Assessments of the eutrophication status in the German Wadden Sea, based on background concentrations of nutrients and chlorophyll

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Every assessment is based on confident and precise monitoring data which are compared with background data. For deduction of historical background data causal relationships between recent data of eutrophication parameters (nutrients and chlorophyll) and pristine total nitrogen (TN) and total phosphorus (TP) were used. Mixing diagrams allowed the calculation of historical gradients. Modern data have been taken for the period 1997 – 2001. Since the natural variability of these data is high in the German Wadden Sea, mostly caused by hydrodynamic forces, monitoring data of nutrients and chlorophyll were related to mean salinities. Variability has been reduced by elimination of salinity induced fluctuations. By this, the differences between thresholds and recent data, including standard deviations, became more significant. Proposed thresholds, based on natural background concentrations, are used for the classification of Types and Water-bodies in the German Wadden Sea according to the Water Framework Directive. The results for nutrients and chlorophyll are with some exceptions for the North- and (TP good) East Frisian Wadden Sea (phosphate moderate) mostly between poor and bad. Selected long time series for the North Frisian Wadden Sea did not show significant changes. The confidence of the assessments is influenced (i) by the variability, (ii) resolution of sampling in space and time, and (iii) differences between monitoring data and thresholds. Representativity of time series is discussed e.g. for slopes of annual mixing diagrams. Suggestions are given for the improvement of an effective monitoring, considering the assessment confidence. Improvement of assessment and monitoring is an iterative process, which for the monitoring should be supported by specific research, to evaluate the representativity of sampling stations and sampling times and to improve the understanding of causal relationships.

Key words: assessment, natural background conditions, chlorophyll, nutrients, Wadden Sea, Water Framework Directive

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Introduction

Eutrophication processes are still a main issue of coastal pollution. Unbalanced and increased nutrient discharges support the development of harmful and toxic phytoplankton, the accumulation of biomass and the formation of oxygen deficiency. By this the structure and function of coastal ecosystems will be changed significantly (Cloern 2001).

The causative relationships between eutrophication processes in coastal and transitional waters start with elevated nutrient discharges, increasing nutrient concentrations, improving primary production, increasing biomass (Nixon 1995, Cloern 2001, EUC 2005), and reducing the light climate and the depth distribution of macrophytes (Nielsen et al. 2002 a). High biomasses may be accumulated in enclosed bottom layers of stratified areas, causing oxygen depletion during degradation (Dethlefsen & von Westernhagen 1982, 1983, Brockmann & Eberlein 1986).

Especially the Wadden Sea is accumulating organic matter, receiving directly from the passing rivers or by the estuarine type circulation and asymmetric tidal currents importing material from the sea as well. For these reasons the Wadden Sea is *per se* dominated by heterotrophic processes (Postma 1984, Tillmann et al. 2000, van Beusekom et al. 2001).

The increased phytoplankton production may be connected with the formation of harmful/toxic algae at silicate limitation, affecting the whole ecosystem significantly (Zevenboom 1994). A moderate increased biomass production will also cause an increase of macrozoobenthos until oxygen depletion will occur (Pearson & Rosenberg 1978), often coupled with kills of animals and complete changes of the ecosystem (Rachor 1980, 1990, Dyer et al. 1983).

To some degree these relationships can be quantified allowing the calculation of background concentrations from historical TN (total nitrogen.) or TP (total phosphorus): Significant correlations were found between TN and dissolved inorganic nitrogen (DIN), TP and phosphate, TN and chlorophyll (Nielsen et al. 2002 b, Tett et al. 2003, Udy et al. 2005, Brockmann & Topcu 2003), TN and depth minima of macrophytes (Nielsen et al. 2002 a), secchi depth (Nielsen et al. 2002 b, Tett et al. 2003) and chlorophyll and maximum macrozoobenthos biomass (Beukema et al. 2002 , Hargrave & Peer 1973). For this reason the presented assessment, limited to nutrients and chlorophyll, could be extended to other eutrophication parameters, if non linear relationships and interfering processes can be differentiated (s.a. van Beusekom et al. 2001).

Most assessments are based on the comparison between modern data and natural background concentrations. However, natural background data are difficult to achieve in industrialised areas, but especially for nutrients background data have been collected (Meybeck 1982, Laane 1992, Howarth et al. 1996, van Raaphorst et al. 2000, Topcu et al. 2006 in prep.).

For the deduction of historical background data causal relationships between recent eutrophication parameters (nutrients and chlorophyll) and pristine total nitrogen (TN) and total phosphorus (TP) can be used. TN and TP are basic parameters because they include all phases of the nutrient elements N and P, and TN and TP are often given as references for rivers, so that direct links between freshwater and marine areas are possible. Additionally, these values include all primary and secondary effects of eutrophication during the growing season. Therefore, they are seasonally more robust than the inorganic nutrients alone, which often become depleted during the growing season. Only for trend analyses in temperate latitudes inorganic nutrients during winter will be compared for longer time periods, reflecting maximum river discharges during seasonally low biological activity.

Mixing diagrams (nutrients plotted against salinity) allow the calculation of pristine gradients, assuming the same salinity distribution during historical times. These gradients can be compared with recent data, allowing a quantitative, regionally differentiated assessment from the differences.

Recent data have been compiled from 1997 – 2001 only, in order to assess a 5-years period as recommended by OSPAR. No data from research projects have been used, only monitoring data, allowing therefore also an evaluation of the representativity of present monitoring.

Any assessment is based on confident and precise monitoring data which are compared with background data. During the assessment, monitoring aspects like the distances between sampling stations will be evaluated briefly.

For assessments of eutrophication processes, both OSPAR and the Water Framework Directive (WFD) have selected similar parameters. However, significant differences between OSPAR and WFD are the consideration of nutrients which are for OSPAR an important causative factor classified equally to the biological components which are only supporting elements for the WFD during assessing biological elements (ECOSTAT 2004). However, nutrients are the first causative factors within the chain of eutrophication effects. For this reason the nutrients are in the WFD classified in five classes in order to achieve a differentiated classification for all parameters. Another reason is that most of the available eutrophication data are nutrients. Therefore, it is still discussed to give the nutrient conditions for WFD assessments similar weights as the biological elements (COAST 2002). Other differences are the small areas assessed by the WFD in comparison to the OSPAR areas. The differences between the final classes (five for the WFD; two finally for OSPAR), are already under discussion and proposals for an adaptation have been published (EUC 2005). A proposal for the quantitative assessment of nutrients and chlorophyll will be presented here.

Natural variability of modern data is high in the German Wadden Sea, mostly caused by hydrodynamic forces. Therefore, monitoring data of nutrients and chlorophyll were related to mean salinities. Time series of nutrients are normalised for changing salinities by calculation of slopes of annual mixing diagrams. By that, confidence intervals of recent and historical status were reduced and differences became more significant.

The confidence of the assessments is dependent on the (i) differences from background conditions, (ii) steepness of gradients, (iii) residence times, (iv) differences to thresholds, and (v) sampling distances and frequencies. Already simple data inventories can be used for an evaluation of sampling representativity in space and time.

For the final classification according to the five classes of the WFD of nutrients and chlorophyll, compiled scores allow a general impression of the status of the German Wadden Sea concerning key parameters of eutrophication processes. It is suggested to consider insufficient data by decreasing scores.

Material & Methods

Recent data have mainly been compiled by the MUDAB (Marine Umwelt Datenbank) of the DOD (Deutsches Ozeanographisches Datenzentrum, Hamburg). However, many data have also been received from the data originators directly. Data sources are the ARGE Elbe (Arbeitsgemeinschaft Elbe, Hamburg), BFG (Bundesanstalt für Gewässerkunde, Koblenz), BSH (Bundesamt für Seeschifffahrt und Hydrographie, Hamburg), LANU with AlgFes program (Landesamt für Natur und Umwelt, Flintbek/Kiel), NLÖ (Niedersächsisches Landesamt für Ökologie, Norderney) and WGEHH (Wassergütestelle Elbe - Hamburg, Hamburg), IMRN (Institute for Marine Research, Bergen), IFOE (Institute für Fischereiökologie, BFA, Hamburg). For the adjacent areas data have also been involved from national data centres in Denmark and the Netherlands. Generally the quality of data has not been checked.

Background concentrations of nutrients in the German Bight area have been compiled from the literature (Topcu et al. unpublished data). For the rivers, entering or passing the German Wadden Sea natural background data have been estimated by model calculations (Behrendt et al. 2003) (Tab. 1). From this only those of TN (total nitrogen) and TP (total phosphorus) are used without seasonal differentiation. Significant correlations of recent data (1980 – 2001) between recent TN and DIN (dissolved inorganic nitrogen), TP and phosphate were used for the calculation of pristine winter data (November – February) for DIN and phosphate. Significant correlations between recent TN and chlorophyll (1980 – 2001) during the growing season (March – October) were used to estimate historical mean chlorophyll gradients. For this relationship the estuaries were excluded due to the light limitation by high suspended matter especially in the maximum turbidity zones.

