize background and elevated levels for nutrients and chlorophyll in the area with WFD classification scheme.

8 Conclusions

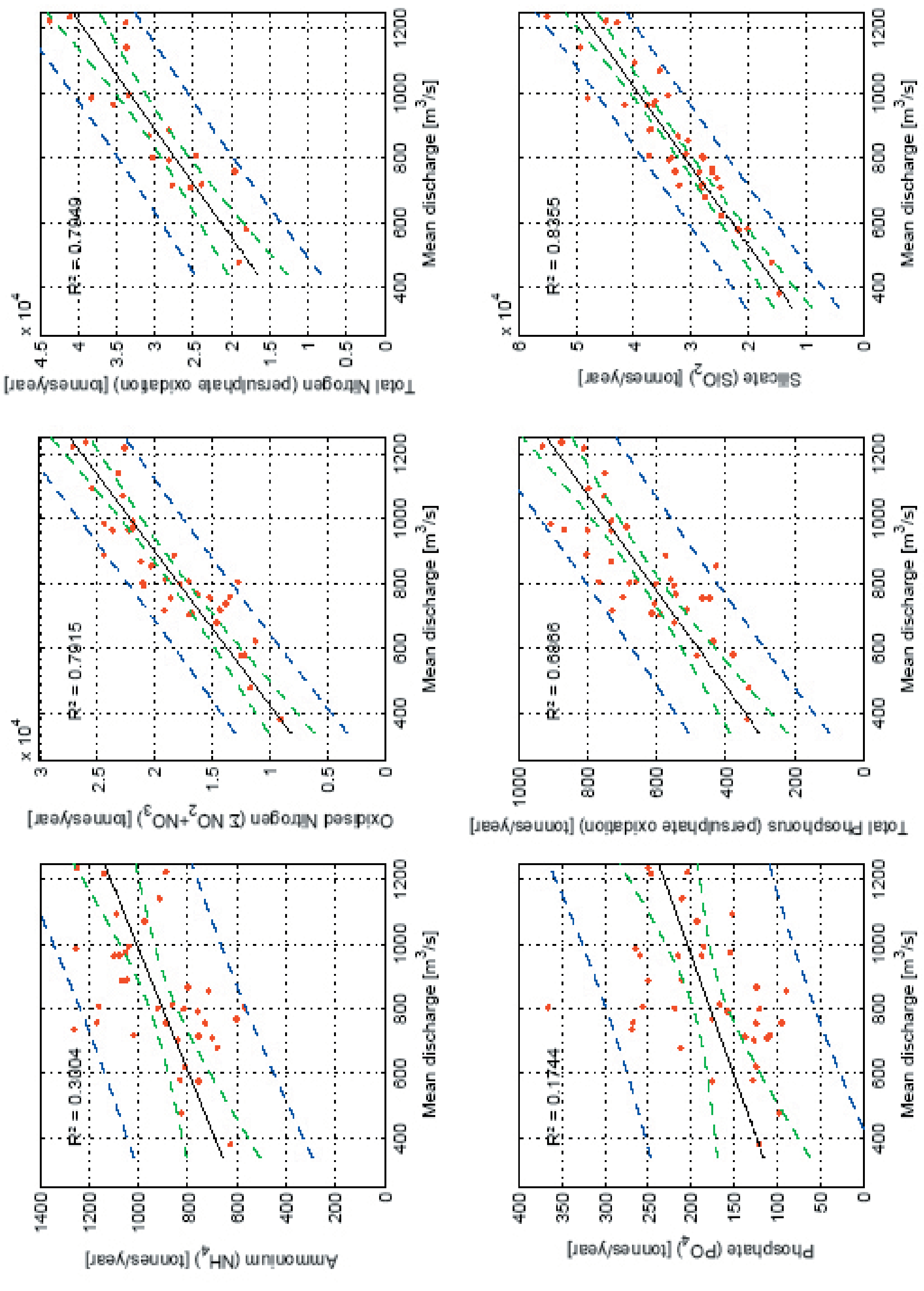
Biological parameters as phytoplankton indicator species, chlorophyll, zoobenthos and algal toxins show disturbances above elevated levels in Inshore and Offshore Kattegat, while in Skagerrak Inshore waters the OSPAR categories I - IV indicate a slight incoherence in the assessment.
Hence, it is recommended that further investigations are necessary in this sub-area. Under the WFD further assessments will take place, which hopefully will clarify the situation. For example, an improved assessment procedure will be introduced for perennial oxygen conditions in fjord areas, which takes into account natural oxygen depletion.
The offshore Skagerrak is a non-problem area according to the available data.
Despite the identified problem areas we found positive trends for Chlorophyll and Secchi disk depth in the Skagerrak and Kattegat, although not significant at 95 % confidence level. Nevertheless, it supports the decreasing trends for dissolved nutrients. In addition, the primary production time series from one station in the inshore Skagerrak (Gullmar fjord) shows decreased levels as compared to the previous assessment period.
The Skagerrak and Kattegat area is influenced by transboundary fluxes to a great extent. Especially the inflow of nitrogen and phosphorus from the Baltic Sea is a major source for both nutrients, according to the budgets presented. Lowering the inputs to the area is best achieved by reduction of nitrogen from land but also from the Baltic Sea. For phosphorus the most effective source of reduction should be to lower the concentration in the southern Baltic Sea, i.e. to combat eutrophication in the Baltic. Nitrogen reduction is more important than phosphorus, taking into account the OSPAR and WFD classification schemes.

Acknowledgement

We thank the Swedish Environmental Agency for support. The Marin Monitoring AB for providing the assessment on zoobenthos and Dr. Odd Lindahl at Kristineberg Marine Research Station for assessment of the primary production in the Gullmar fjord. Thanks also to the County Boards of Halland and Bohuslän for letting us use their data from inshore waters bodies and especially the Water Quality Association of the Bohus Coast in charge of the monitoring and assessment in Bohuslän. In addition, we thank Anita Taglind for lay-out and typing of the report.

Appendix I - Mixing diagram and time series

10 Appendix I



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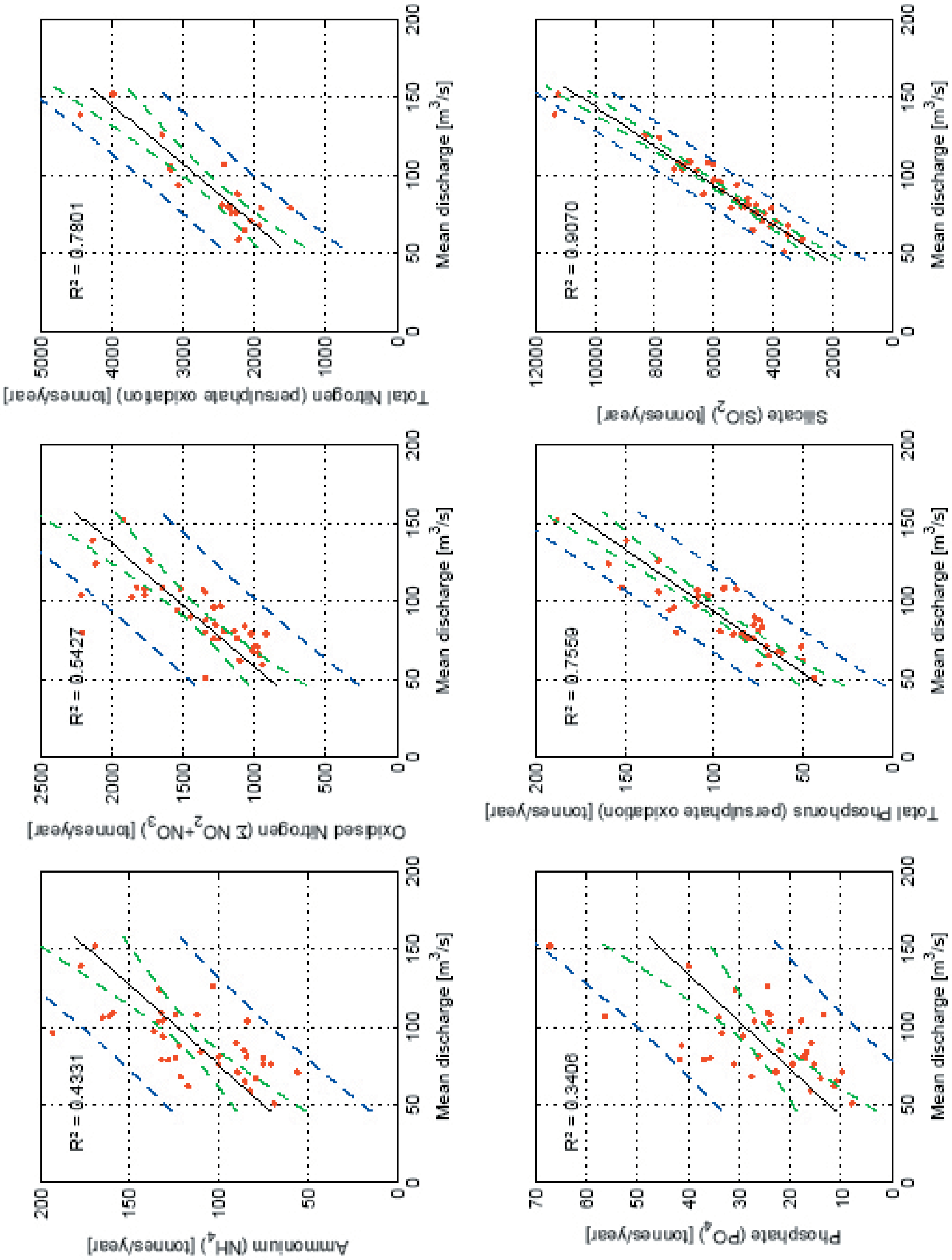

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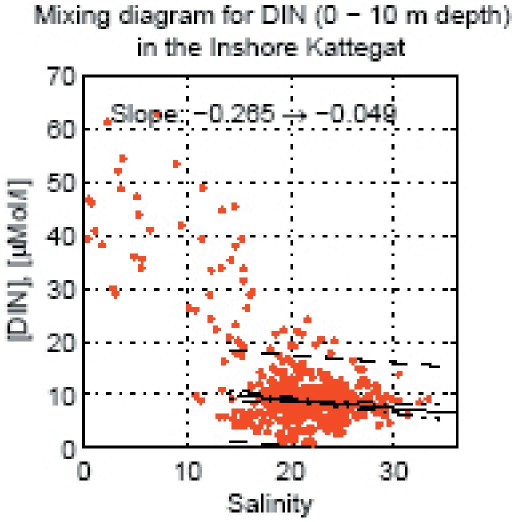

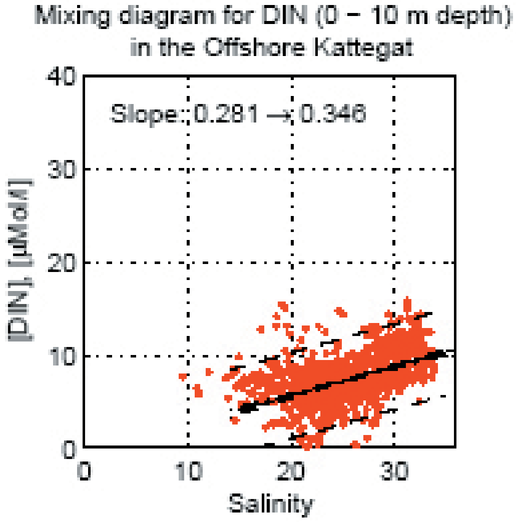

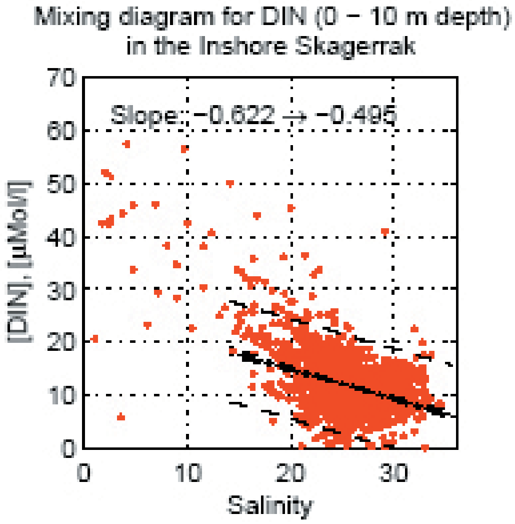

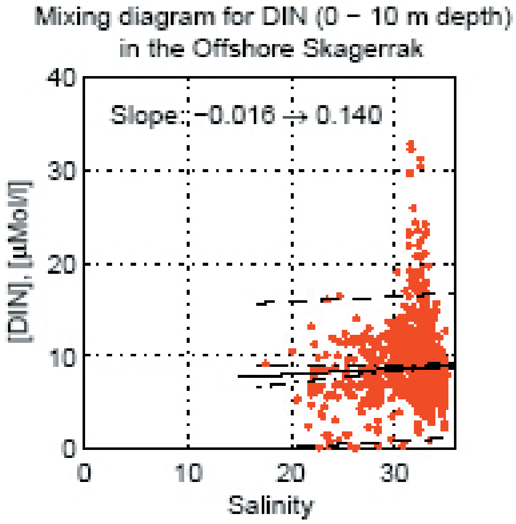

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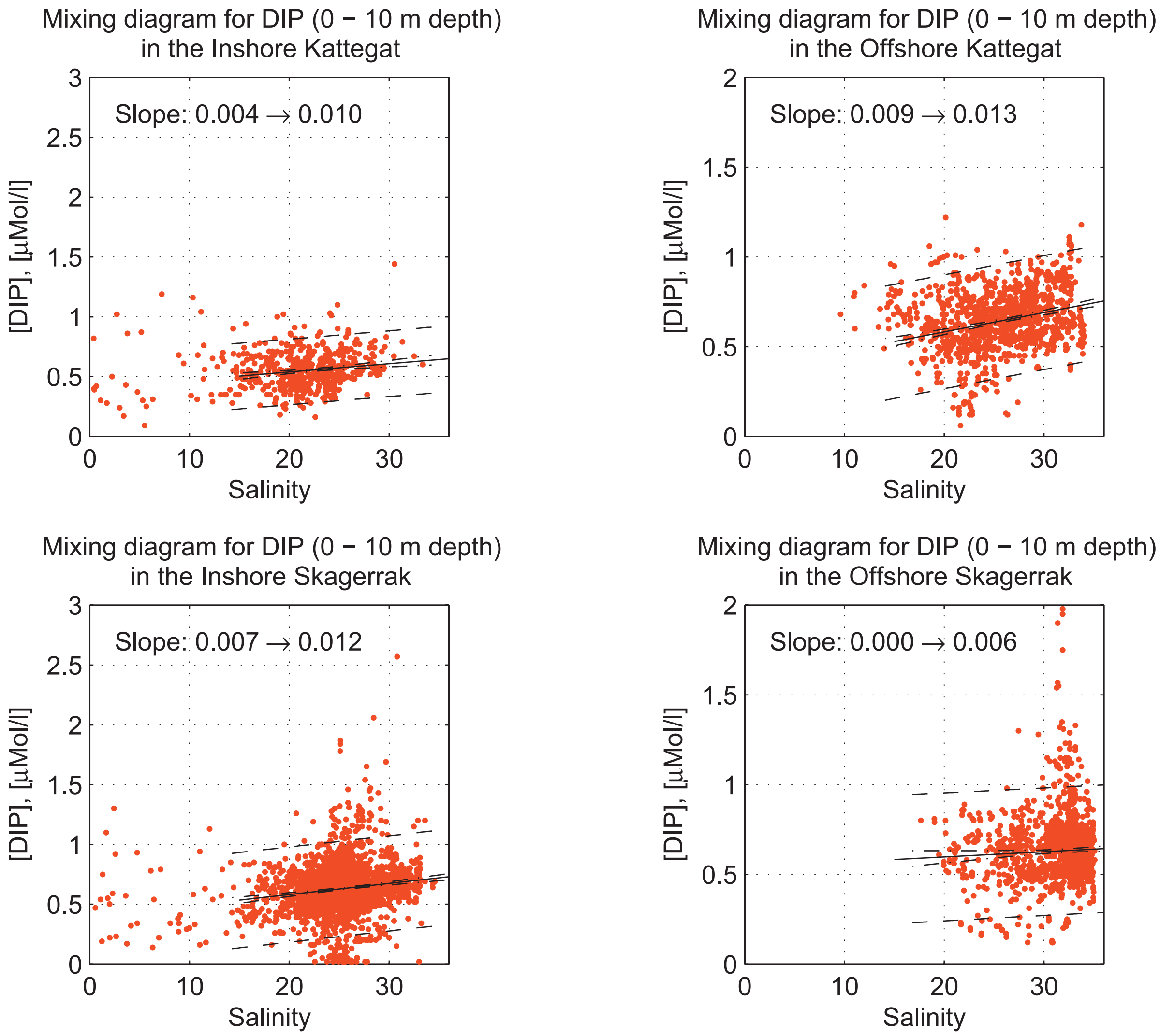

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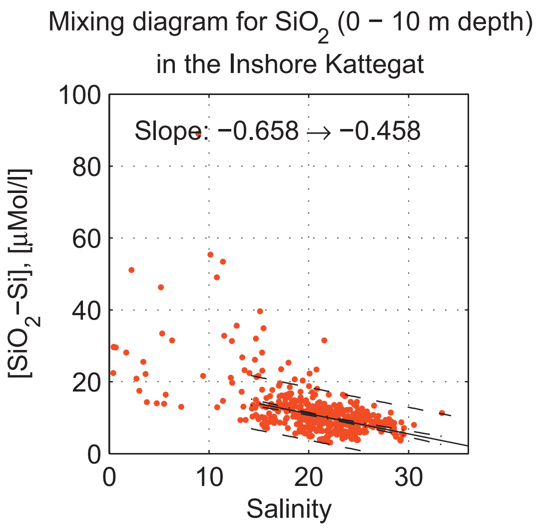