The relationship between mean and maximum chlorophyll concentrations of recent data were taken for the calculation of historical maximum chlorophyll data. Since the background concentrations are different for each river, the areas of their mean influences (extension of river plumes) have been estimated roughly from the mean salinity gradients, considering the different amounts of freshwater discharges as well (Fig. 1). The inner German Bight has been divided into squares of about 140 km^2. This allows the calculation of local means and more homogenous analyses and interpretation of data. The mean localities from where the data are originating are indicated by dots within the squares.

The data have been normalized for salinity, using mixing diagrams. For the estuaries and inner coastal waters, including the Wadden Sea, linear regression functions have been used, assuming that mixing is dominating. For the outer coastal waters exponential regression functions have been applied, assuming increasing interferences of different sources towards the marine area. The point of intersection of the fits is at a salinity of about 31.5 (Fig. 2). This means that in the maps beyond this point the exponential relationships are used. For the pristine data similar relations were established, allowing the calculation of historical data for each salinity. Assuming that the mean salinity gradients were at pristine conditions similar as today, historical gradients were calculated, based on mean salinity gradients during all seasons for TN and TP, during winter for DIN and DIP (phosphate), and during the growing season for chlorophyll.

Since the differences between the different thresholds and means of recent data including standard deviations (SD) often are not significant due to overlapping, the variability coupled with fluctuating salinity were excluded. For this reason, the correlations of the regional specific mixing diagrams were used to calculate for every salinity a corresponding value of nutrients or chlorophyll from the linear regressions (mostly) or the exponential regression for the open waters with a salinity > 31.5.

Table 1. Natural background concentrations for nutrients in the German Bight area (all seasons or winter).

Location/Parameter	salinity	TN µM	DIN µM winter	Nitrate *ammonium* µM winter	TP µM	Phosphate µM winter
Eider*	0	29			1.40	
Schleswig-Holstein*	0	37			1.30	
Elbe*	0	39			1.20	
Weser*	0	25			1.00	
Lower Saxonia*	0	25			0.90	
Ems*	0	24			1.50	
Rhein, Lobith*	0	20			1.00	
Wadden Sea	27.5	13			0.77	0.6
Inner Coastal water[1]	30.5	11.5			0.77	
Outer Coastal water (winter) [2]	32	15	15	16 *4*	0.8	0.7
Open Sea [3]	~34.5	10	9	8.5 *0.6*	0.65	0.6

* River data from Behrendt et al. 2003 & pers. comm.

[1] Van Raaphorst et al. 2000, [2] Brockmann & Topcu. 2003, [3] Zevenboom 1994

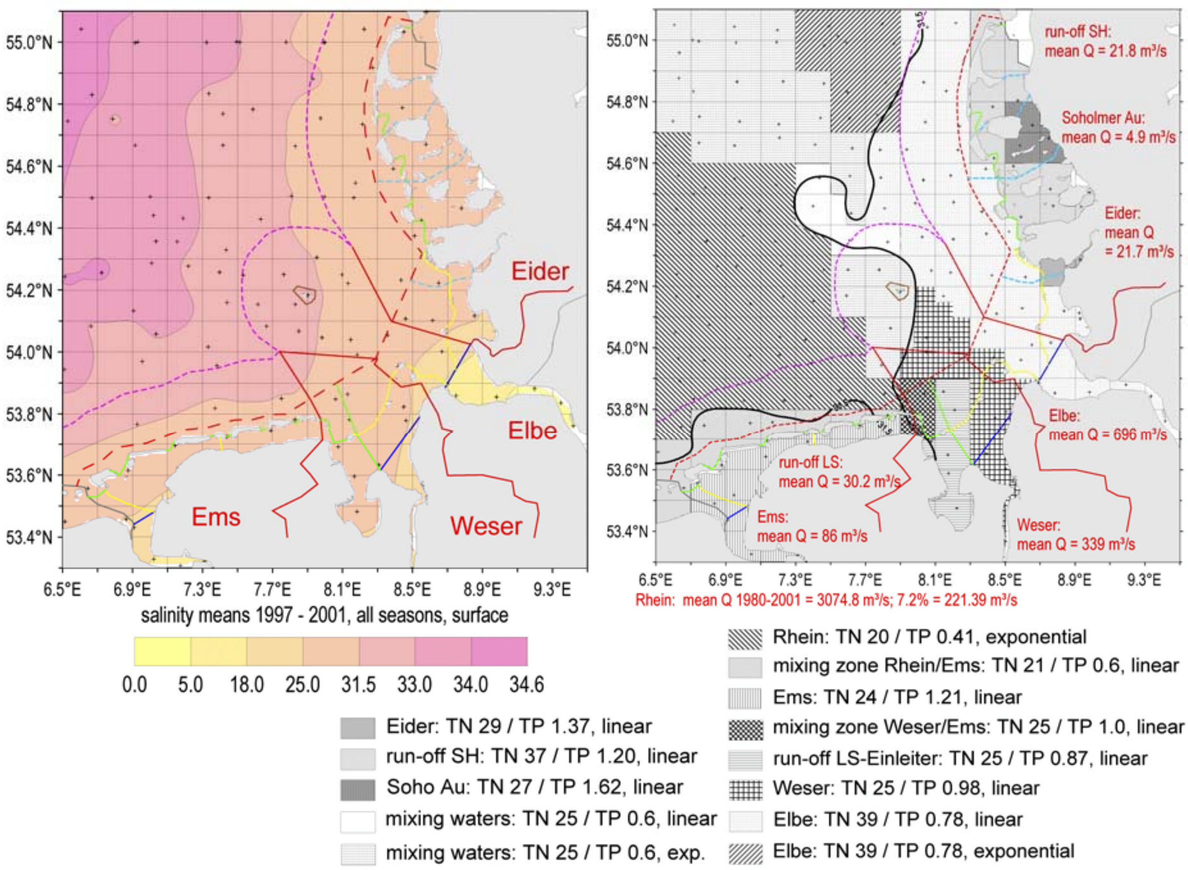
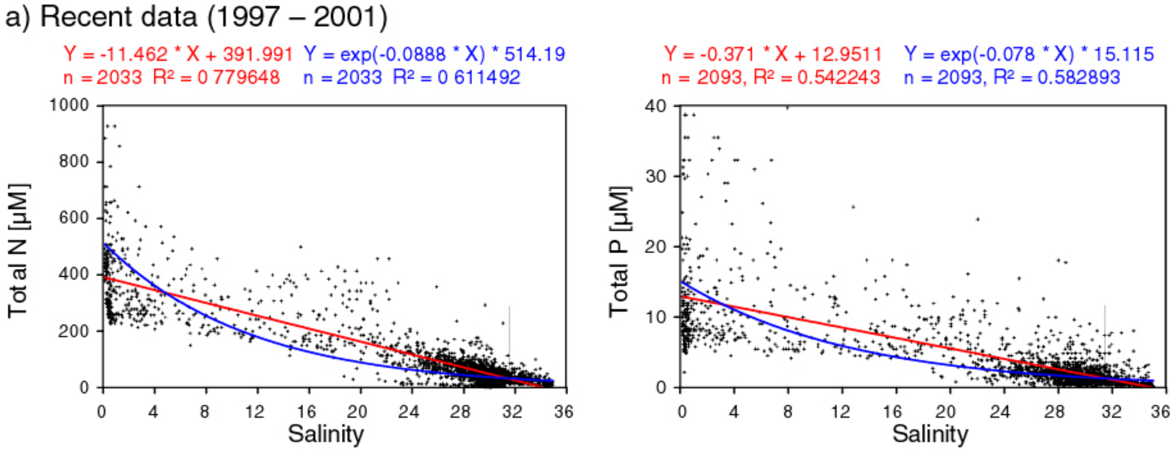


Figure 1. Mean salinity and areas affected by different river plumes.



Data: Alg Fes 1997-2001, ARGE Elbe: 1997-2000, BFG: 1997-1998, BSH: 1997-2001, LANU: 1997-2001, NLÖ: 1997-2001, WGEHH: 1997-1998, 2001

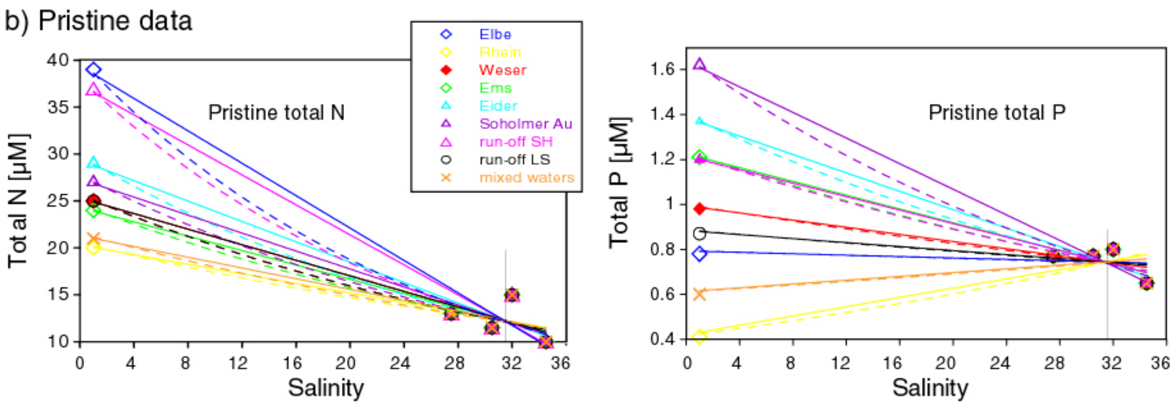


Figure 2. Correlations of TN and TP with salinity, recent (1997-2001) and pristine data.