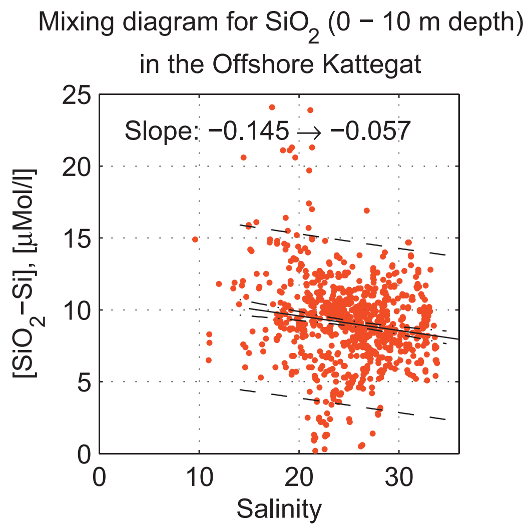

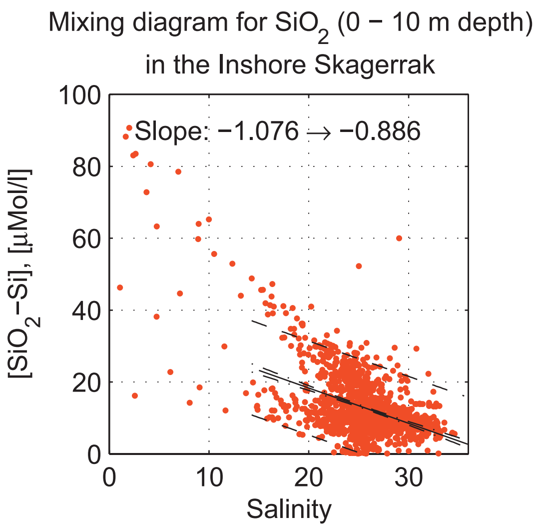

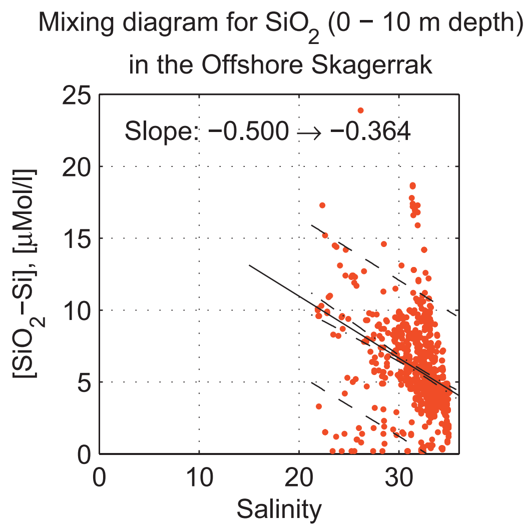

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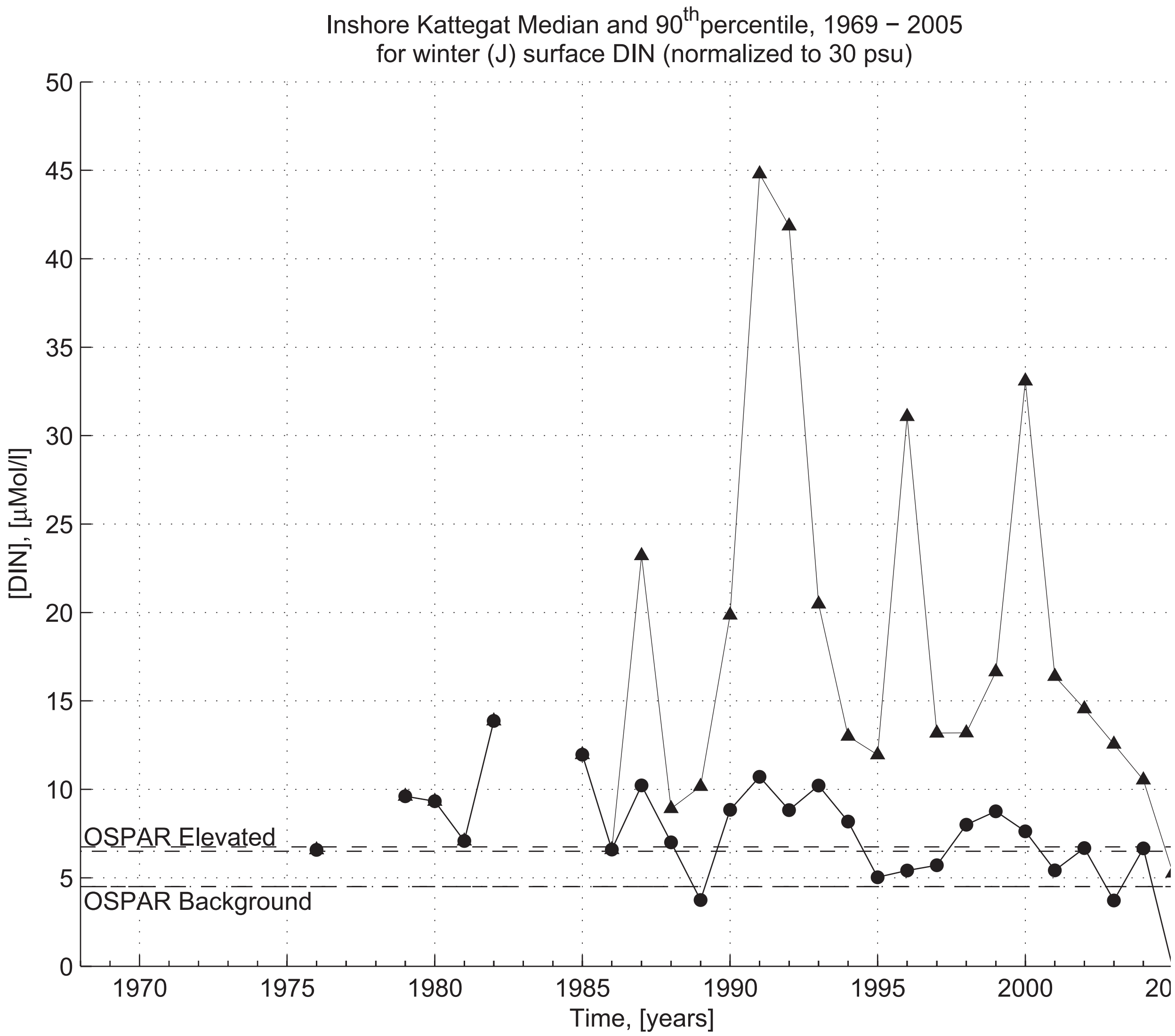

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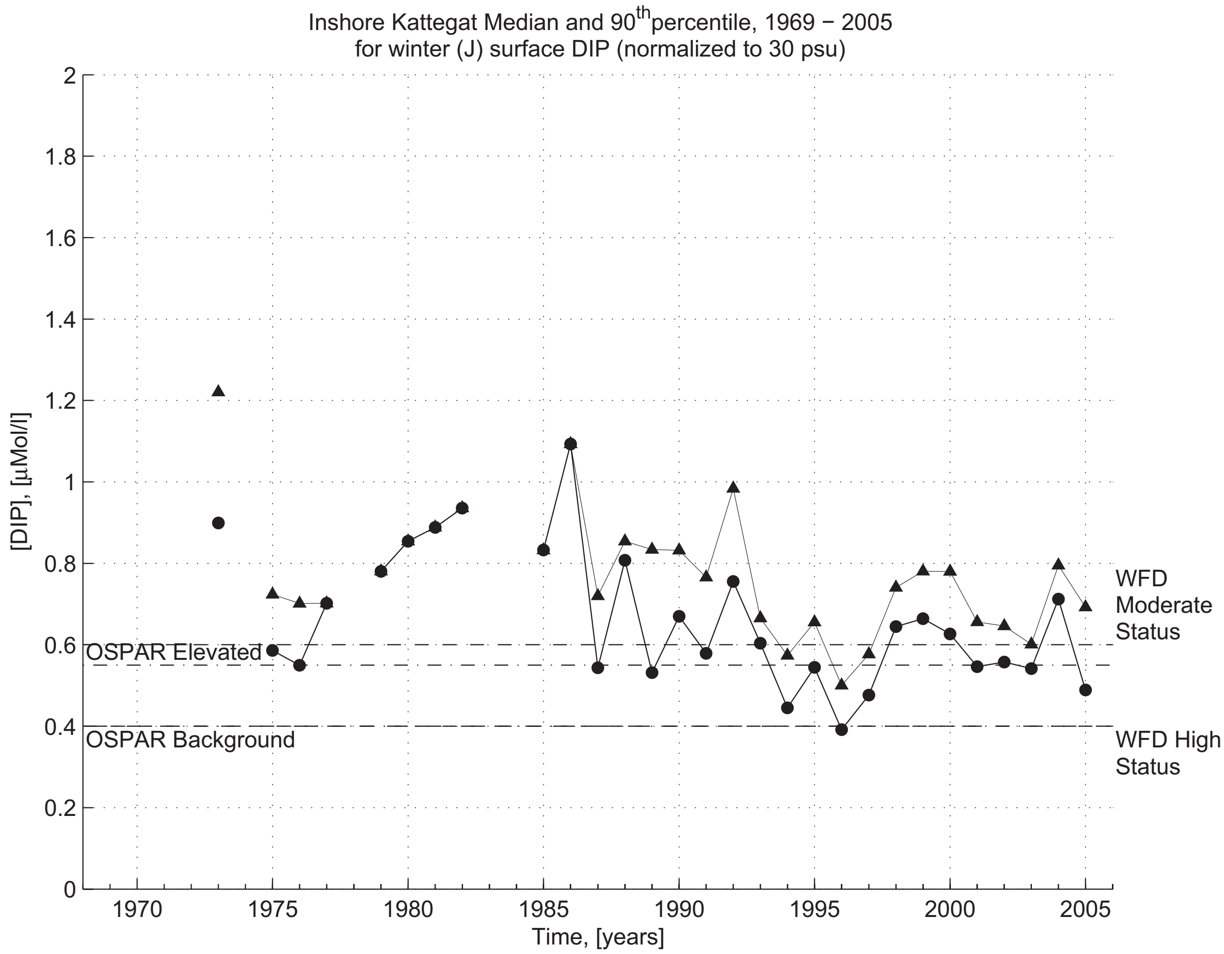

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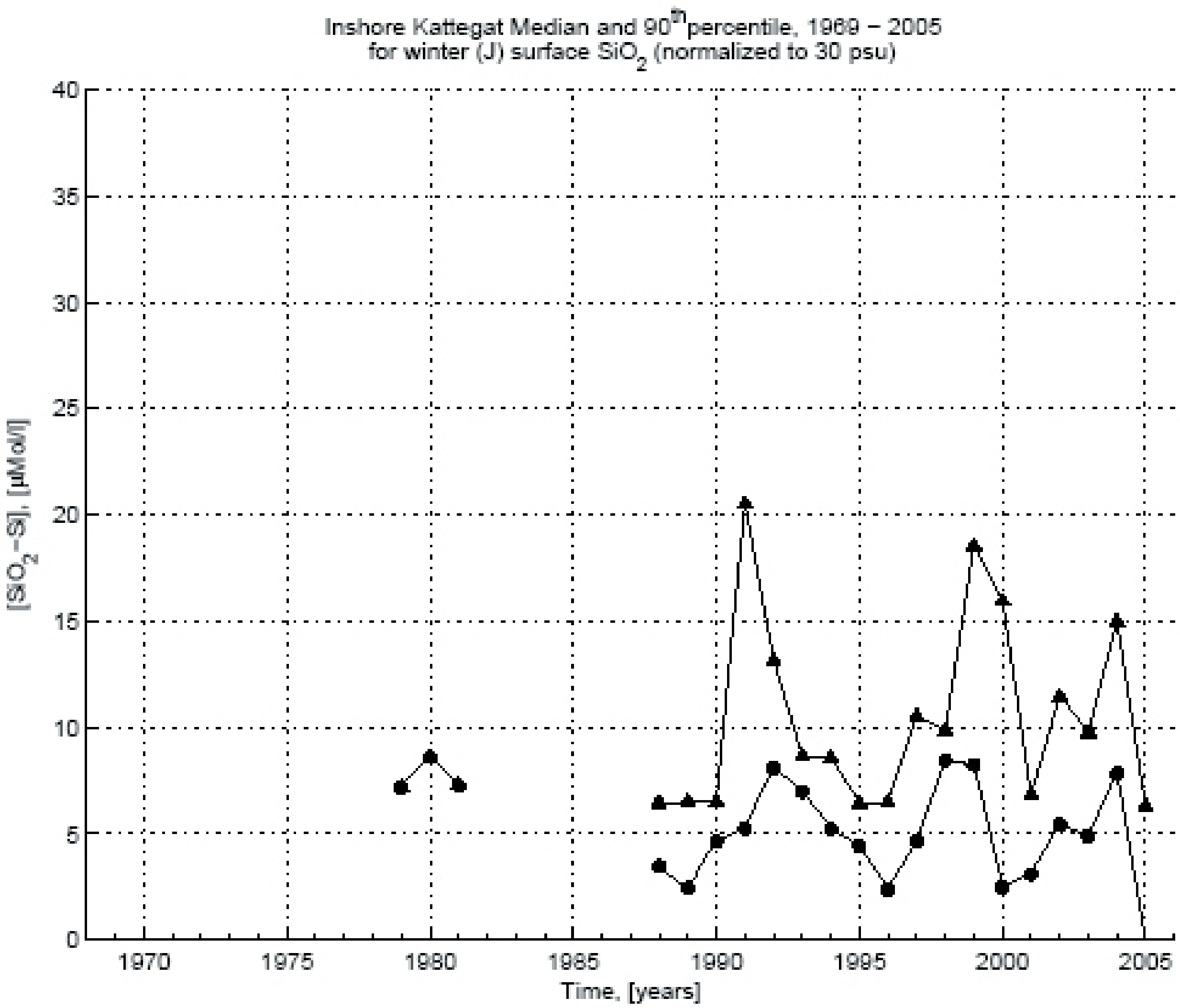

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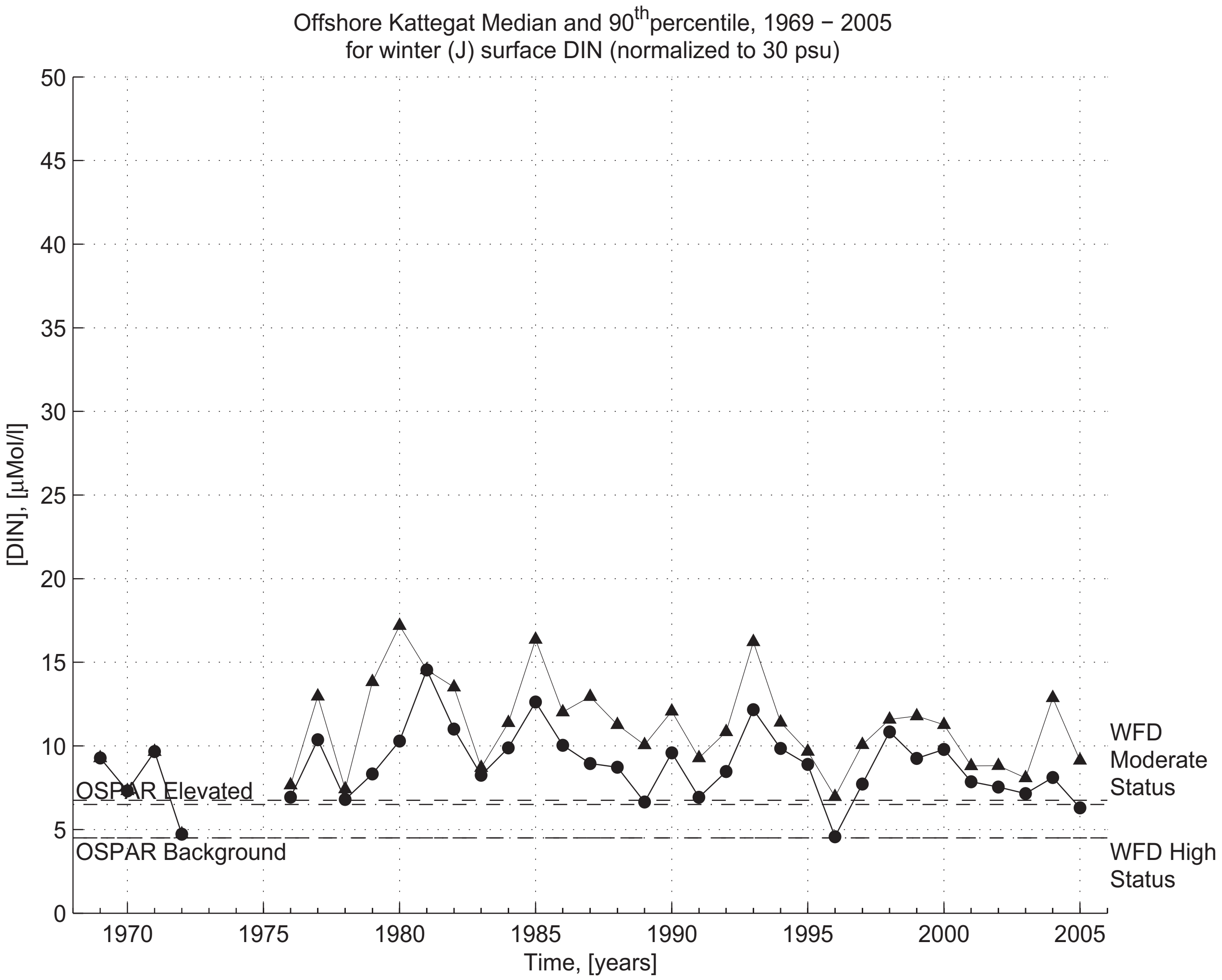

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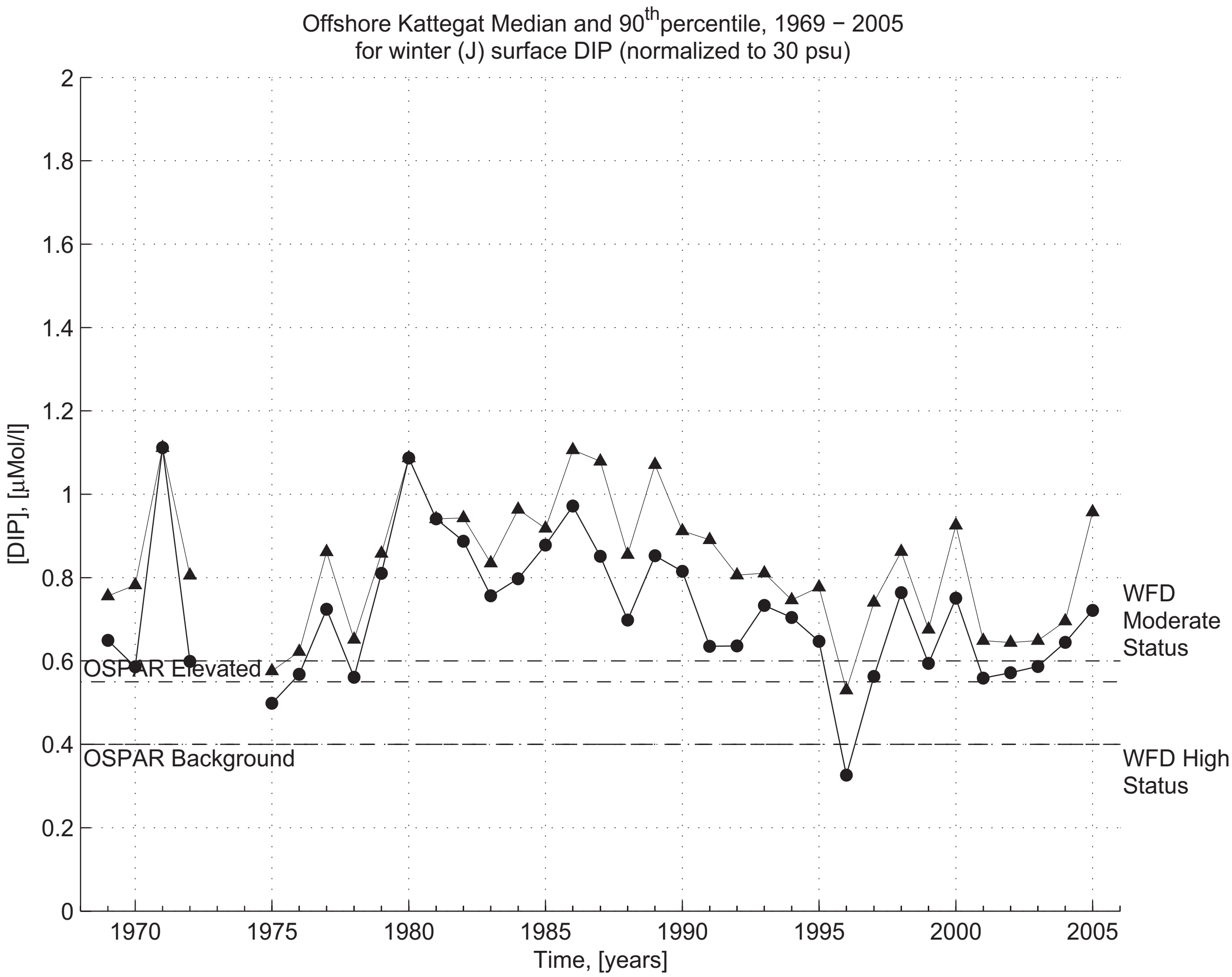