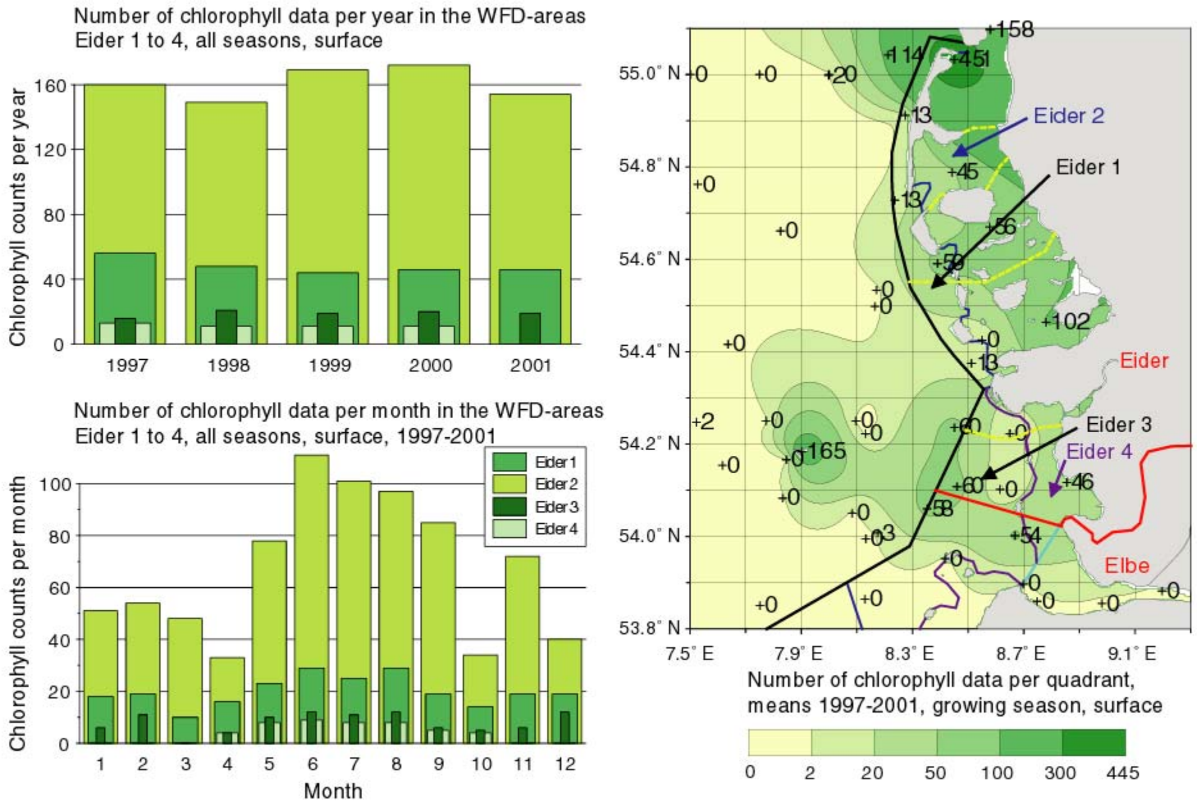


Figure 3. Inventory of chlorophyll data during1997 – 2001.

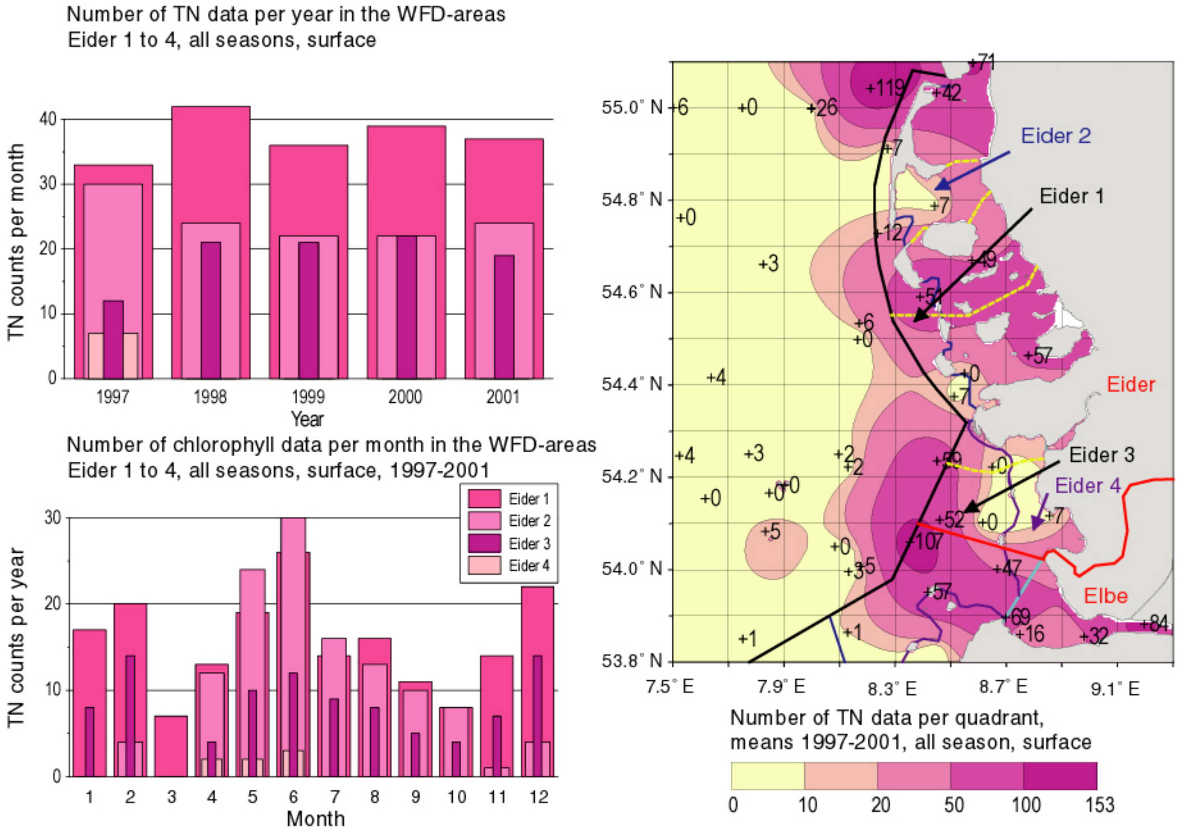


Figure 4. Inventory of TN data during1997 – 2001.