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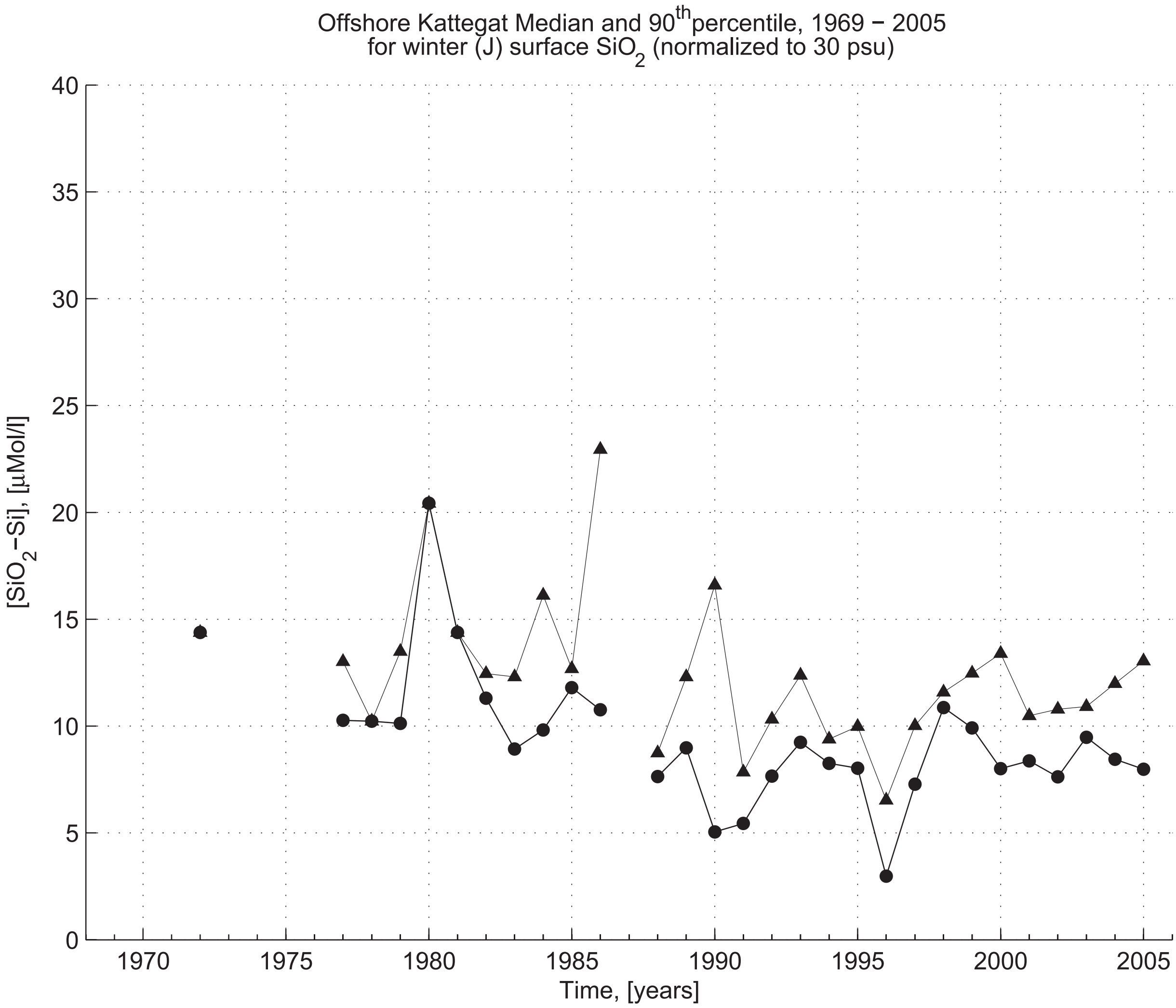

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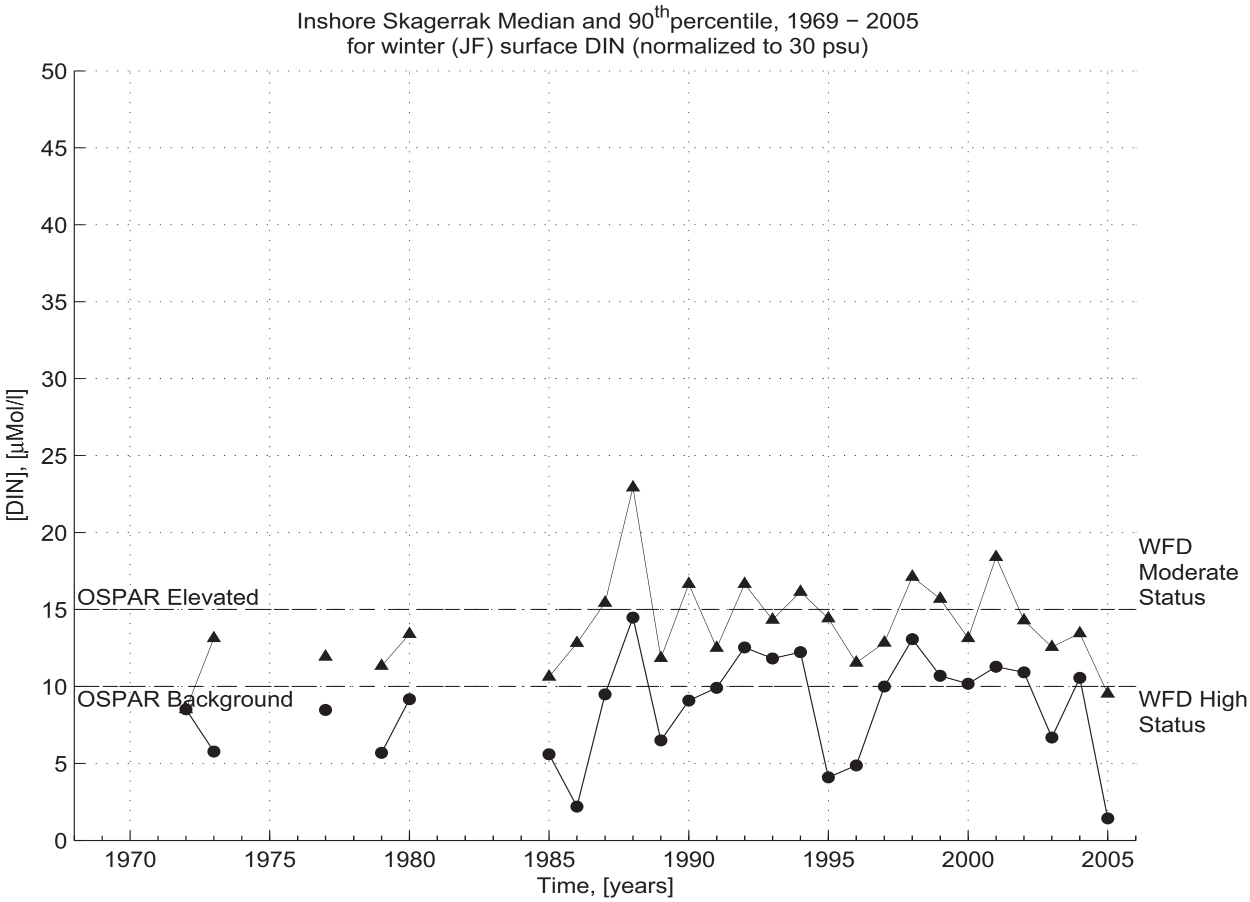

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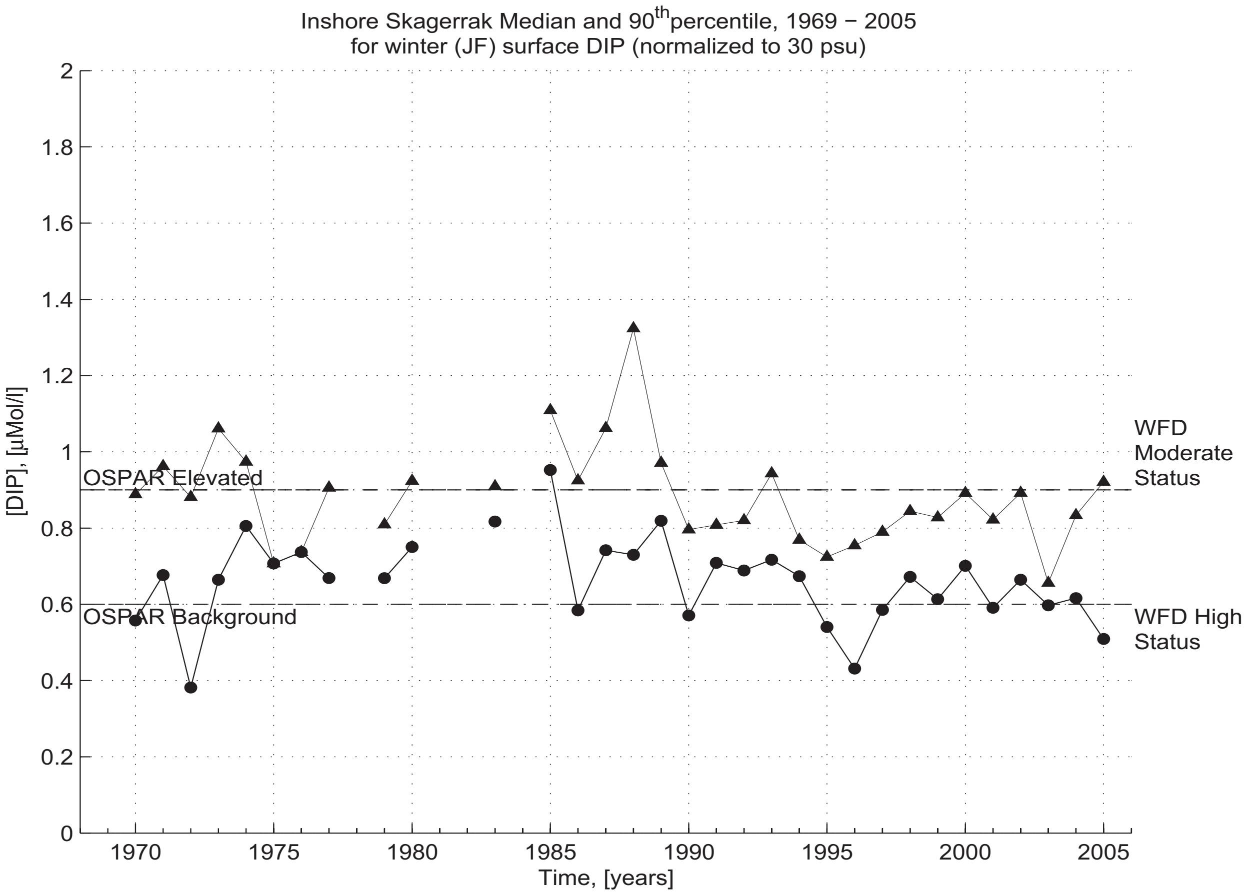

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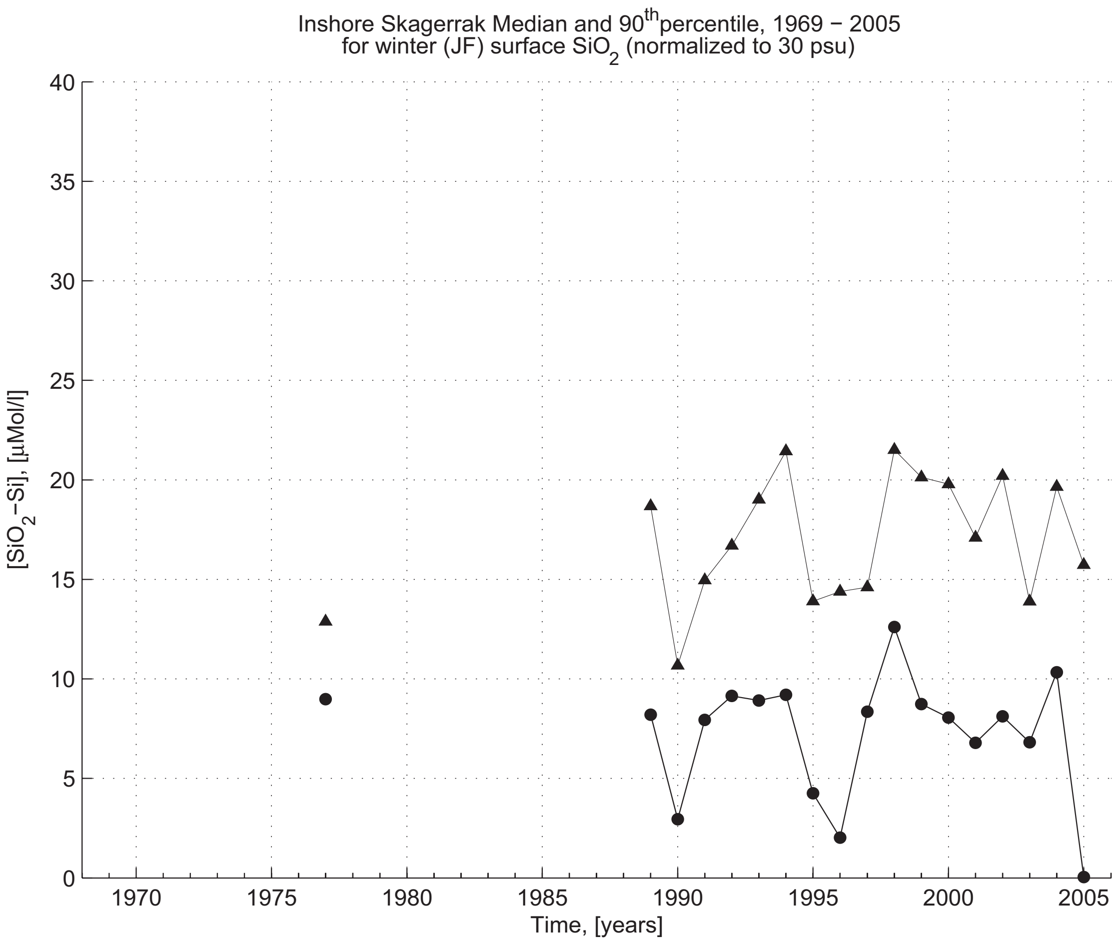

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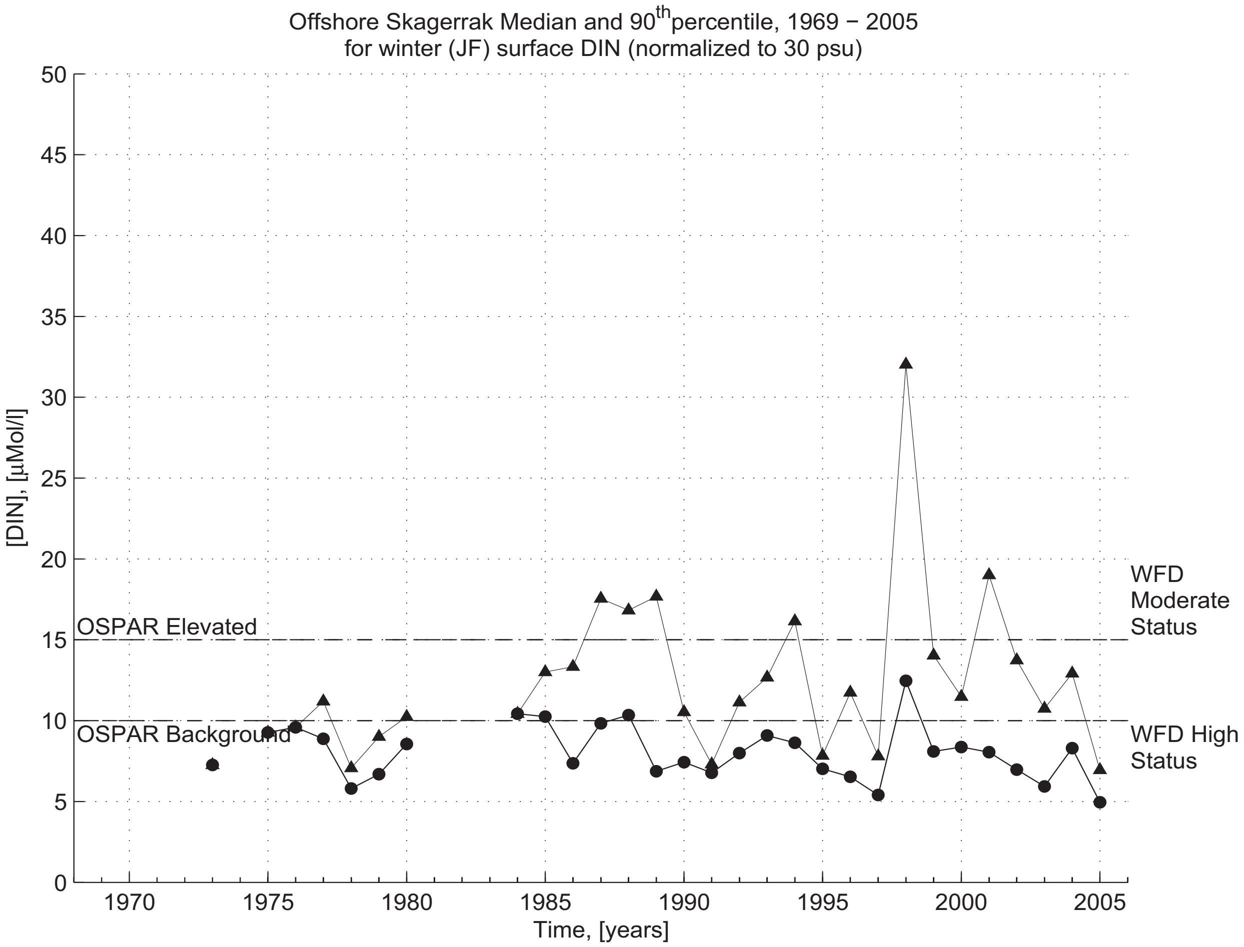

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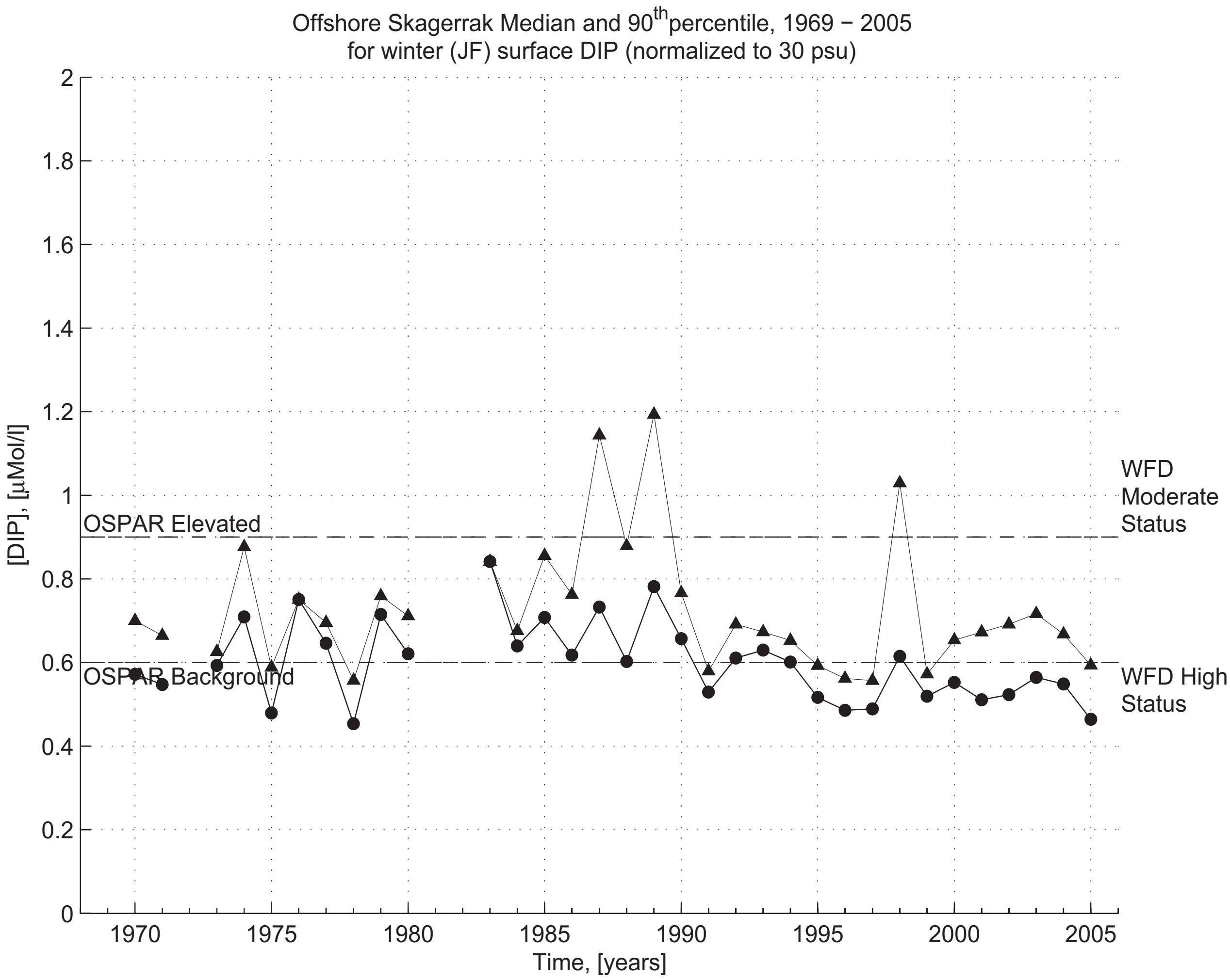