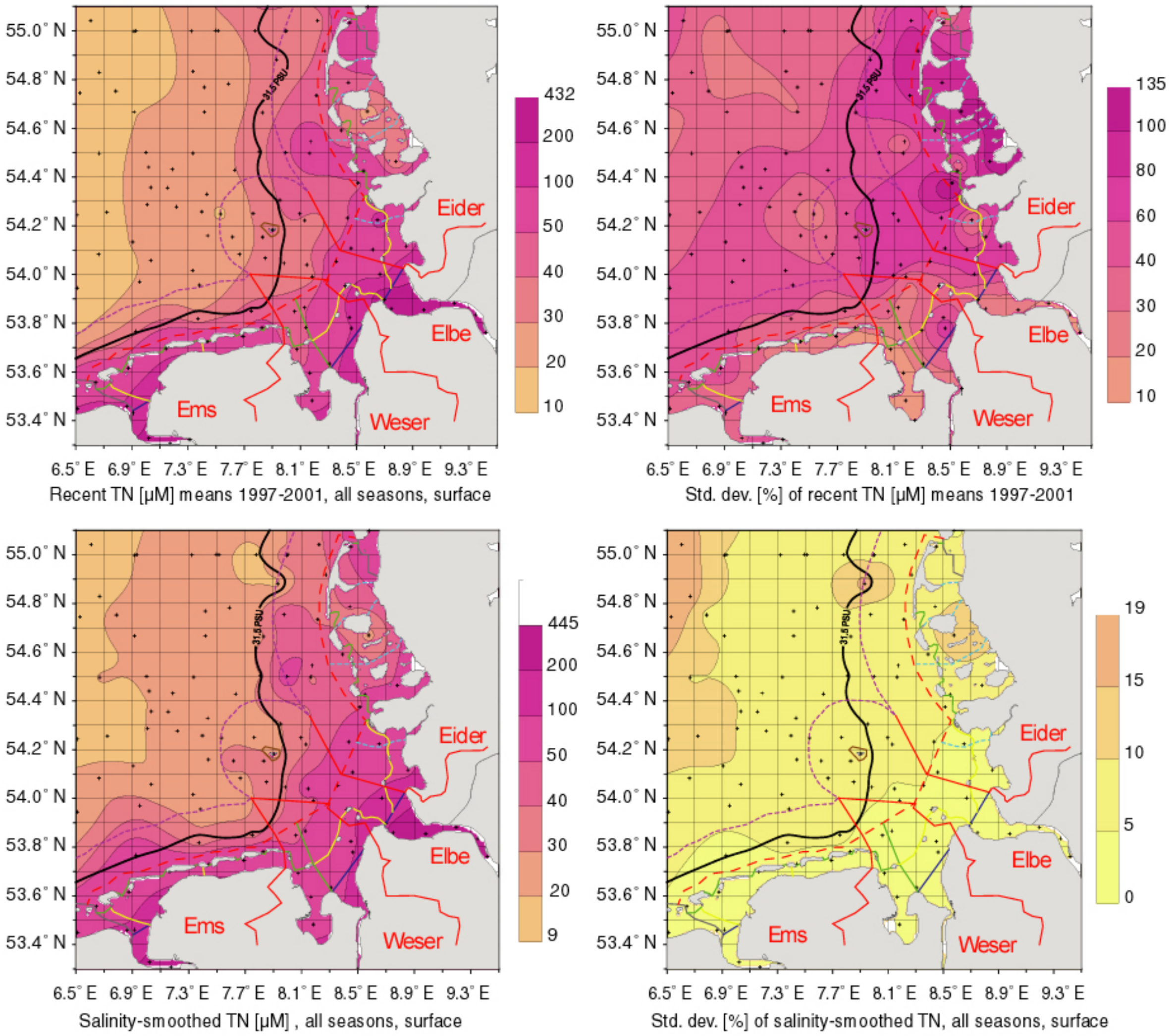


Figure 5. Mean gradients of TN during1997 – 2001 (all seasons), and salinity-smoothed data with standard deviations.

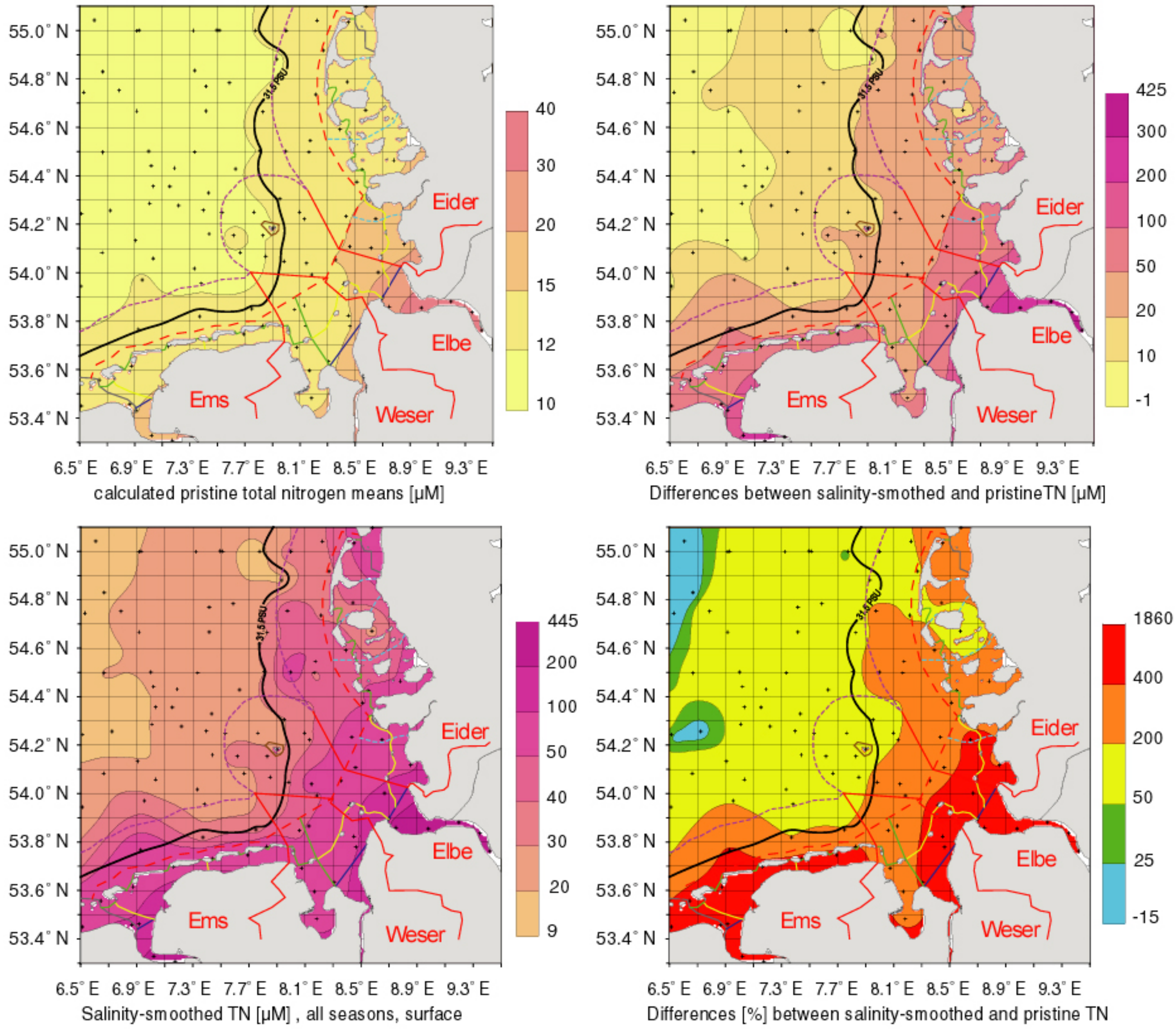


Figure 6. Natural background concentrations, salinity-smoothed recent data and differences for TN.

These data are used as "salinity smoothed" data for the assessment. The correlated data were combined stepwise for each full salinity unit (1 PSU-step, PSU = practical salinity unit), for which means and SD were calculated. These "salinity smoothed" data were inserted into the boxes according to their original positions.

DIN and phosphate (DIP) were calculated for the winter period (November – February) only, representing maximum concentrations. Chlorophyll was mainly analysed for the growing season (March – October).

Differences between background concentrations and recent data were calculated as absolute concentrations and additionally as % of deviations from background values. These calculations allow a comparison of deviations from background data for different parameters and can be used for a classification as well.

Maps and time series have been plotted, using SURFER 7 (Golden Software), x/y diagrams with GRAPHER (Golden Software).

Results

Processing of data

As examples of the available data for the period 1997 – 2001 inventories for TN and chlorophyll are presented for the North Frisian Wadden Sea (Fig. 3 and 4). The data originate mostly from locations of research institutions (Helgoland and List/Sylt) whereas some areas, indicated as individual Waterbodies, are only scarcely sampled. Most data are originating from the Type "Eider 2" which includes the frequently measured station at List. The number of available data was similar during the different years, as well as for the main part of the growing season (May – September).

For TN, as an example for nutrients, the inventory shows in the coastal water of Schleswig-Holstein a similar distribution of data density as for chlorophyll (Fig. 4). However, the number of data was reduced and the monthly distribution was more fluctuating. Along the Wadden Sea of Lower Saxonia mostly only 10 data for each square were available for the period 1997 – 2001.