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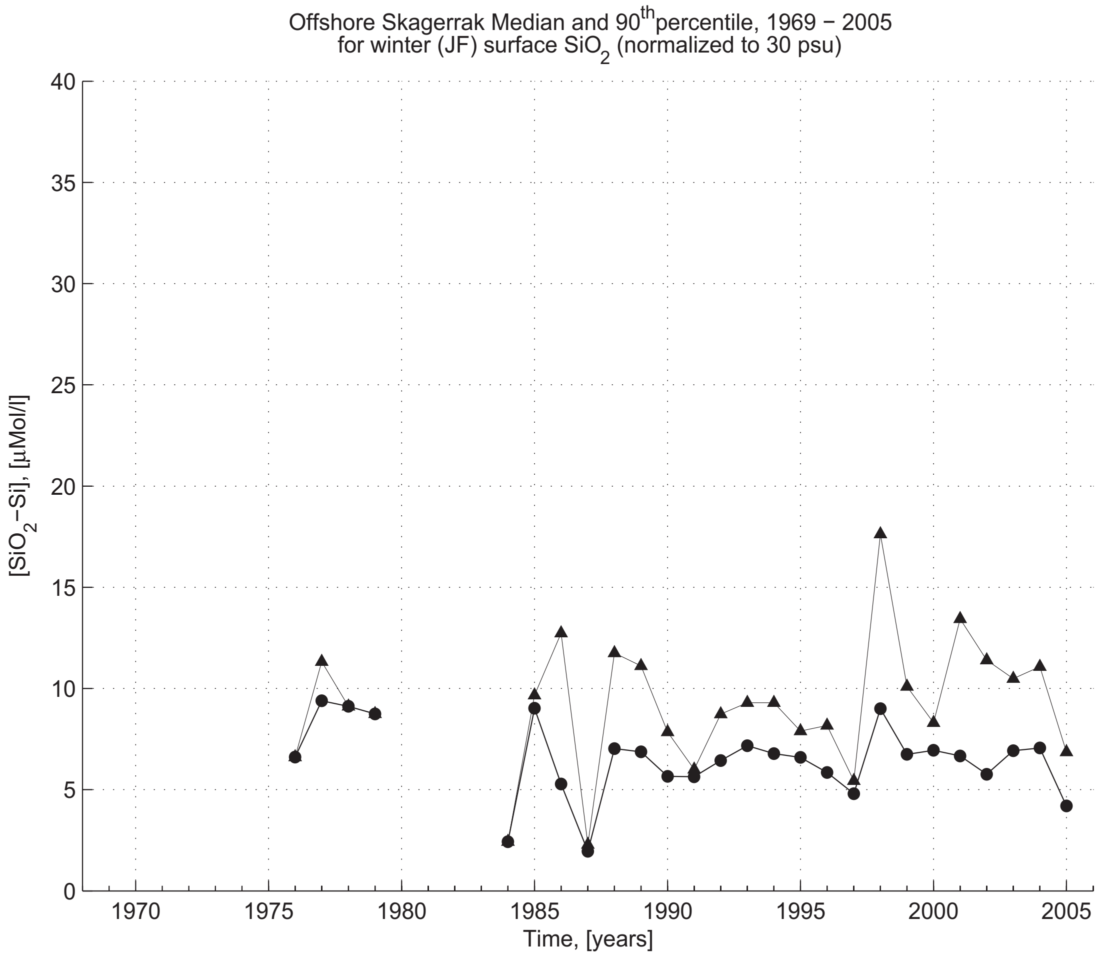
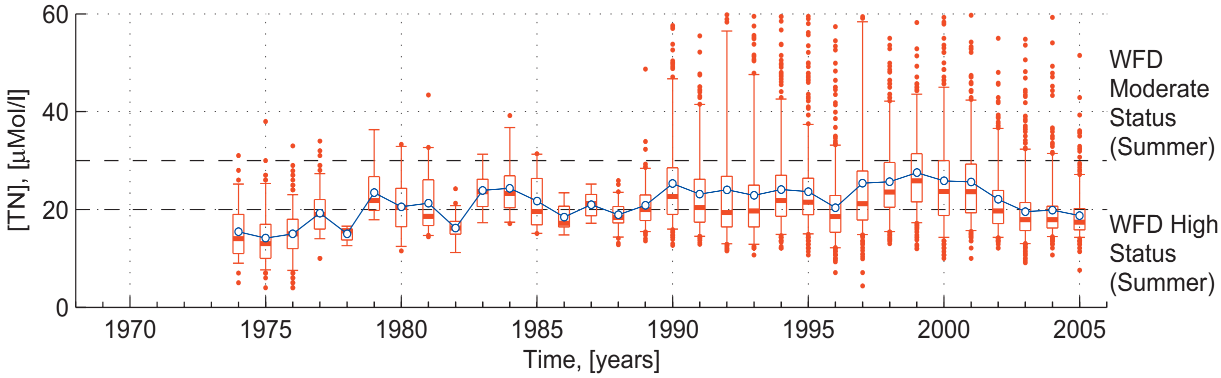
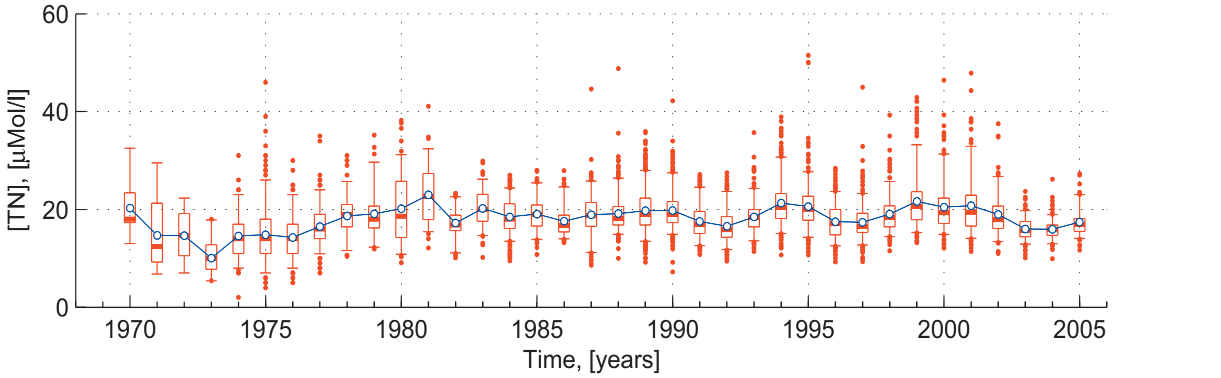


Appendix I - Mixing diagram and time series

Inshore Kattegat Box plot and means, 1969 – 2005
for surface TN



Offshore Kattegat Box plot and means, 1969 – 2005
for surface TN



Inshore Skagerrak Box plot and means, 1969 – 2005
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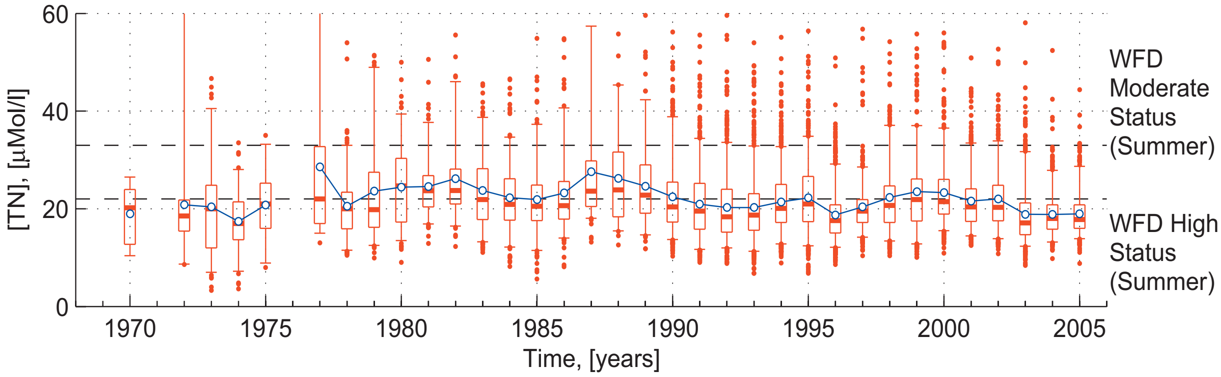
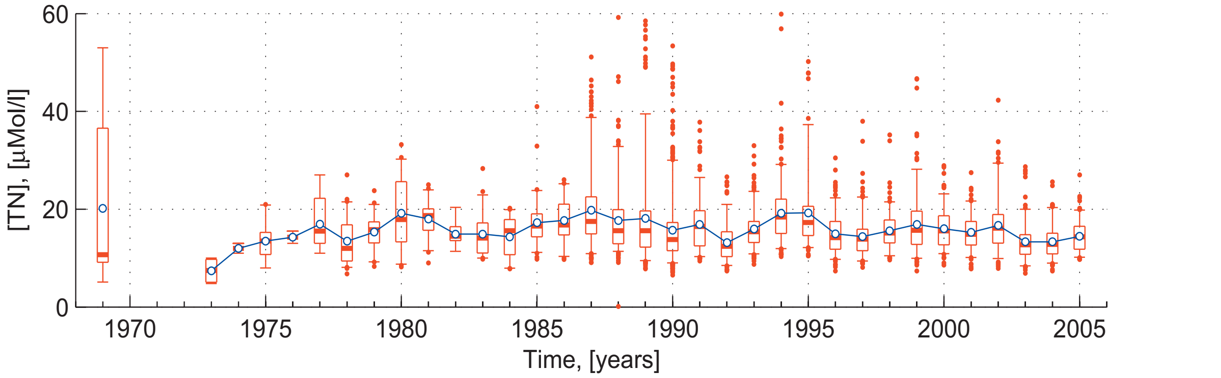


Offshore Skagerrak Box plot and means, 1969 – 2005
for surface TN



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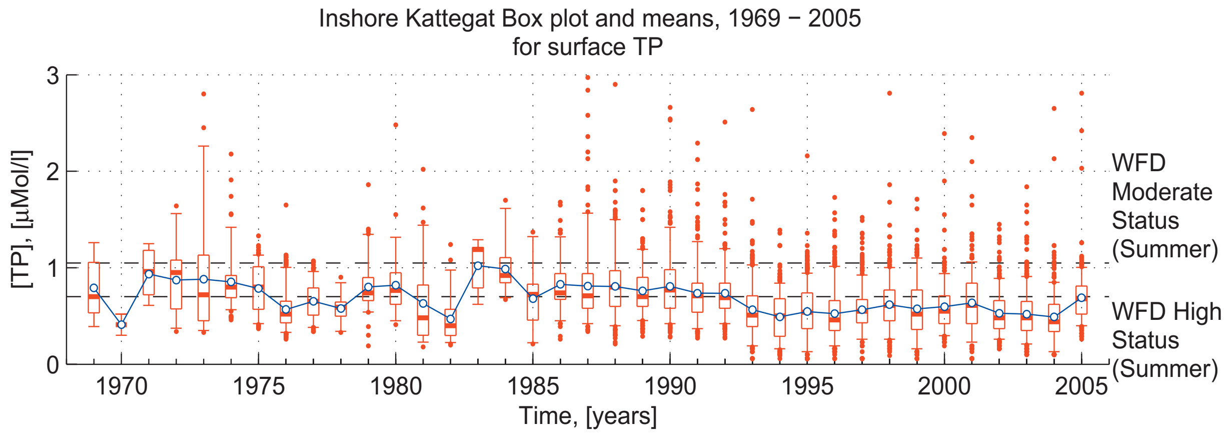

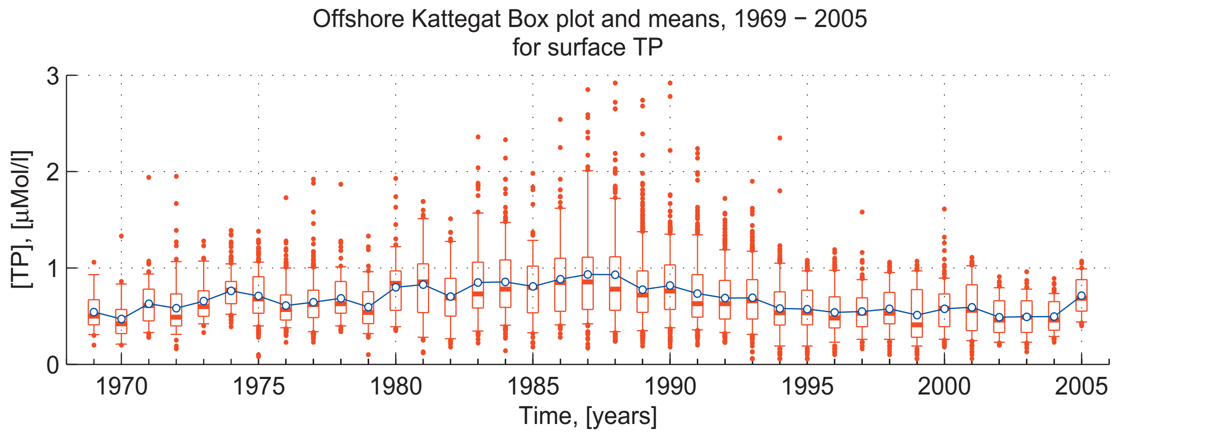

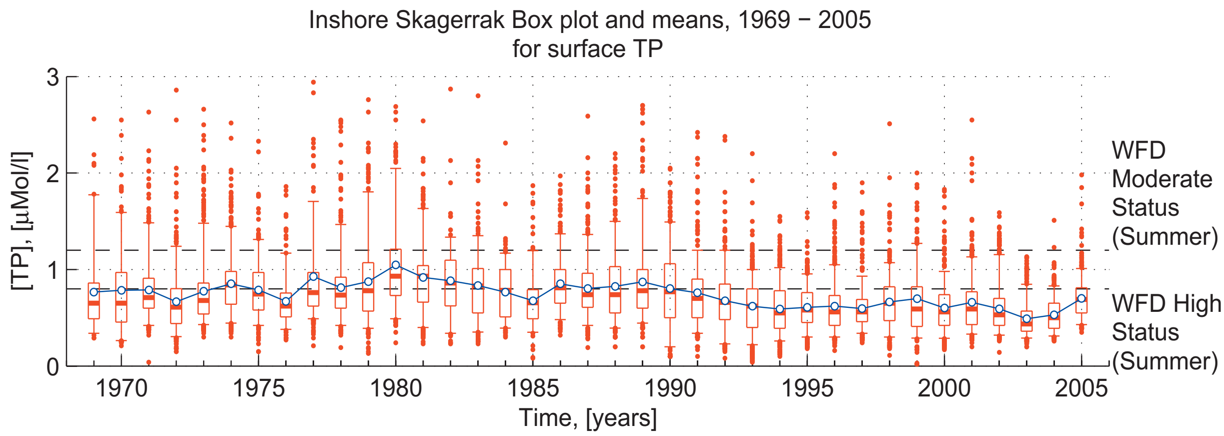

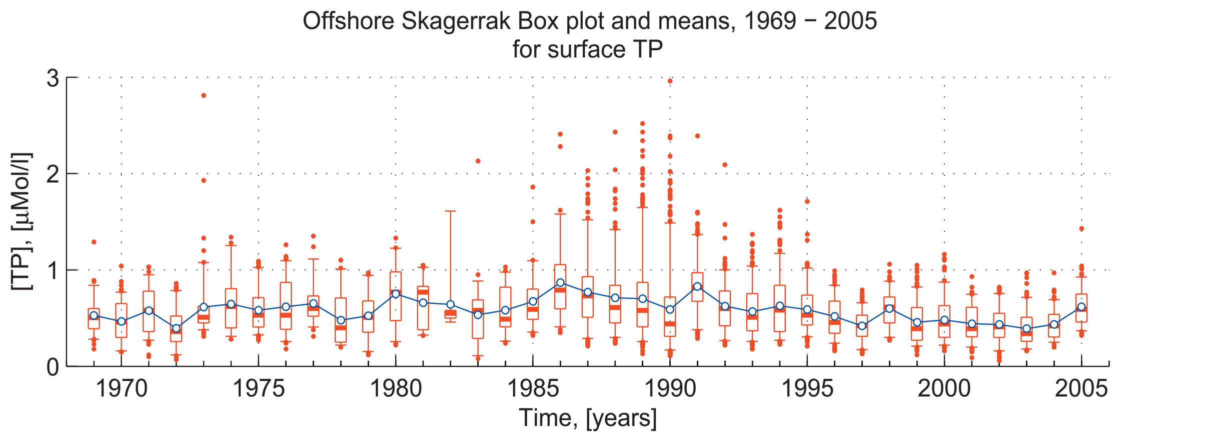

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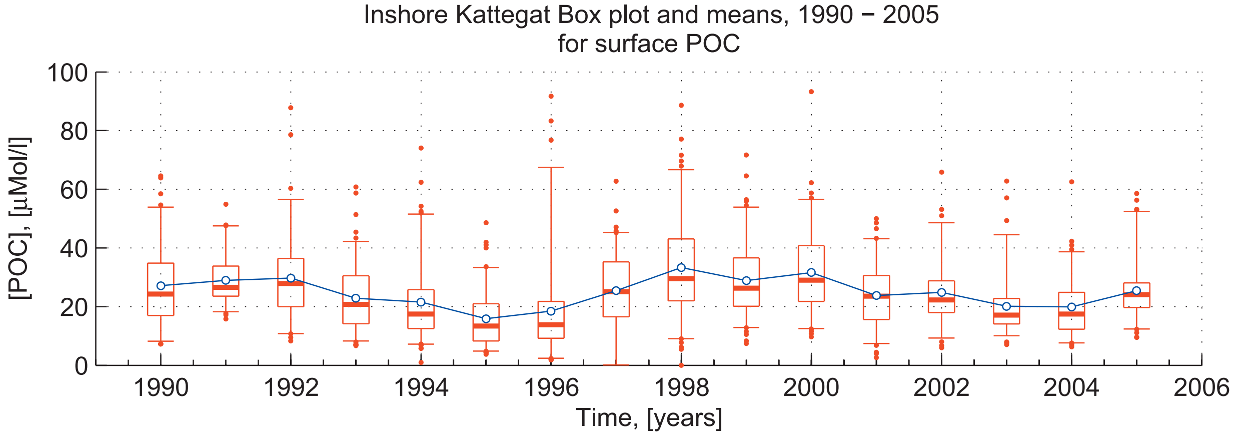

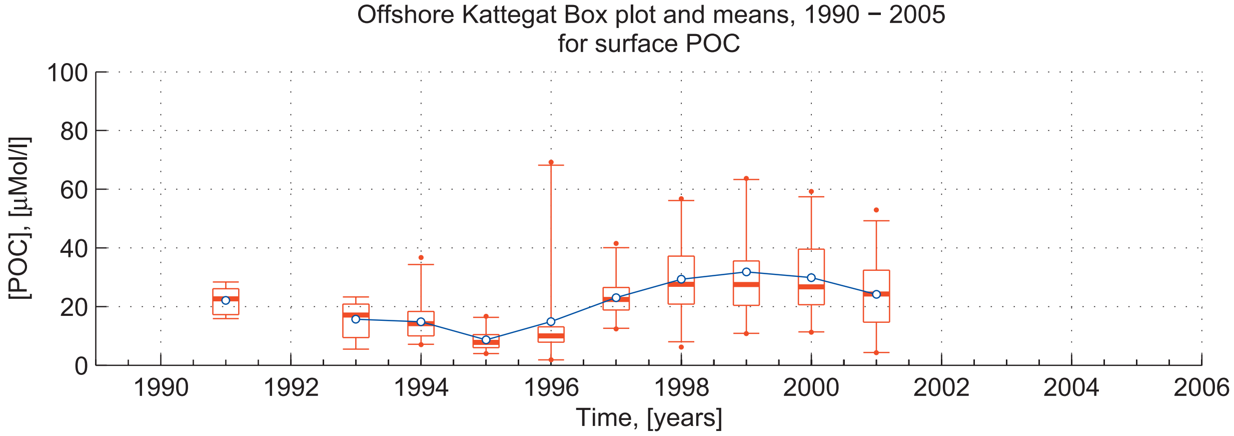

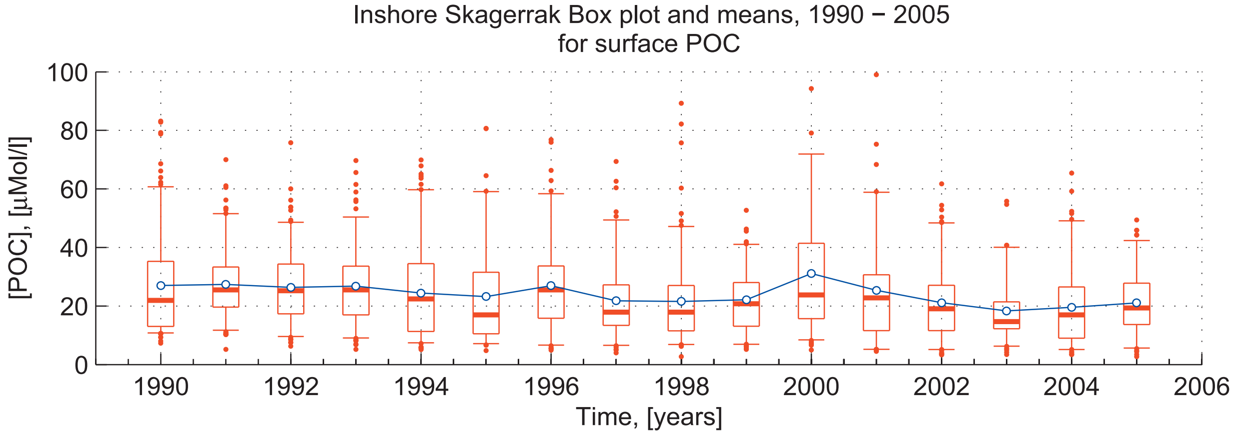

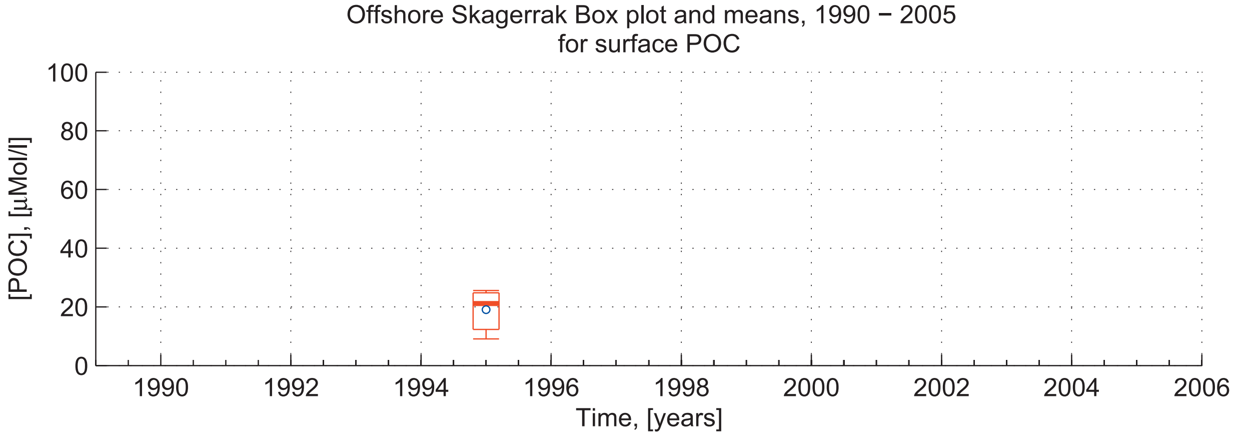

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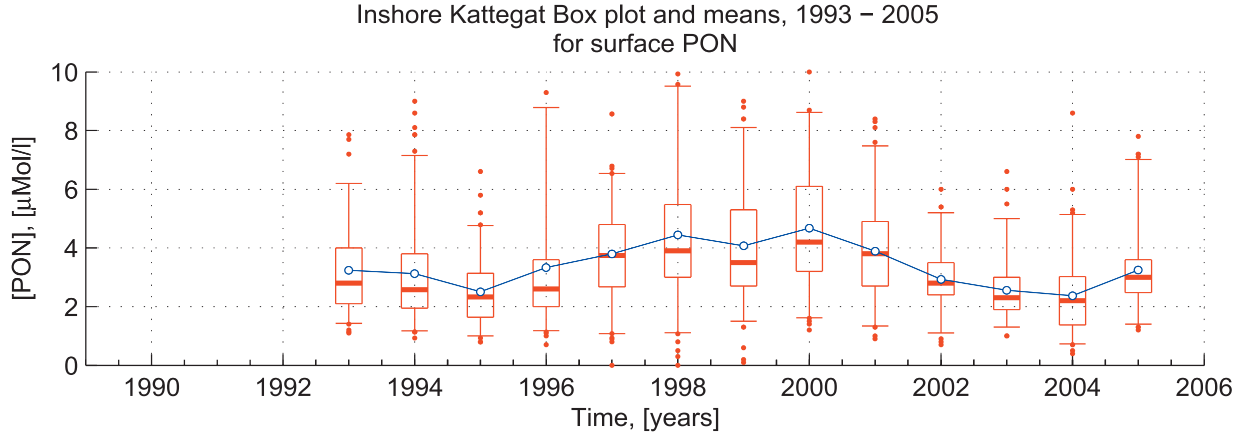

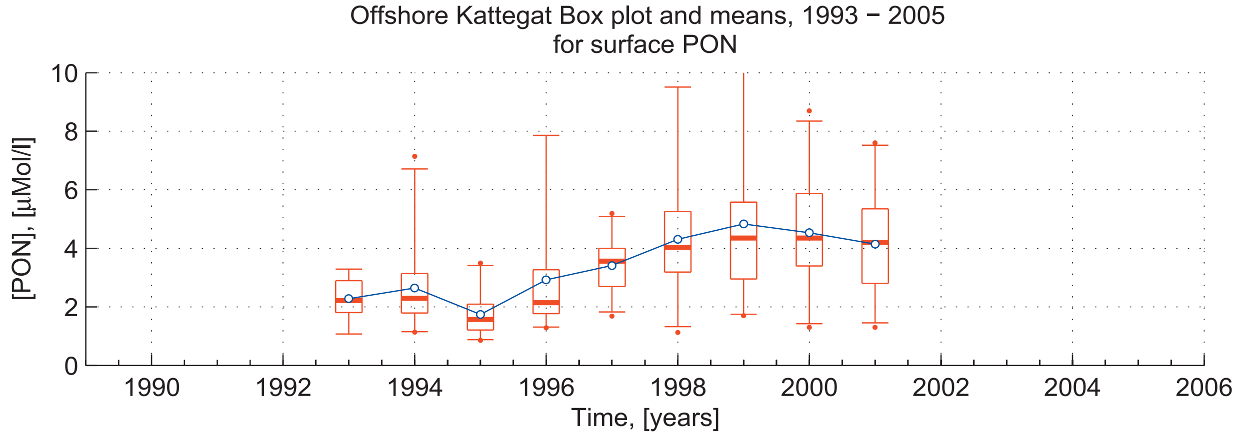

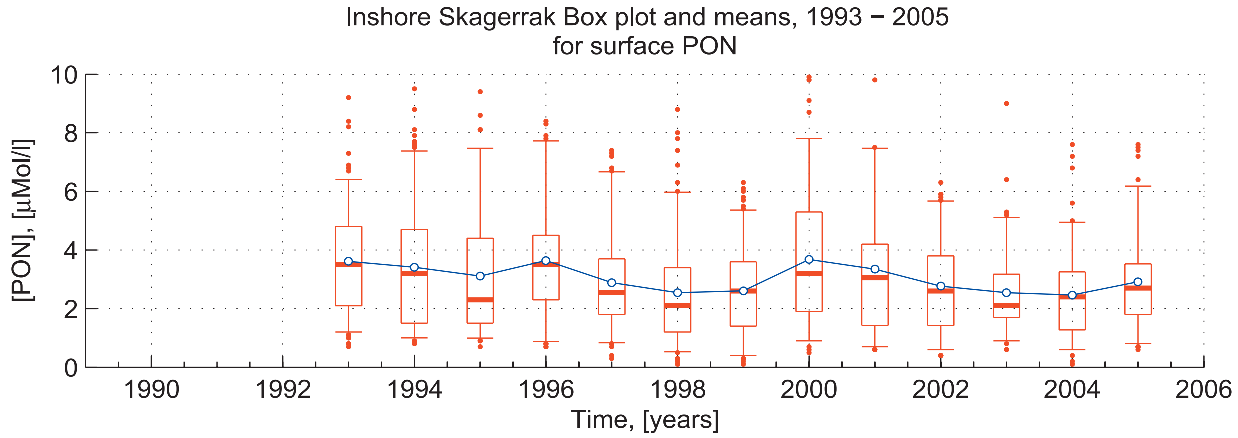

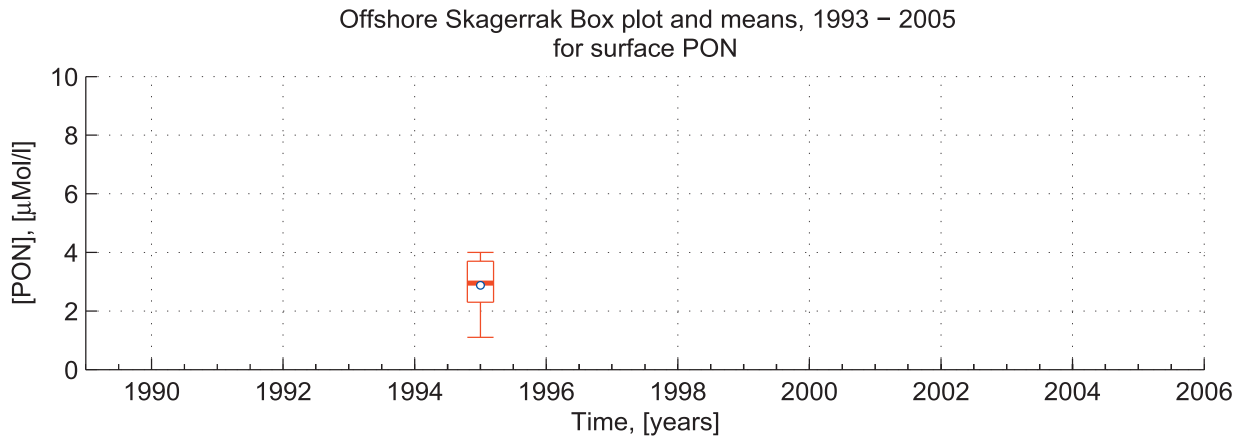

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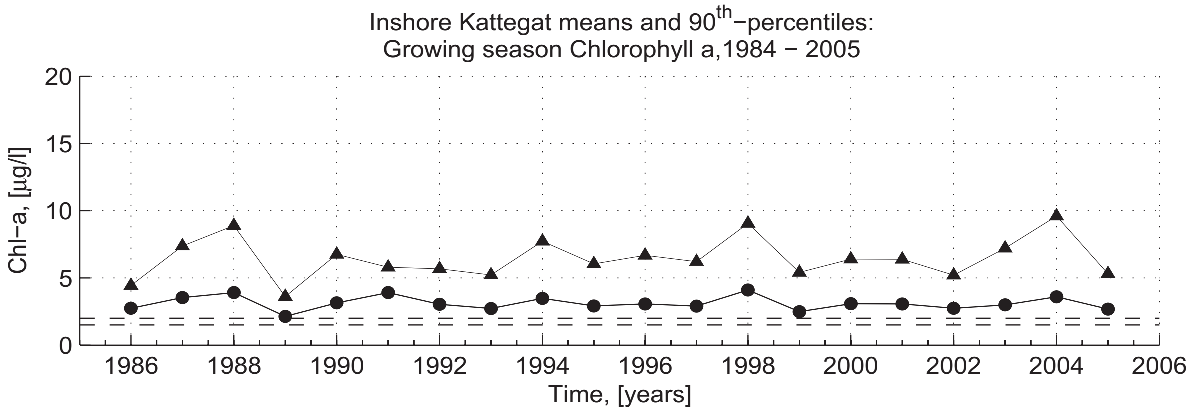
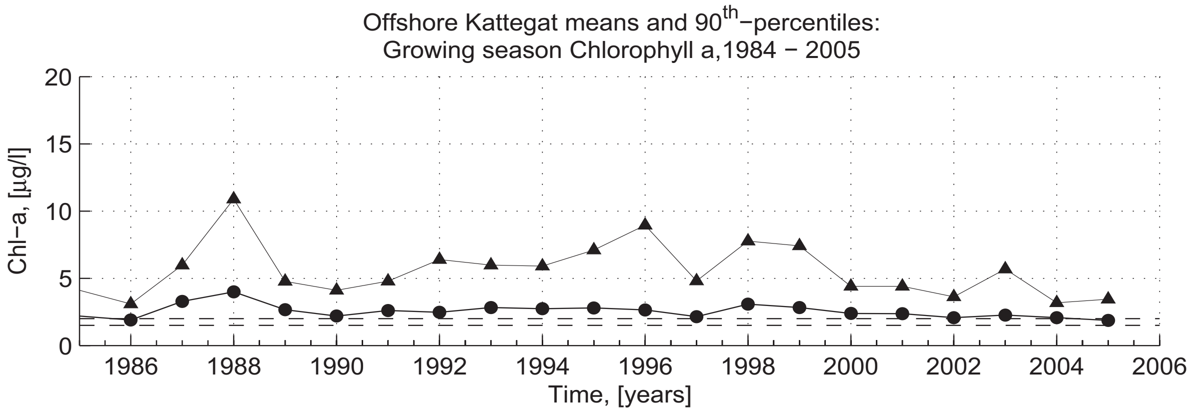
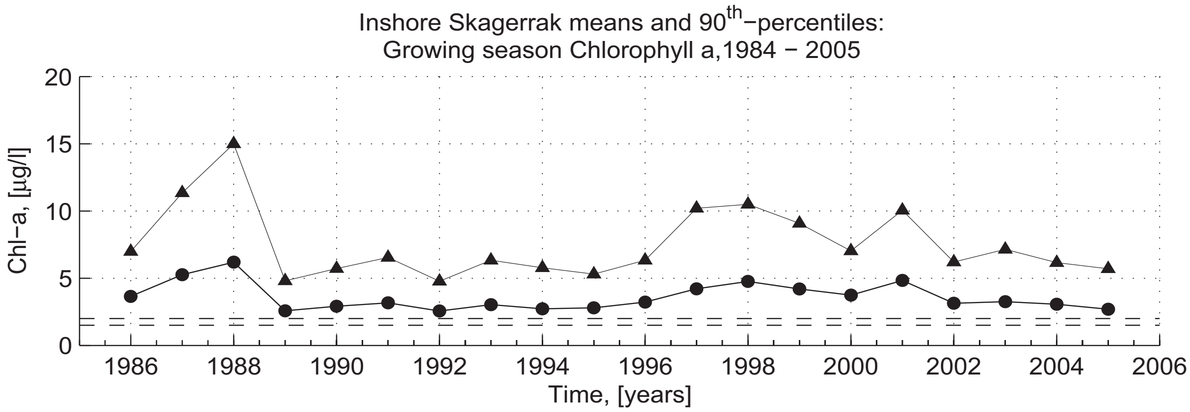
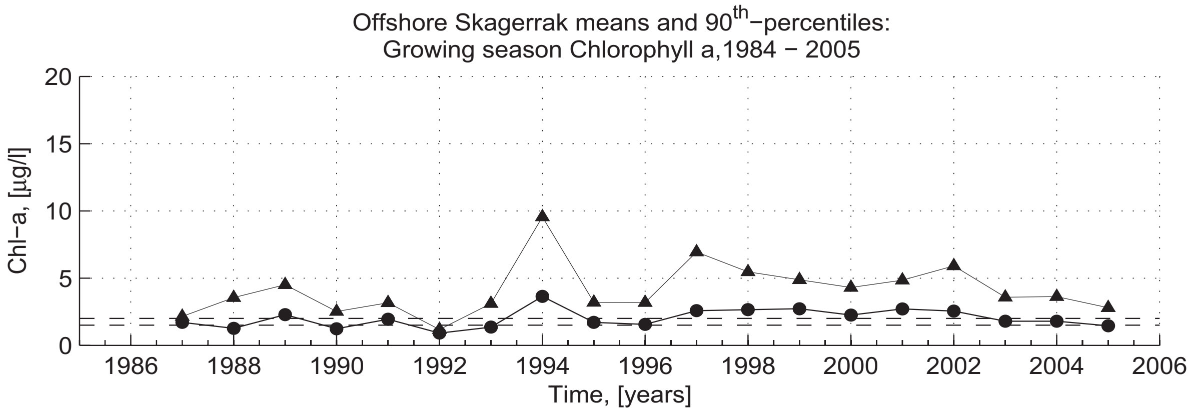