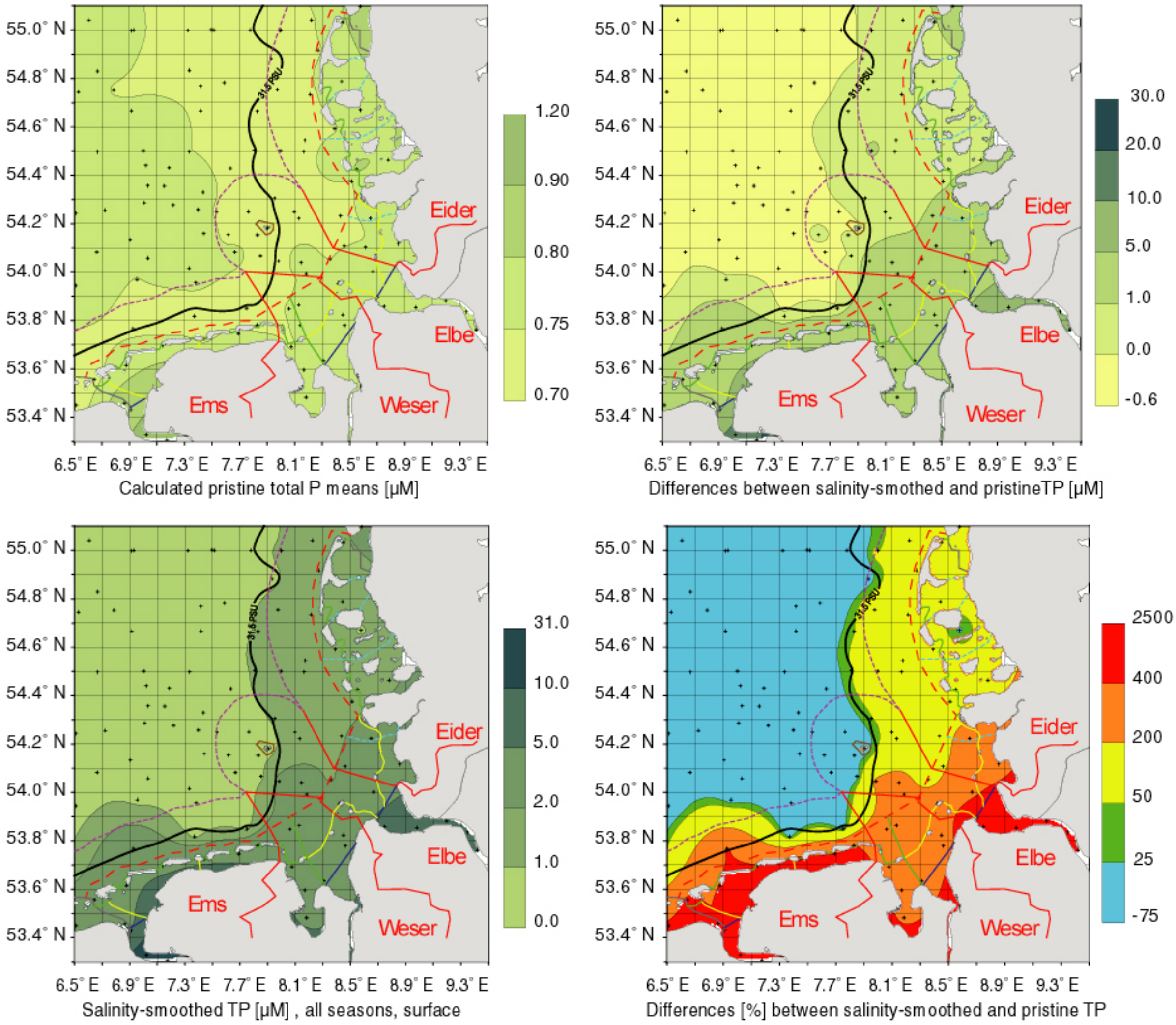


Figure 7. Natural background concentrations, salinity-smoothed recent data and differences for TP.

In order to exclude the hydrodynamic variability, coupled with changing salinity, the data within the different boxes of about 140 km² had been transformed in relation to the mean salinity. For comparison as an example TN is shown (Fig. 5). The gradients of TN remained nearly unchanged after transformation with 20 – 30 µM at salinities > 31.5 and increasing concentrations, partly of more than 60 µM in the Wadden Sea. However, the standard deviations were reduced from 40 – 100% to mostly less than 10%.

Comparison of pristine and recent data

The recent (1997 – 2001), salinity smoothed data have been compared with the background data estimated for the same salinity. The calculated pristine TN concentrations were mainly around 13 µM in the Wadden Sea and increased within the estuaries to more than 20 µM (Fig. 6). The salinity smoothed recent (1997-2001) data, reached 30 – 100 µM in the tidal flats and more than 300 µM in the estuaries. The differences were mostly between 20 - 70 µM. In relation to the background concentrations between 100 and 400% were surpassed. Along the coast of Lower Saxonia and around the Elbe mouth recent TN concentrations were more than 400% above background data.

Pristine TP were in the Wadden Sea between 0.75 - 0.8 µM (Fig. 7). Recent TP concentrations surpassed 1 – 5 µM, resulting in differences of 0.1 – 4 µM, or less than 50 to more than 400% of background concentrations.

In the Wadden Sea concentrations of DIN were calculated as 9 – 11 µM (Fig. 8). Recent concentrations in this area were about 40 µM and up to 100 µM near the Elbe mouth. The differences were correspondingly 30 – 90 µM or 300 – 500% of background values.

Historical phosphate data were in the Wadden Sea during winter calculated to around 0.5 µM (Fig. 9). Recent mean data surpassed 1.6 µM along the coast of Schleswig-Holstein and 1.1 µM along the coast of Lower Saxonia between 1997 – 2001. The corresponding differences were 1.1 or 0.6 µM, or between 100 and more than 200% of pristine data.

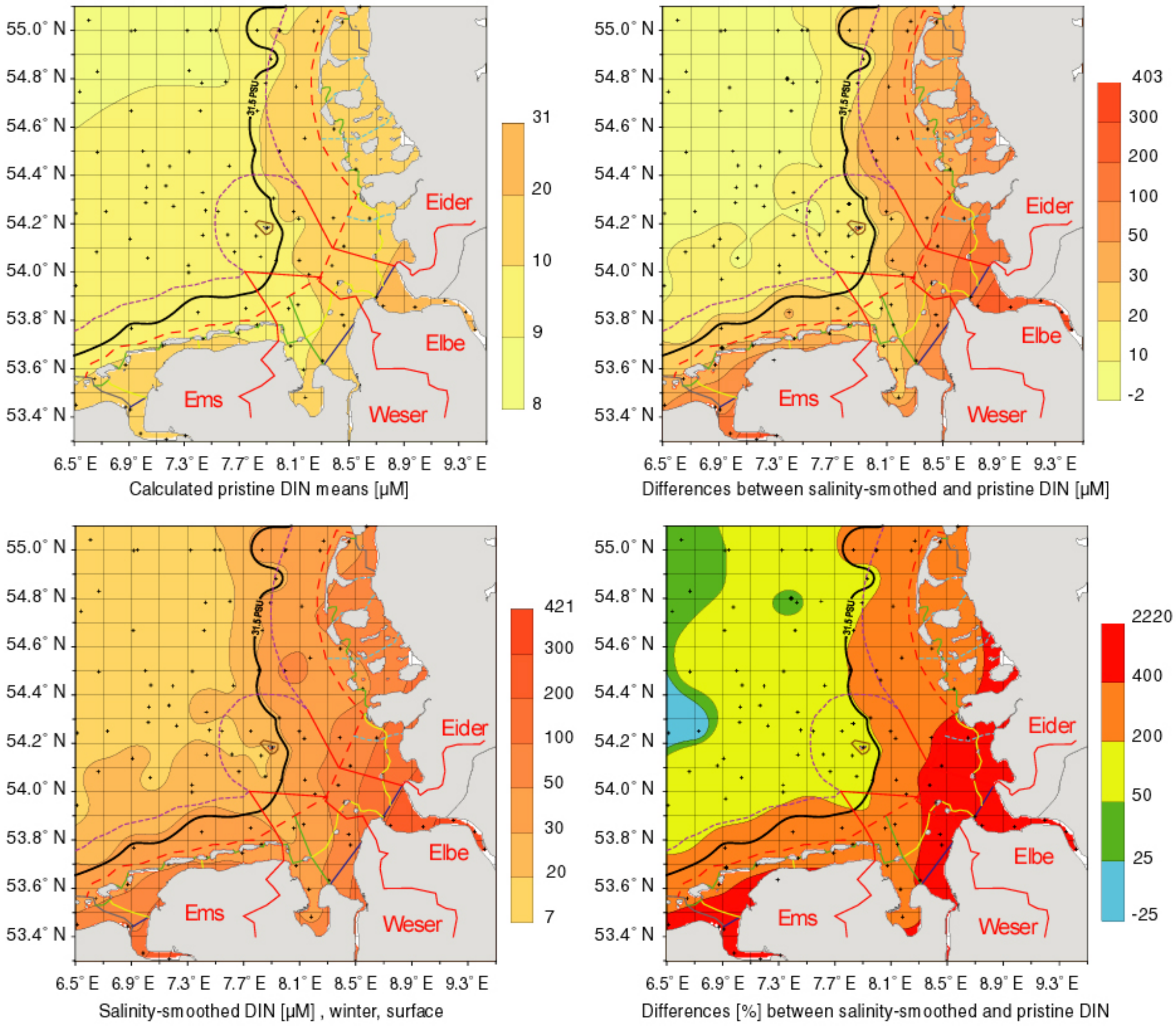


Figure 8. Natural background concentrations, salinity-smoothed recent data and differences for DIN.

The calculated natural mean background concentrations of chlorophyll were in the Wadden Sea during the growing season between 2 - 2.5 µg/L (Fig. 10). Modern mean chlorophyll concentrations were mostly in the range between 7 and 10 µg/L. However, the standard deviation of the original, not "salinity smoothed data were mostly above 50%, often in the range of 80%. For the salinity smoothed data SD was < 10% mostly. The differences between recent and pristine mean chlorophyll were in the tidal flats in the range of 4 – 7 µg/L or between 100 and 300% of background data. Near the Elbe mouth 400% were surpassed.