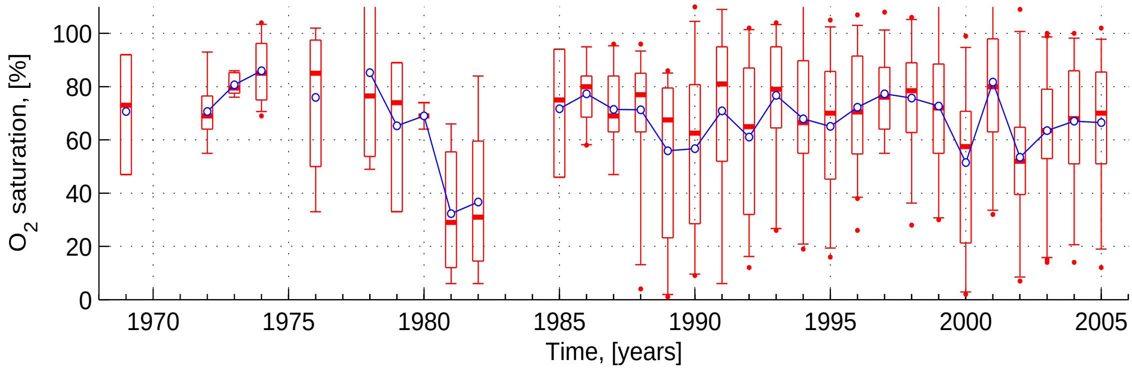




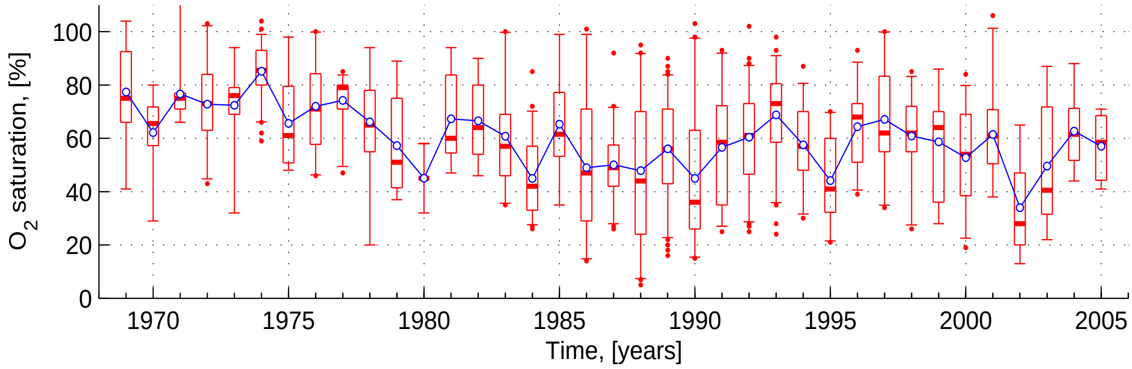


Appendix I - Mixing diagram and time series

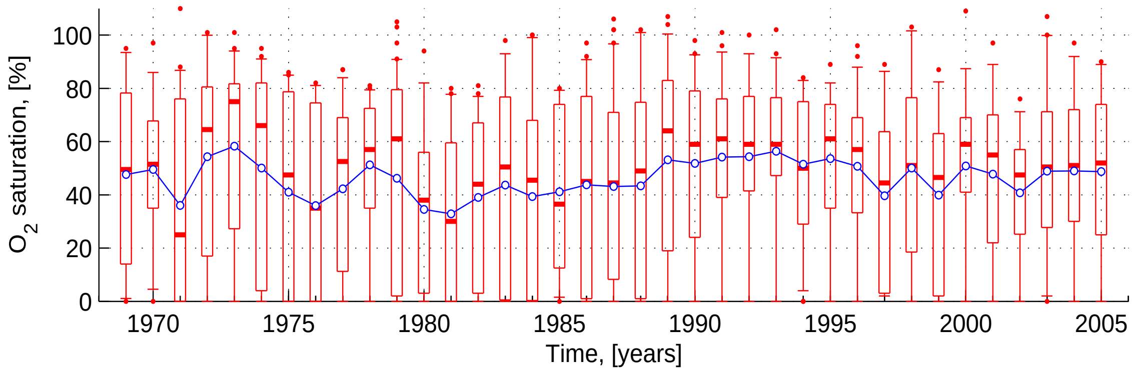
Inshore Kattegat Box plot and means:
Autumn Bottom oxygen Saturation,1969 − 2005



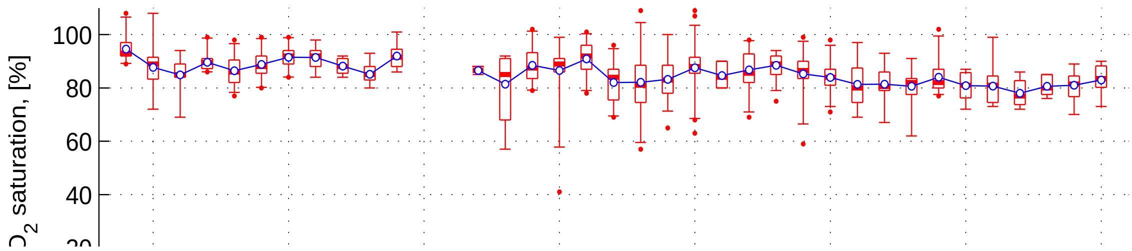
Offshore Kattegat Box plot and means:
Autumn Bottom oxygen Saturation,1969 − 2005



Inshore Skagerrak Box plot and means:
Autumn Bottom oxygen Saturation,1969 − 2005



Offshore Skagerrak Box plot and means:
Autumn Bottom oxygen Saturation,1969 − 2005



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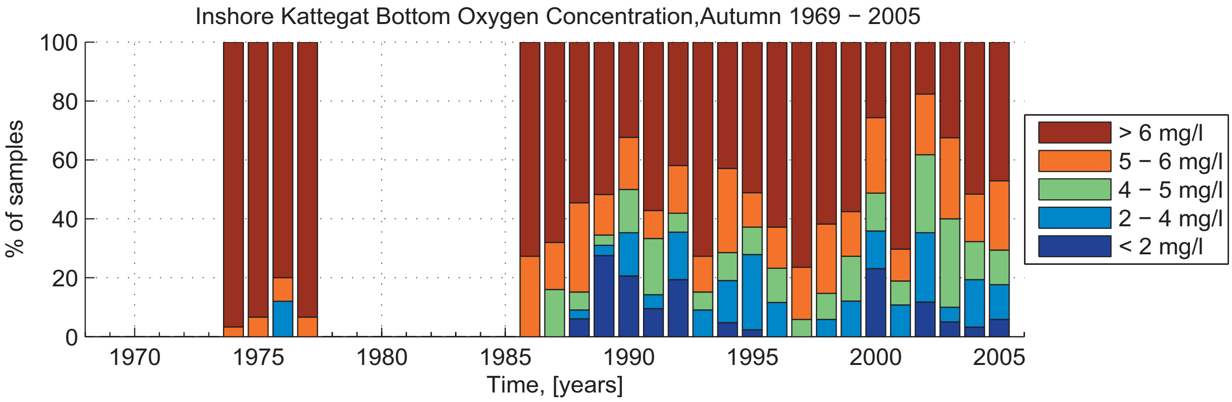

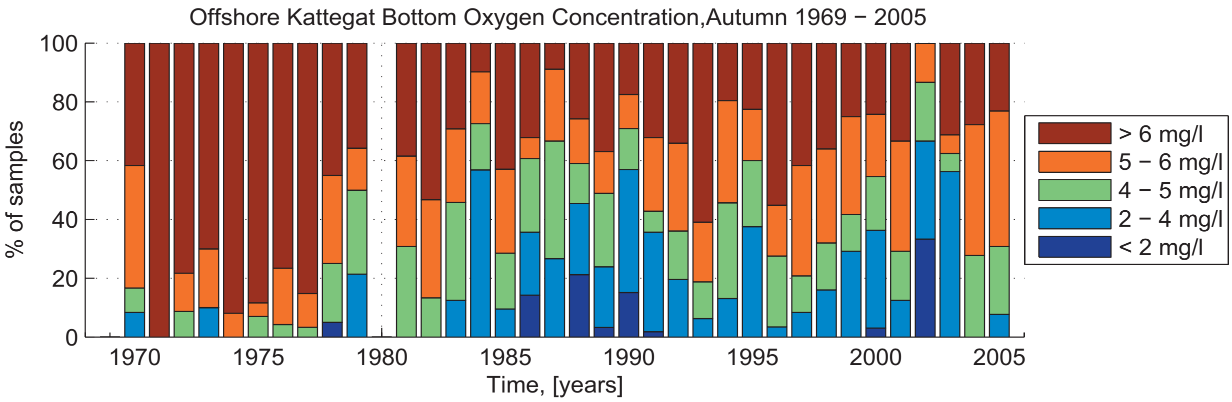

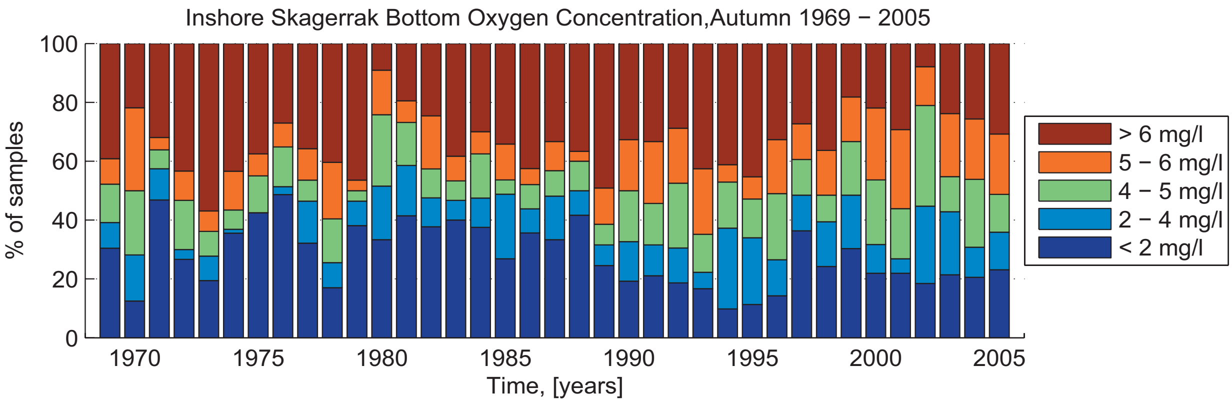

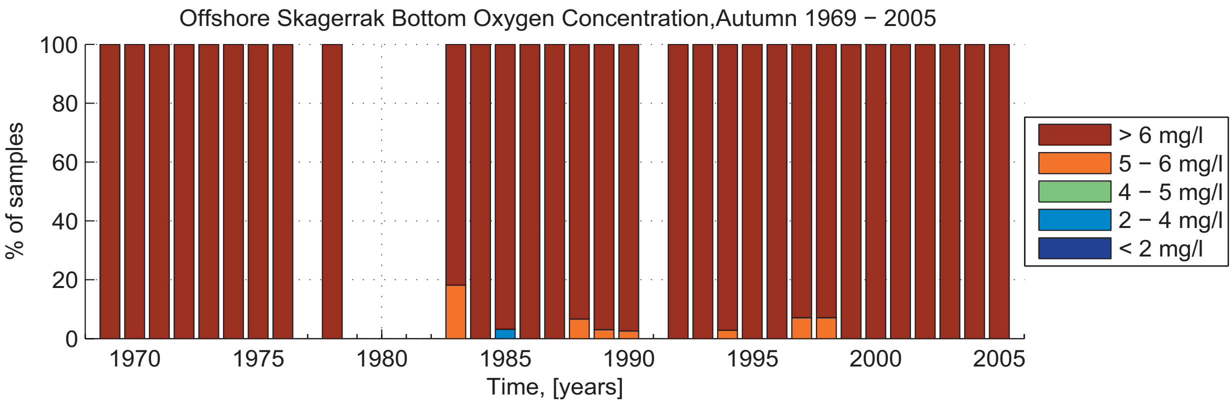

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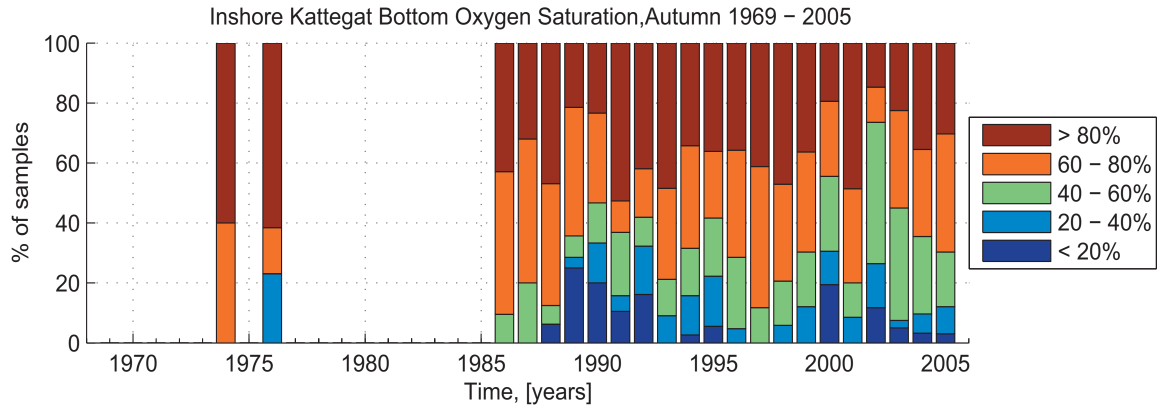
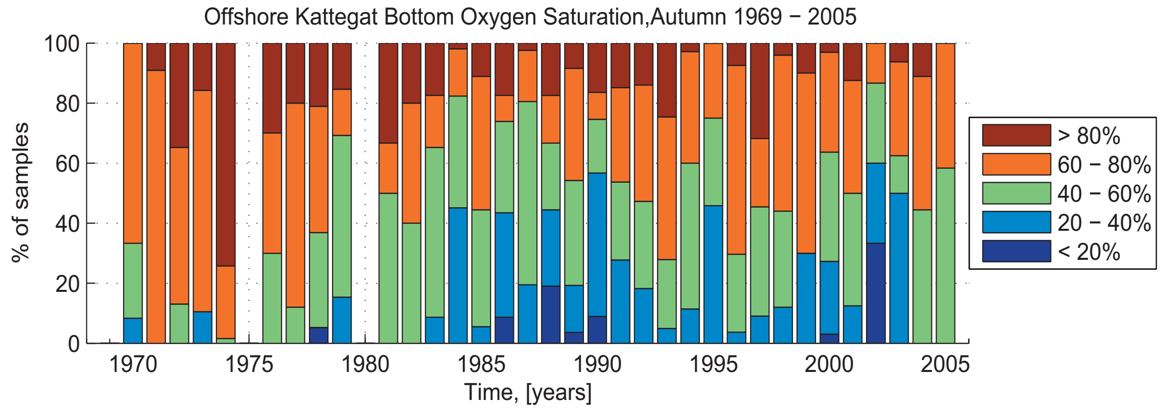
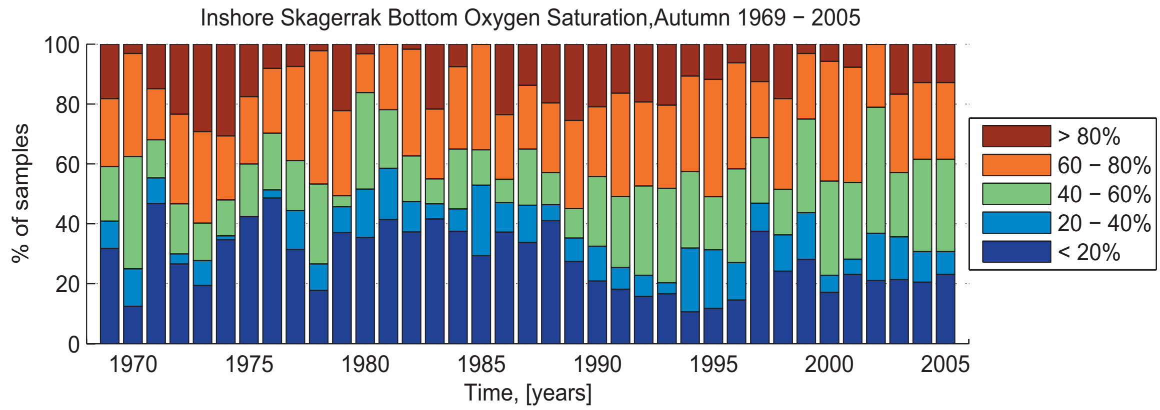
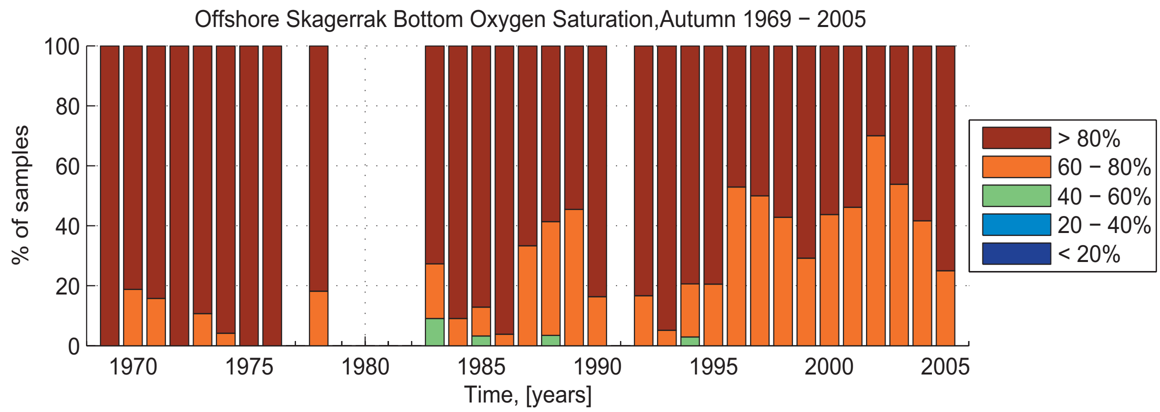








Appendix I - Mixing diagram and time series

Abundance of OSPAR phytoplankton indicator spicies of in the Skagerrak and the Kattegat

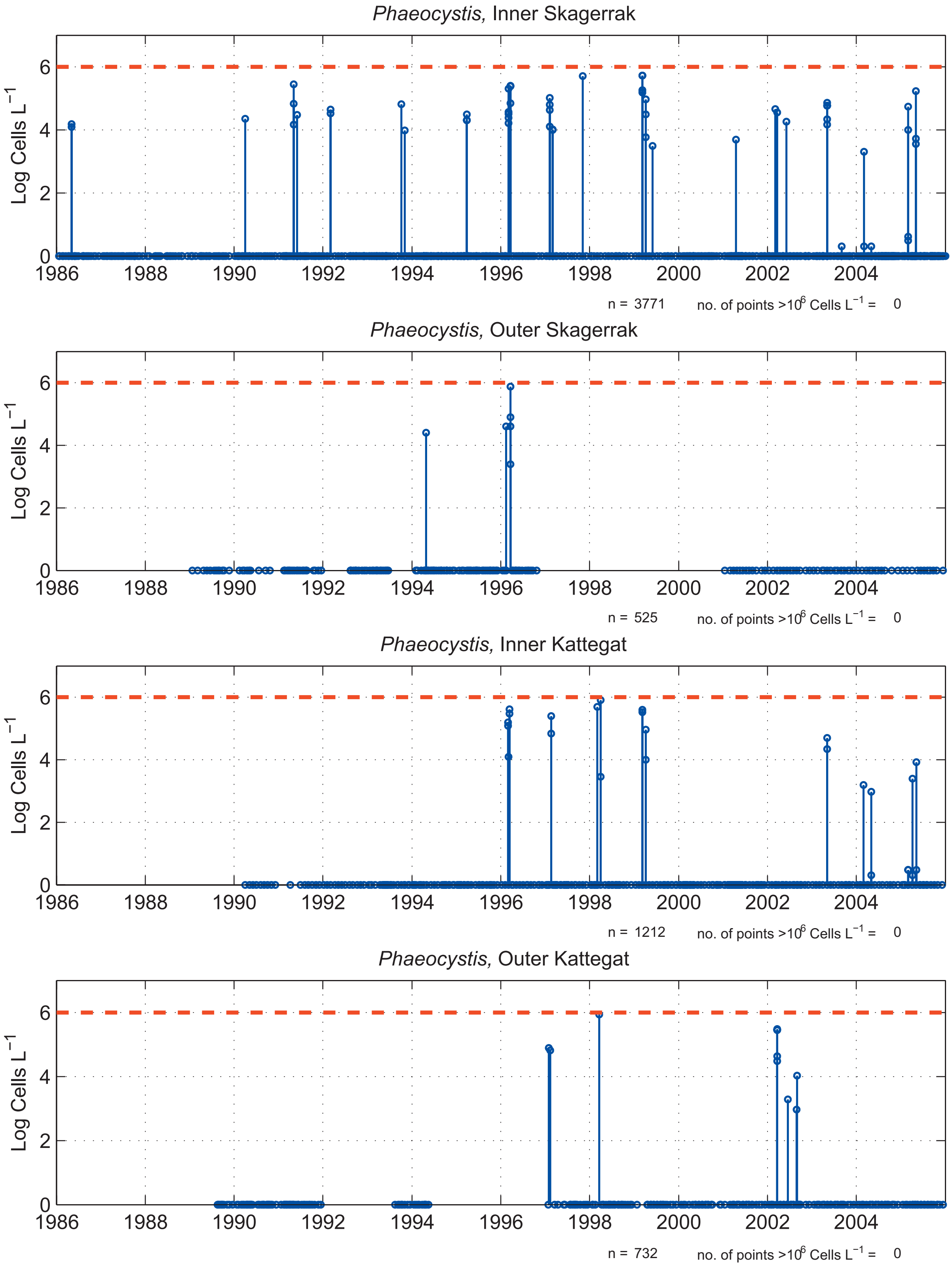


Fig. 1. Abundance of Phaeocystis spp. The red line indicates the abundance for elevated levels according to OSPAR.