In the Wadden Sea as background concentrations of maximum chlorophyll about 11 µg/L were estimated. For recent data mostly 20 – 80 µg/L were detected (Fig. 11). The differences were correspondingly 12 – 50 µg/L or between 100 and 400%. Exceptionally low differences were detected in front of the Jade and Ems. There the differences were below 50%, or 5 µg/L, caused by recent maxima below 15 µg/L.

Assessment consistency

As an example for the consistency of data during a longer time period, chlorophyll means and maxima measured in the North Frisian Wadden Sea (Type Eider 1 & 2) are compared with the number of measurements/month/year (Fig. 12). For this area a consistent time series is available between 1987 and 2001.

For 1987 - 2001 the most frequent sampling was performed between May and September. Objective of the AlgFes-programme of LANU was to detect nuisance or toxic phytoplankton species. However, during March already chlorophyll increased and maxima of more than 90 µg/L were detected. The minima of means during winter dropped to less than 3 µg/L, but maxima remained mostly above 5 µg/L.

Time series of TN and TP for all seasons and mean chlorophyll concentrations during the growing season were normalised to changing salinities by calculation of slopes of annual mixing diagrams for the Types "Eider 1 and 2" (Fig. 13). For some years there were no significant correlations, due to

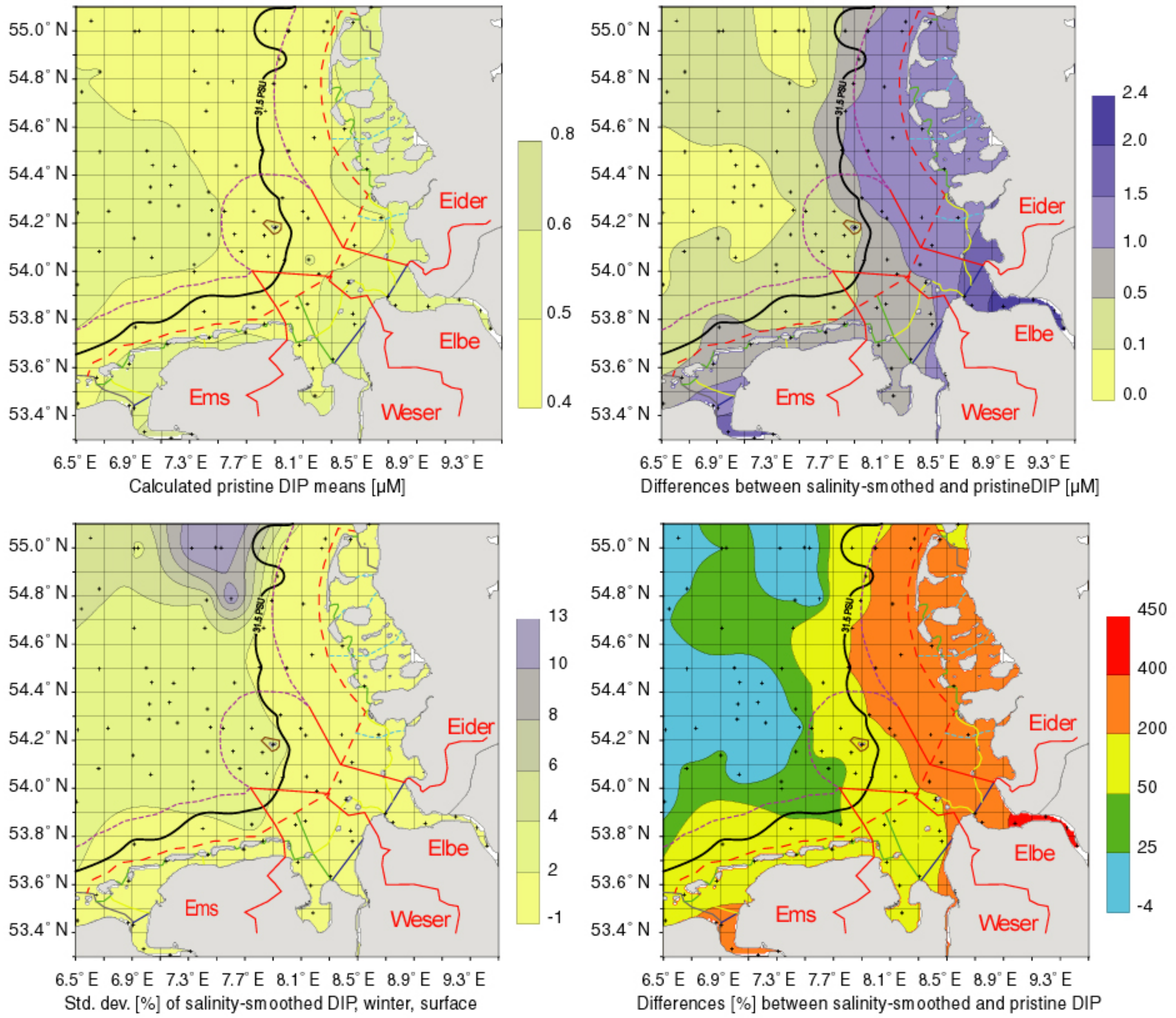


Figure 9. Natural background concentrations, salinity-smoothed recent data and differences for DIP.

the lack of data mostly. Non significant or inverted mixing diagrams have been excluded. The slopes for TN were in the range of -10 to -20 mostly, those of TP around -0.4 and mean chlorophyll showed a high variability around -3. All slopes remained above those of natural background data, deduced from historical mixing diagrams (Fig. 2). There are no significant trends, neither for chlorophyll nor for the nutrients.

Comparing of scoring according to the WFD and COMPP

To enable a comparison between the scoring by WFD and COMPP (Comprehensive Procedure) by OSPAR (EUC 2005) a classification schema was proposed for the WFD, including an adaptation between the present three classes in OSPAR and the five classes in the WFD (Fig. 14). The classes high and good correspond to the final Non Problem Area (NPA) of OSPAR and the classes moderate, poor and bad to the final OSPAR Problem Area (PA). Transitionally a Potential Problem Area (PPA) is used by OSPAR for areas where elevated nutrient concentrations but no effects are observed or where the assessment remains unclear.

The threshold for good/moderate was laid at a level corresponding to the "elevated" concentrations as defined by OSPAR as 50% above natural background concentrations (EUC 2005). The range below 50% above natural background conditions was divided at 25% into high and good, the range above 50% was divided at 200% and 400% into moderate, poor and bad.

The rough differentiation of the classes moderate – bad was proposed at 200 and 400% above natural background data according to the ranges of recent data to achieve similar numbers of data for each of the classes. The colours selected for Fig. 6-11 have been chosen in a way that they illustrate the differences (%) between recent and pristine data.

The differences have been compiled as a first classification, using the colours, proposed by the WFD (Fig. 15). The different scores for nutrients (TN & DIN, TP & DIP) and chlorophyll (means & maxima) have been compiled for N, P and chlorophyll (Fig. 15). The Types are indicated by numbers for the catchment areas. In the coastal waters, nitrogen concentrations were classified as poor, phosphorus