Appendix I - Mixing diagram and time series

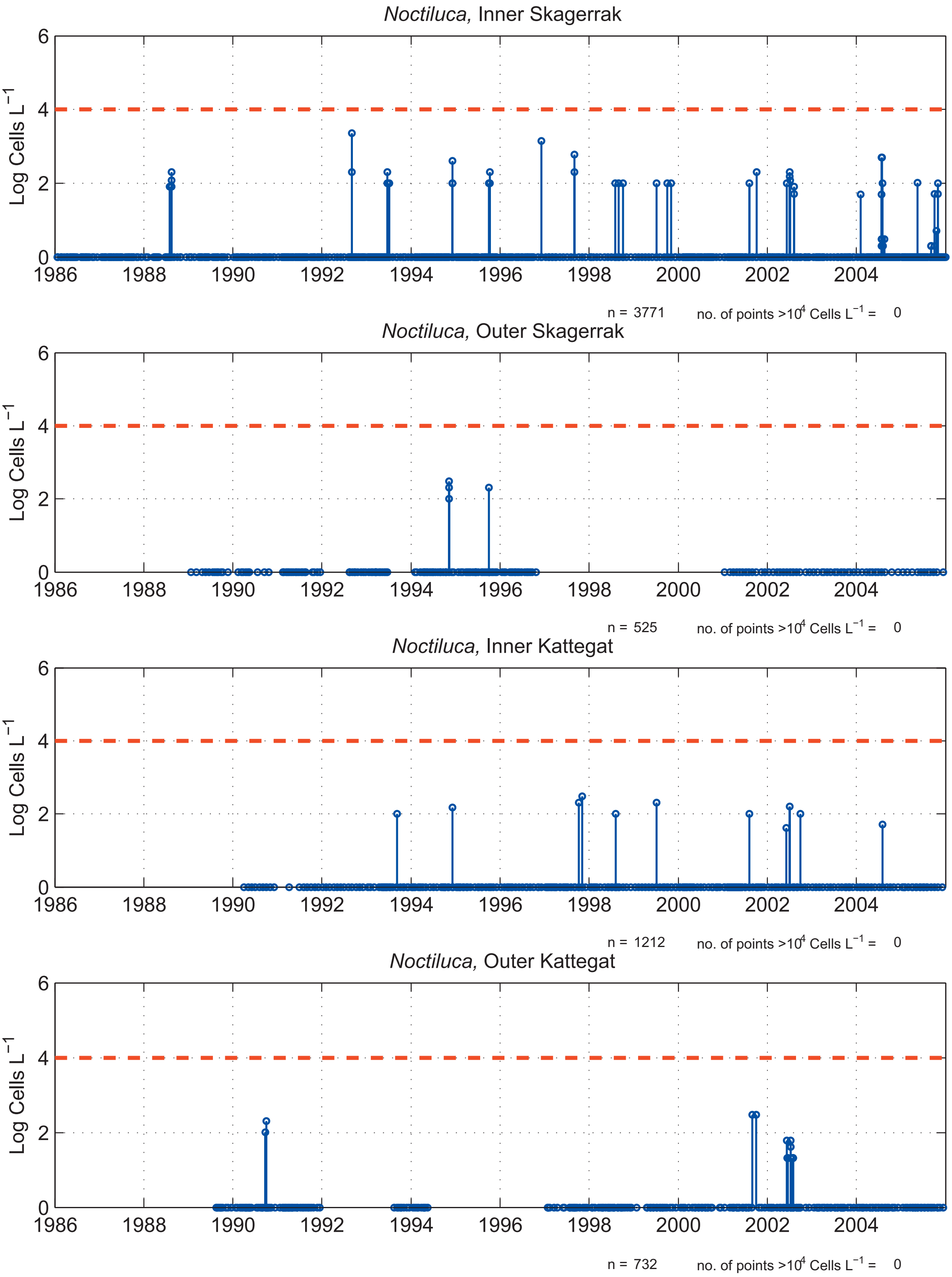


Fig. 2. Abundance of Noctiluca scintillans The red line indicates the abundance for elevated levels according to OSPAR.

Appendix I - Mixing diagram and time series

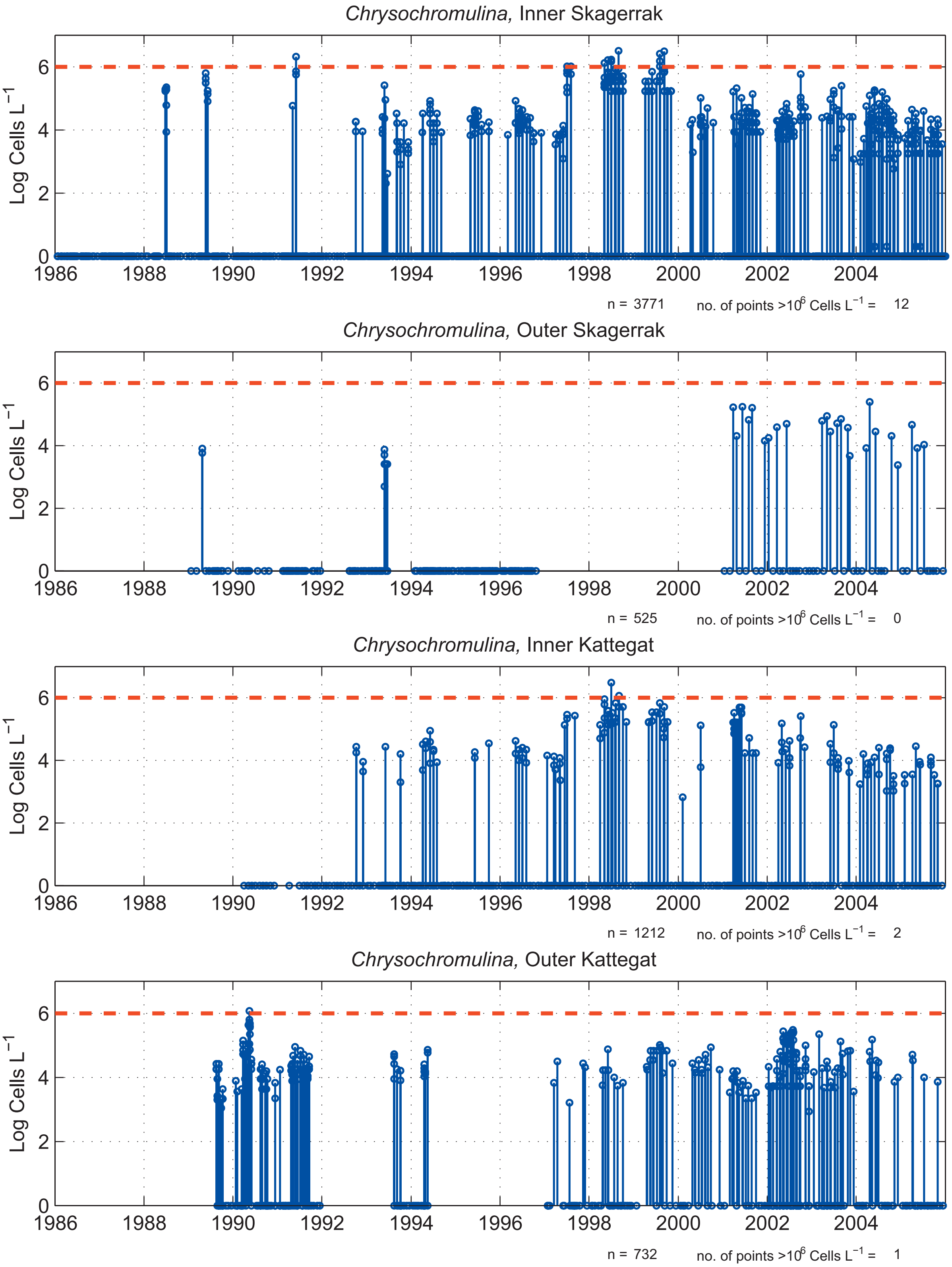


Fig. 3. Abundance of Chrysochrolmulina spp. The red line indicates the abundance for elevated levels of Chrysochromulina polylepis according to OSPAR.

Appendix I - Mixing diagram and time series

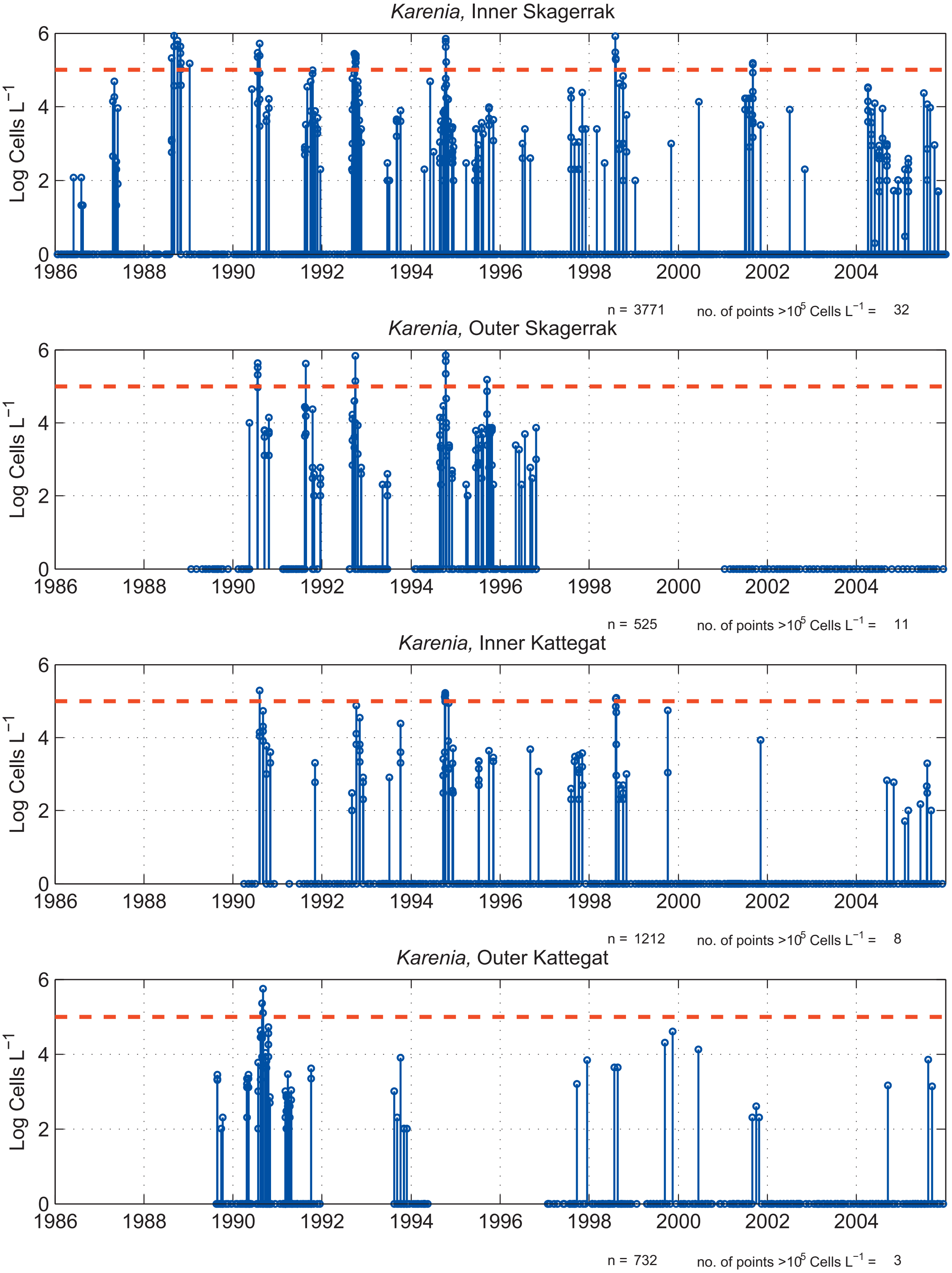


Fig. 4. Abundance of Karenia mikimotoi (synonym Gymnodinium mikimotoi which has been called the European Gyrodinium aureolum). The red line indicates the abundance for elevated levels according to OSPAR.

Appendix I - Mixing diagram and time series

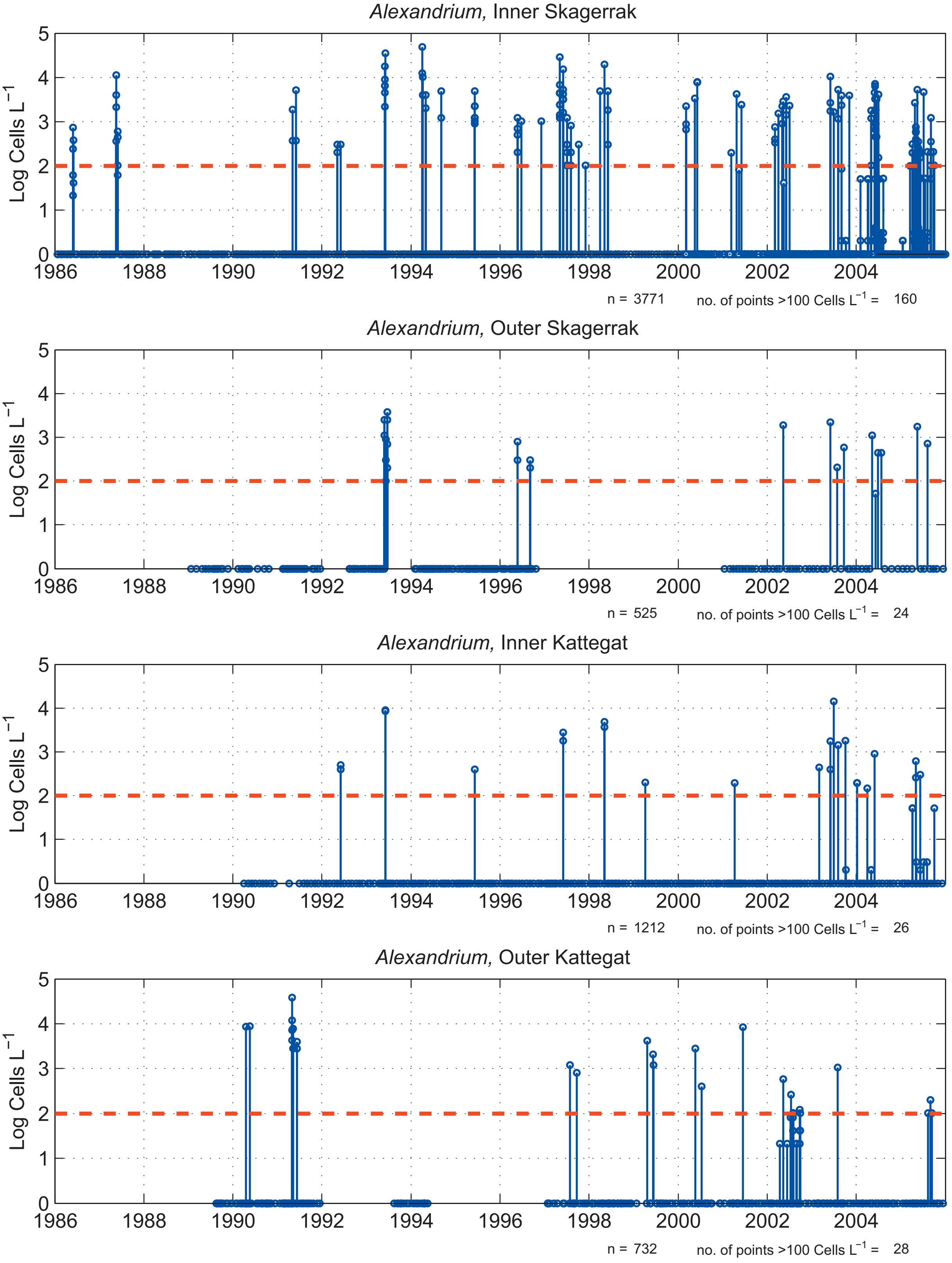


Fig. 5. Abundance of Alexandrium spp. The red line indicates the abundance for elevated levels according to OSPAR.

Appendix I - Mixing diagram and time series

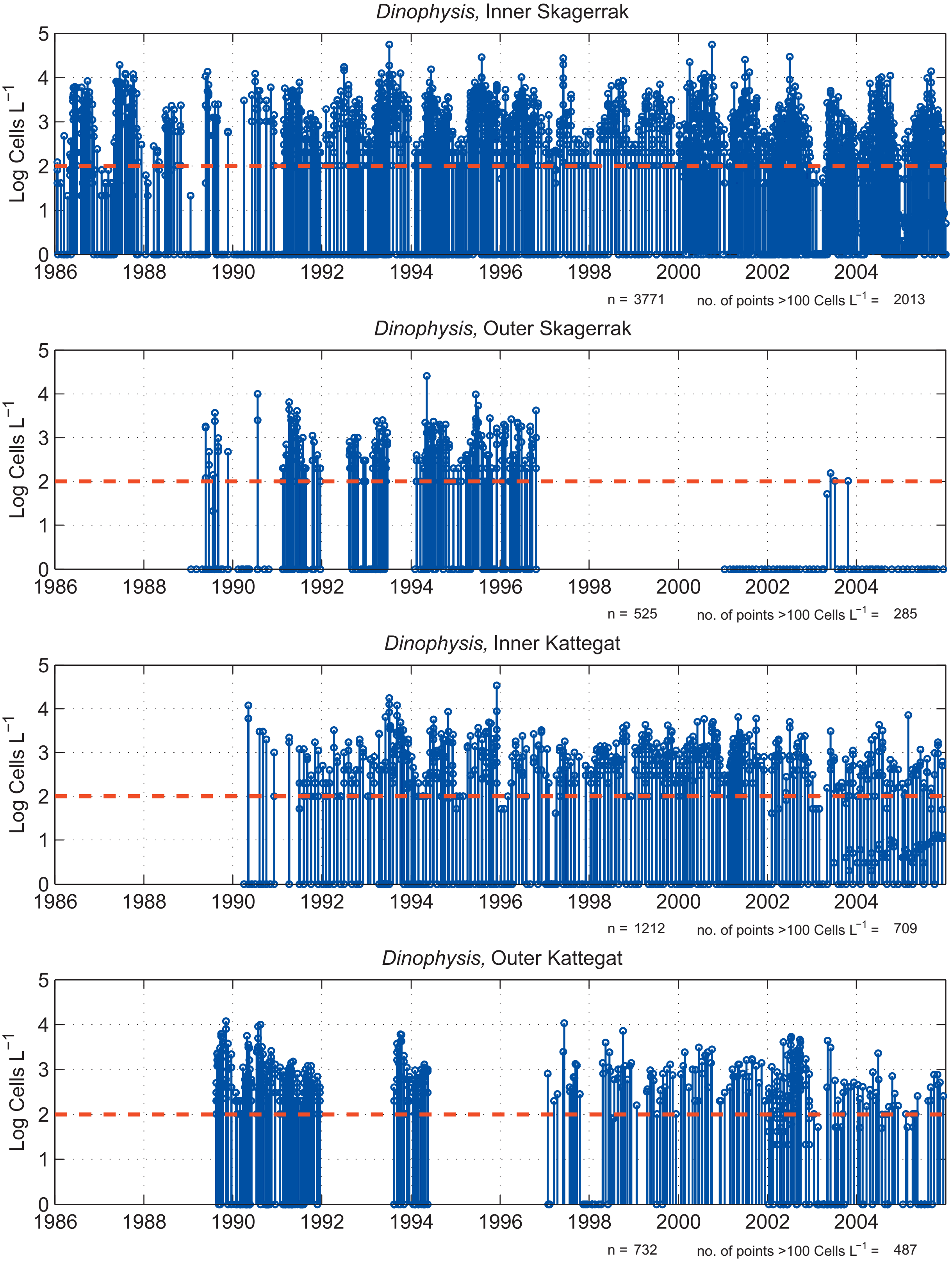


Fig. 6. Abundance of Dinophysis spp. The red line indicates the abundance for elevated levels according to OSPAR.