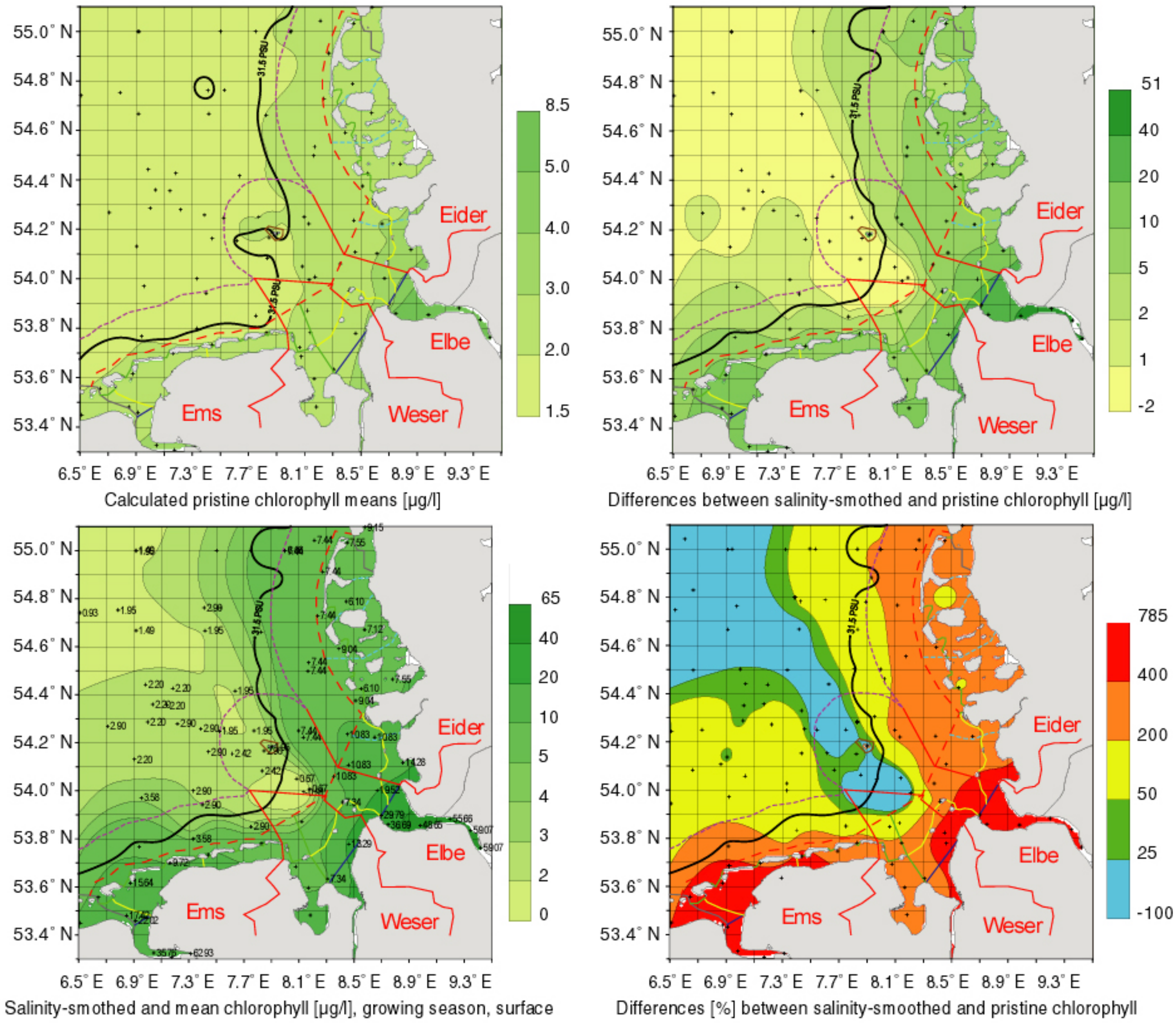


Figure 10. Natural background concentrations, salinity-smoothed recent data and differences for mean chlorophyll.

as moderate, and chlorophyll as good. For the Wadden Sea the nitrogen status was mostly poor, near and within the estuaries even bad. The phosphorus status was mostly classified as poor, of which phosphate was classified as moderate along the East Frisian Wadden Sea. In this area mean chlorophyll was scored as moderate and maximum chlorophyll often as good or high. Lack of data is indicated by white columns.

A 3D-plot for the North Frisian coast shows from the shore towards offshore (north – west) the deviation of the mean salinity-smoothed concentrations of TN from the natural background concentrations and the different thresholds (Fig. 16). The mean concentrations and the residual standard deviations have been plotted as three narrow layers. The variability of background concentrations and thresholds, which is mostly below 10%, has been neglected.

The TN concentrations are mainly between the thresholds moderate/poor and poor/bad. This means that most of the area was classified as poor (Fig. 6). South of the peninsula Eiderstedt TN was surpassing 400% of background concentrations, classifying the area as bad. Around the island of Föhr differences between recent and natural background concentrations were below 200% of background data. This area was classified as moderate. By this 3D-plot the differences between monitored recent data and threshold become more visible which is important for the estimation of classification precision.

Discussion

Natural background conditions

Natural background conditions are needed as references for the assessments in the WFD as well as the Comprehensive Procedure by OSPAR. Background concentrations for nutrients and chlorophyll have been deduced from historical and modelled TN and TP data for the German Wadden Sea (Brockmann & Topcu 2003). Causal relationships, reflected by significant correlations between recent data sets in different areas (Nielsen et al. 2002 b, Tett et al. 2003, Udy et al. 2005) are assumed that they have been

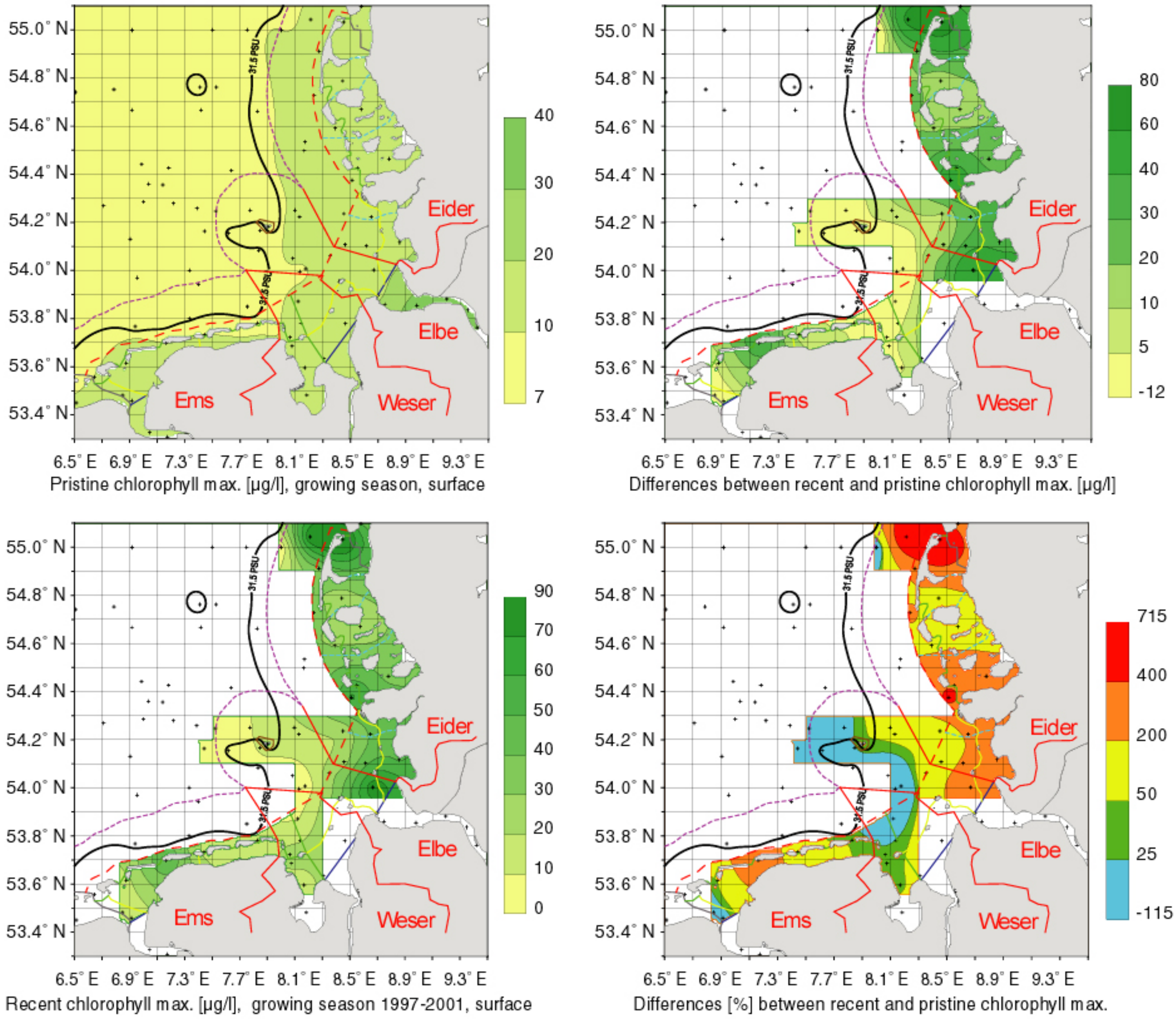


Figure 11. Natural background concentrations, salinity-smoothed recent data and differences for maximum chlorophyll.

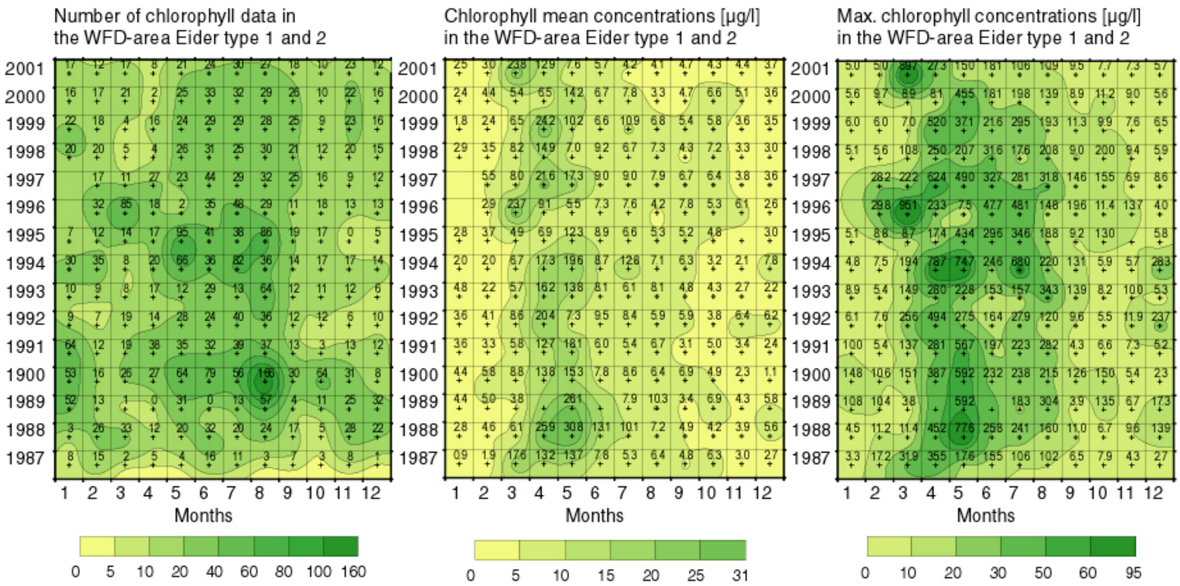


Figure 12. Time series of chlorophyll (1987- 2001) for Eider-Types 1 and 2.