Appendix I - Mixing diagram and time series

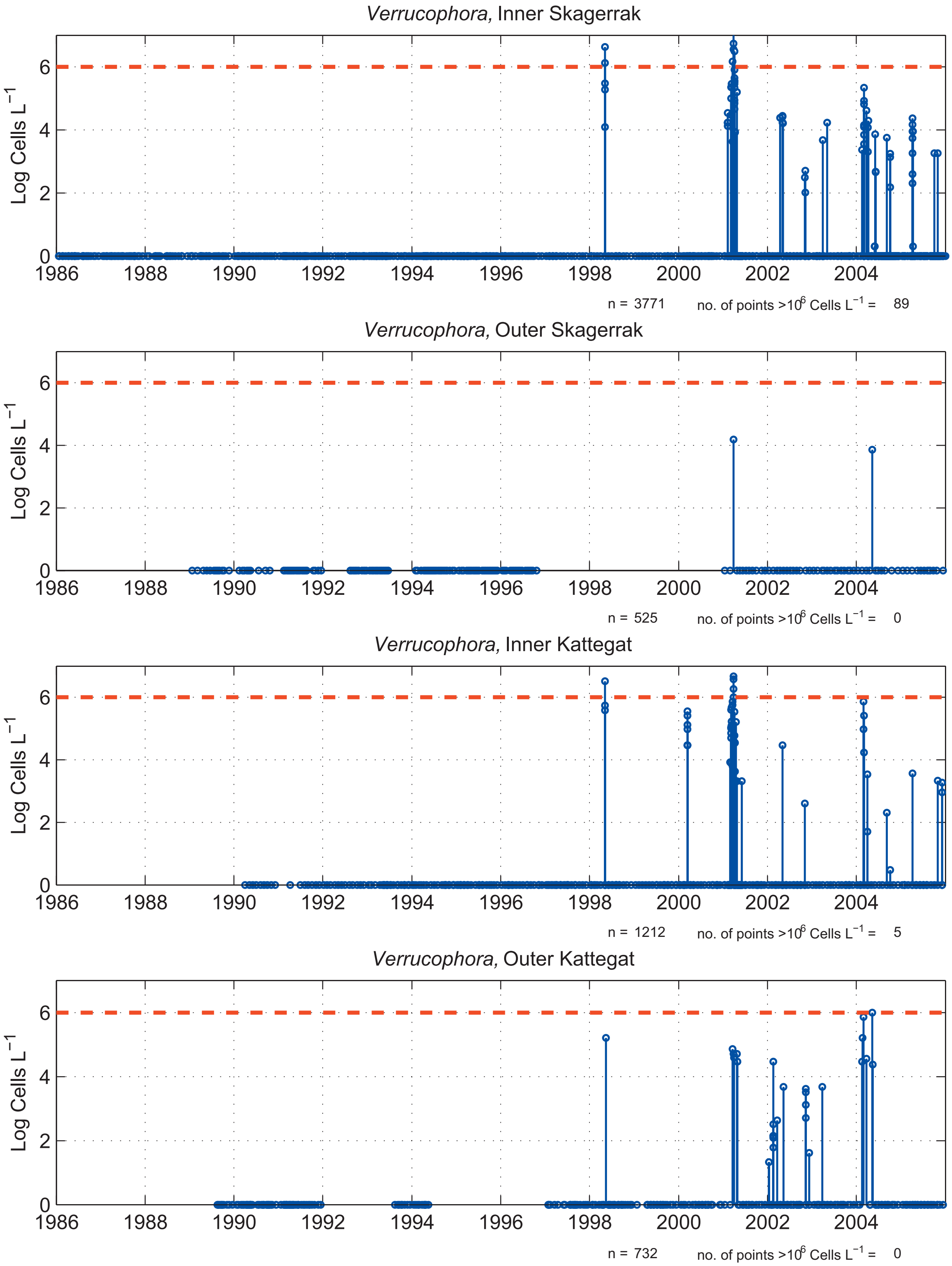


Fig. 7 Abundance of Verrucophora spp. (former name in the Skagerrak and the Kattegat was Chattonella spp.) The red line indicates the abundance for elevated levels according to OSPAR.

Appendix I - Mixing diagram and time series

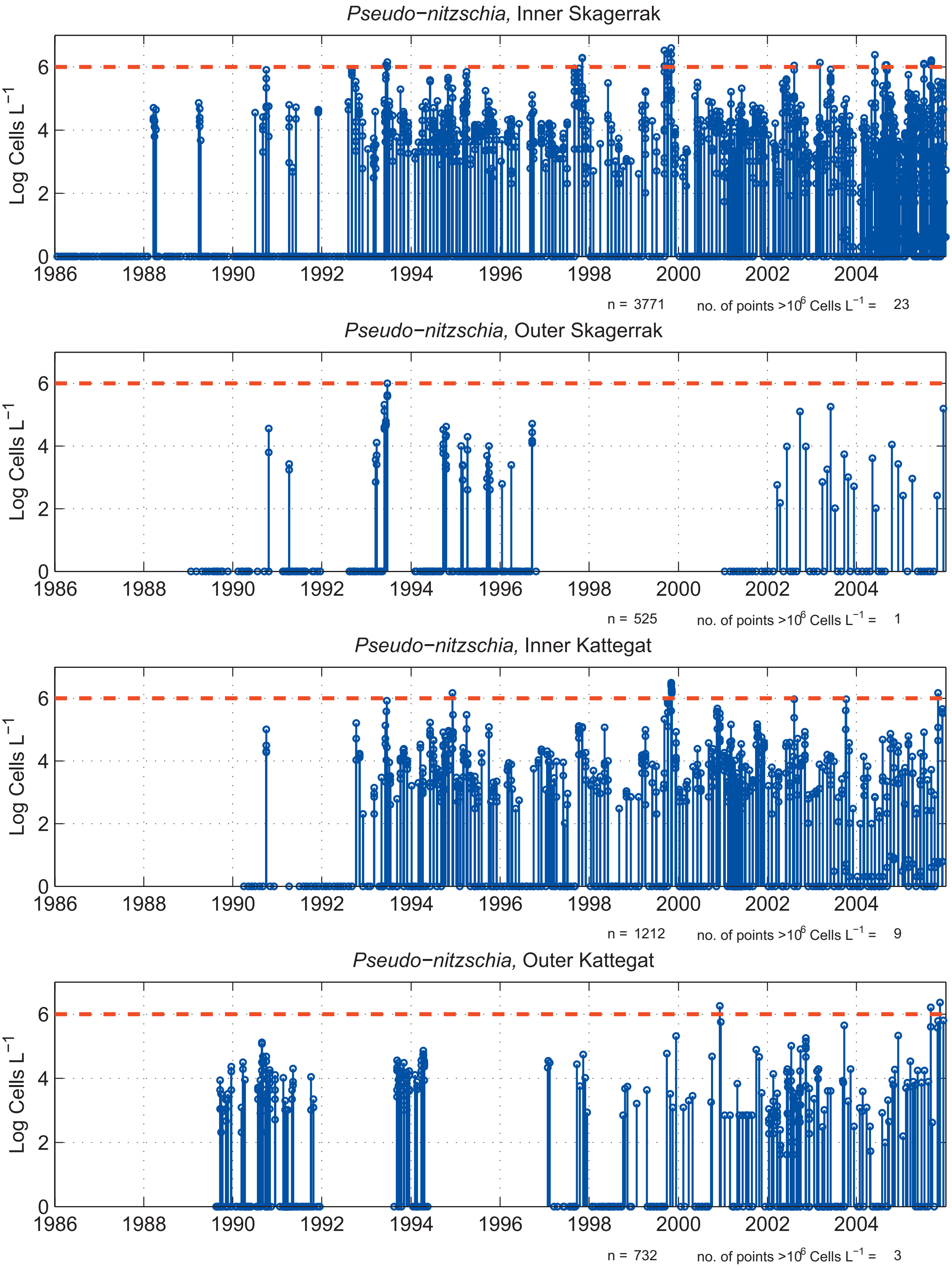


Fig. 8. Abundance of Pseudo-nitzschia spp. Several species from this diatom genus may produce amnesic shellfish toxins. It is not one of the OSPAR indicator species. The red line indicates the abundance for elevated levels according to the Swedish National Food Administration.

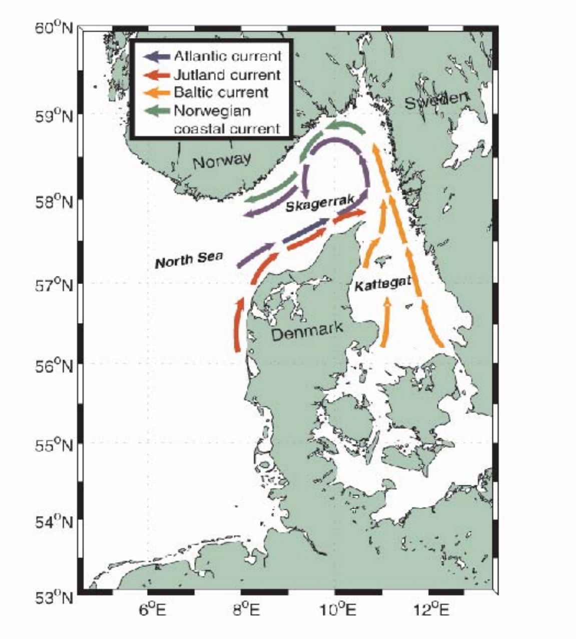
Appendix II - OSPAR Reporting Format

11 Appendix II

Reporting format on the results of the OSPAR Comprehensive Procedure

National Report from Sweden
Swedish Environmental Protection Agency &
Swedish Meteorological and Hydrological Institute
March 2007

1. Area of the Skagerrak and Kattegat



2. Description of the area

The surface area of the Kattegat and the Skagerrak is about 22 000 km^2 and 32 000 km^2, and the mean depth is about 23 m and 210 m, respectively. The Skagerrak and the Kattegat forms the inner end of the Norwegian trench, which has the characteristics of a deep (700 m) fjord connecting the Baltic Sea with the Norwegian Sea (e.g. Rodhe, 1987). The sill depth of the fjord is about 270 m.

The average outflow of low-saline water from the Baltic Sea and the Kattegat transports nutrients from the Baltic along the Swedish (the Baltic current) and the Norwegian coasts (the Norwegian Coastal current) in the Skagerrak. A deep-reaching high-saline inflow from the central and the northern North Sea circulates in a cyclonic direction and forms the bulk of the Skagerrak water. A weaker, less saline inflow from the southern North Sea transports nutrients to the surface layers of the Skagerrak along the northern Jutland off the Danish coast (the Jutland current). These currents may reach the Swedish coast and add to the northward flow below the less saline Baltic current. The inflows from the North Sea also contribute to the inflows to the northern Kattegat. About 65 % of the freshwater volume of the Skagerrak is contained in a band of about 30 km width along the western Sweden and southern Norway (Gustafsson and Stigebrandt, 1996). Shifting wind speed and direction on the Skagerrak area may modulate the general circulation pattern on short terms.

3. Assessment

Category	Assessment Parameters	Description of Results	*Score* (+ - ?)
Degree of Nutrient Enrichment (I)	Riverine inputs and direct discharges of total N and total P	Elevated inputs and no trends	+
	Winter DIN and/or DIP concentrations	Elevated levels in Kattegat	+
	Winter N/P ratio (Redfield N/P = 16)	Below assessment levels	-
Direct Effects (II)	Maximum and mean chlorophyll *a* concentration	Elevated levels in Kattegat and inshore Skagerrak	+
	Area-specific phytoplankton indicator species	Elevated levels in Kattegat and Skagerrak	+
	Macrophytes including macroalgae	Time series too short for assessment	?
Indirect Effects (III)	Oxygen deficiency	Decreasing trends in Kattegat and inshore Skagerrak and concentrations at or even below deficiency levels	+
	Changes/kills in zoobenthos and fish kills	Disturbed habitats in some fjords and bays in Kattegat and Skagerrak	+
	Organic carbon/organic matter	No new information compared with OSPAR assessment 2002	?
Other Possible Effects (IV)	Algal toxins (DSP/PSP mussel infection events)	Algal toxins occur in the area during the assessment period	+

Key to the Score

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

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

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

Reporting format on the results of the OSPAR Comprehensive Procedure (continued)

4. Overall Classification

Key to the table

NI P	Riverine inputs and direct discharges of total N and total P
DI	Winter DIN and/or DIP concentrations
NP	Increased winter N/P ratio
Ca	Maximum and mean chlorophyll *a* concentration
Ps	Area-specific phytoplankton indicator species
Mp	Macrophytes including macroalgae
O_2	Oxygen deficiency
Ck	Changes/kills in zoobenthos and fish kills
Oc	Organic carbon/organic matter
At	Algal toxins (DSP/PSP mussel infection events)

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

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

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

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

Area	Category I Degree of nutrient enrichment	Category II Direct effects	Category III and IV Indirect effects/ other possible effects	Initial classification	Appraisal of all relevant information (concerning the harmonised assessment parameters, their respective assessment levels and the supporting environmental factors)	Final classification	Assessment period
Offshore Skagerrak	NI + DI - NP -	Ca - Ps + Mp ?	O_2 - Ck - Oc ? At ?	No problem area	No extra information available. Only one phytoplankton indicator species occur above assessment levels and this species is not a good indicator of eutrophication	No problem area	2002-2005
Inshore Skagerrak	NI + DI + NP +	Ca + Ps + Mp ?	O_2 + Ck + Oc ? At +	Problem area	Additional parameters such as TP and TN shows elevated concentrations according to the WFD. Primary Production is high compared to historical data (OSPAR Assessment 2002), while clearly below treshold values set by Nixon (1995)	Problem area	2002-2005
Inshore and Offshore Kattegat	NI + DI + NP +	Ca + Ps + Mp ?	O_2 + Ck + Oc ? At +	Problem area	Additional parameters such as TP and TN shows elevated concentrations according to the WFD assessment critera. The area also influenced by inflow of nutrients from southern Baltic Sea, which is autrophicated according to HELCOM asssessments and WFD preliminary classification scheme	Problem area	2002-2005

5. Discussion

Inshore Kattegat

The input from land and atmosphere shows elevated levels without any significant trends during the 2001 to 2005 period. The levels of input were much about the same as during the last 10 years.
DIN median concentrations where generally above elevated levels and for the 90 percentile about double the elevated level during the assessment period. DIP median concentrations on the other hand was clearly above background but at or close to the elevated concentrations, while the 90 percentile was just above elevated concentrations.
Chlorophyll median concentrations were above elevated concentrations, while oxygen concentrations show deficiency. Both oxygen concentrations and saturation has a negative trend in the area. Only in Laholm Bay the benthic fauna showed bad to poor conditions (according to the WFD classifications scheme).
The monitoring and modelling data indicate that the inshore Kattegat is eutrophicated area with increased levels of nutrients coming from both local land sources but also from transboundary influx of nutrients i.e. from the Baltic Sea.
The overall classification shows Inshore Katttegat to be a problem area. The Comprehensive Procedure is transparent, reliable and verifiable enough for the judgement. However, data or information on bottom flora is to some extent missing in the Swedish national monitoring programme of Kattegat Inshore waters. Also information on phytoplankton indicator species are to some axtent missing in this area. Nevertheless, improvements are expected to take place during the ongoing implementation of the WFD.

Offshore Kattegat

The input from land and atmosphere shows elevated levels without any significant trends during the 2001 to 2005 period. The levels of input were much about the same as during the last 10 years.
The monitoring and modelling data indicate that the offshore Kattegat is influenced with increased levels of nutrients coming from both local land sources and atmospheric deposition but also to a large extent from transboundary influx of nutrients i.e. from the Baltic Sea, while deep waters are influenced by a transboundary flow from Skagerrak in the north.
DIN median concentrations where generally above elevated levels during the assessment period. DIP median concentrations on the other hand was clearly above background but at or close to the elevated concentrations, while the 90 percentile was just above elevated concentrations.
Chlorophyll median concentrations were below elevated concentrations, while oxygen concentrations show elevated deficiency and for 2002 even acute toxicity. Both oxygen concentrations and saturation has a negative trend in the area. Benthic fauna showed good to high conditions (according to the WFD classifications scheme).
The monitoring and modelling data indicate that the offshore Kattegat is eutrophicated area with increased levels of nutrients mostly coming from transboundary influx from the Baltic Sea.
The overall classification shows Offshore Katttegat to be a problem area. The Comprehensive Procedure is transparent, reliable and verifiable enough for the judgement. However, it is important to note that a recent performed inventory of offshore bank areas in Kattegat indicated that bottom flora and fauna in general was found to be in a much better condition than corresponding inshore bottom areas. There is only minor information available on the ecological status prior to the inventory made during 2004 and 2005.

Inshore Skagerrak
The input from land and atmosphere shows elevated levels without any significant trends during the 2001 to 2005 period. The levels of input were much about the same as during the last 10 years.
DIN and DIP median concentrations where generally close to background levels during the assessment period, while the DIP 90 percentile was close to elevated concentrations. Chlorophyll median concentrations were above elevated concentrations and oxygen concentrations and saturation show deficiency. The negative trend in oxygen concentration was weak and there was no trend in the oxygen saturation. Only in some fjords with limited water exchange and perennial oxygen deficiency was the benthic fauna bad or poor (according to the WFD classifications scheme). The inshore Skagerrak is also often subjected to harmful algae monitored at mussel farms. Whether these are caused by natural variability in the ecosystem or by eutrophication is by now means clearly shown.
The overall classification shows Inshore Skagerrak to be a problem area. The Comprehensive Procedure is however not fully transparent, reliable and verifiable enough for the judgement. Different Categories in the procedure point towards different directions. It is also worth mentioning that data or information on long time series of bottom flora is missing in the Swedish national monitoring programme in this area. There is also a question mark on the perennial oxygen deficits in the fjords and to what extent these are governed by limited water exchange or too large inputs of nutrients compared to the fjord capacity. The primary production is about 200 gC $m^{-2}year^{-1}$ in the Gullmar fjord, clearly below the critical primary production set by Nixon (1995) to be around 300 gC $m^{-2}year^{-1}$.

Offshore Skagerrak
The monitoring and modelling data indicate that the offshore Skagerrak is governed by atmospheric deposition and by transboundary influx of nutrients i.e. from the Kattegat and the North Sea. Especially from can high nutrients (DIN) inflows emerges from the German Bight. This inflow is intermittent and occurs only now and then.
DIN median concentrations where generally at or below background levels. Only once during the assessment period was the 90 percentile DIN concentrations above elevated concentrations. DIP median concentrations were also below background concentrations and the 90 percentile never passed elevated concentrations.
Chlorophyll median concentrations were below or close to background concentrations. Oxygen concentrations and saturation levels showed no deficiency at all during the assessment period. Nevertheless, both oxygen concentrations and saturation showed a negative trend. Benthic fauna showed good to high conditions (according to the WFD classifications scheme).
The overall classification shows Offshore Skagerrak to be a non-problem area. The Comprehensive Procedure is transparent, reliable and verifiable enough for the judgement.
In addition, it is important to note that a recent performed inventory of offshore bank areas in eastern Skagerrak indicated that bottom flora and fauna in general was found to be in a much better condition than corresponding inshore bottom areas. There is only minor information available on the ecological status prior to the inventory made during 2004 and 2005.

6. Other information

The eutrophication problem in Kattegat and inshore Skagerrak is a complicated matter with several different sources of emissions transported to the area. In an earlier report, by Eilola & Sahlberg (2006), they showed the eutrophication status to be dependent on transboundary fluxes from the Baltic Sea, the German Bight and emissions and sources from Denmark, Norway and Sweden. By reducing nutrient inputs from Sweden to Kattegat, according to the goals set by OSPAR, the Swedish inshore areas of Kattegat can obtain a water quality status of a no problem area. Similarly, the offshore area of Kattegat can only reach a healthy status if all riparian countries reduce their inputs, according to OSPAR goals, and if the interconnected Baltic Sea and the German Bight also achieve a healthy status.
Hence, the work for a healthy marine environment is indeed an international affair even at regional scales.

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