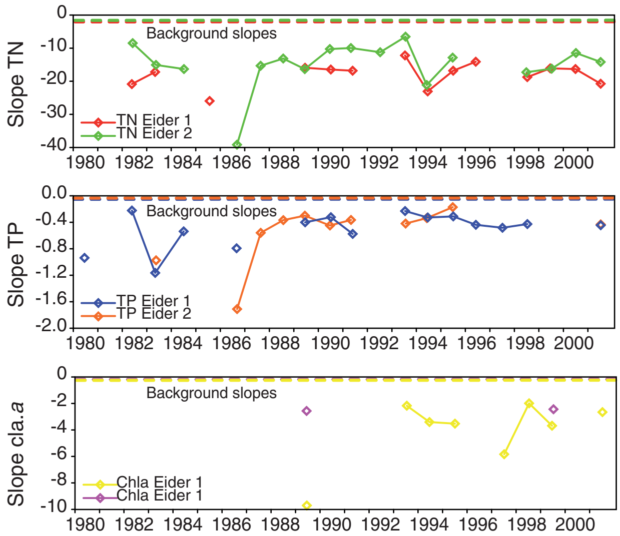


Figure 13. Slopes of mixing diagrams of mean chlorophyll, TN and TP for Eider-Types 1 and 2.

		Ecological Quality Objective Eutro				
OSPAR COMPP	Initial assessment	Non-problem area	Potential problem area		Problem area	
	Further assessment	Non-problem area		Problem area		
WFD	Class	High	Good	Moderate	Poor	Bad
	Numeral for evaluation	1	2	3	4	5
	WFD-Value	>0.8	0.7-0.8	0.5-0.7	0.25-0.5	<0.25
Proposal	% deviation from background	<25	25-50	50-200	200-400	>400

Figure 14. Proposed classification scheme.

valid also during historical conditions. For this reason they were used for the deduction of background concentrations also for parameters for which no or only few estimates of historical conditions have been published. For the ratios between TN and DIN it must be assumed that the historical contribution of DIN to TN was much lower because mainly dissolved organic nitrogen is discharged by rivers in remote areas (Hedin et al. 1995) opposite to the dominance of DIN for high recent nitrogen discharges (Howarth et al. 1996) For the Elbe the contribution to TN is 65% for nitrate and 80% for DIN (Pätsch & Lenhart 2004). However, at least rough estimates can be performed until better historical data are available.

It is very difficult to collect pristine data for anthropogenic modified areas like the Wadden Sea, located within the eutrophicated coastal water. Van Raaphorst et al (2000) calculated natural background values from early seasonal measurements during the 1930s. However, it must be assumed that at that time population density in the catchment areas was so high, that nutrient discharges were already anthropogenically affected (Howarth et al. 1996). For this reason the compiled natural background concentrations of nutrients have been compared with several data from independent estimates in remote areas of temperate latitudes (Brockmann & Topcu 2003) for which mostly lower concentrations have been reported. From this it can be assumed that the chosen values are at least not too high. Additionally, the modelled background data for German rivers (Behrendt et al. 2003) are consistent with area specific freshwater inputs. Therefore it can be assumed that the proposed values are reasonable.

The natural background concentrations in the Wadden Sea are involved within the mixing processes between rivers and the open sea. Estimates by van Raaphorst et al. (2000) for the Wadden Sea and the inner coastal water at the Dutch coast were transferred to the German Bight (Tab. 1, Fig. 2) allowing to establish nearly consistent gradients. Only the data for the outer coastal water, combined from different references are to a small degree too high within the mixing lines and therefore inconsistent. However, these are winter values only, reflecting a minimum biological activity.

Since TN (and TP) include all nitrogen (phosphorus) components within the water column it can be used for assessments of all seasons as a first estimate. A seasonal differentiation of the assessment e.g. of inorganic nutrients during the growing season requires much more data due to the fast turnover which are mostly not available. For inorganic nutrients it is therefore difficult to establish direct quantitative relationships between different causal connections of eutrophication processes, but they are used in ecosystem models and for indications of specific relations (van Beusekom et al. 2001). In shallow areas like the Wadden Sea the sediment plays an important role as a seasonal sink of nutrients where up to 50% of deposited organic matter may be remineralised (van Beusekom et al. 1999, Heip et al. 1995). These interactions are neglected here due to the lack of historical data.

Additionally, dissolved organic compounds are often not analysed and not considered in models, but seasonally they are the dominating compounds (Brockmann et al. 1999a). Also for the particulate matter which is imported to the Wadden Sea it seems to be impossible to establish natural background concentrations due to interfering processes. Already due to the often steep vertical gradients of suspended matter, sufficient sampling along the water column is difficult, also in the tidal channels as has been shown during the TRANSWATT-investigations (Dick et al. 1999).

On the other hand, TN and TP values include all primary and secondary eutrophication effected components during the growing season and are key parameters because of many causal relationships (e.g. Beukema et al. 2002, Nielsen et al. 2002 a, b

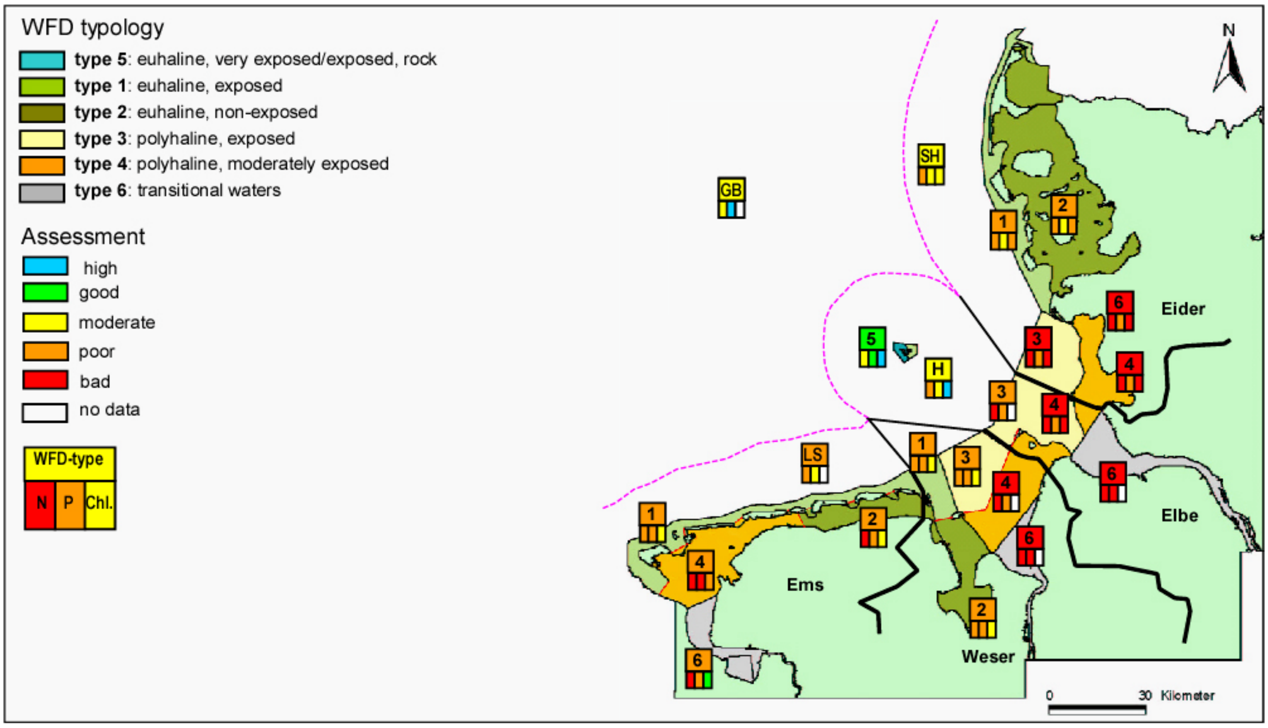


Figure 15. Compilation in the German coastal water of classes used for the OSPAR and Water Framework Directives. Numbers in relation to the corresponding catchment area indicates the types. Letters are indicating the different offshore waters. SH = Schleswig-Holstein, H = Helgoland, LS = Lower Saxonia, GB = German Bight.

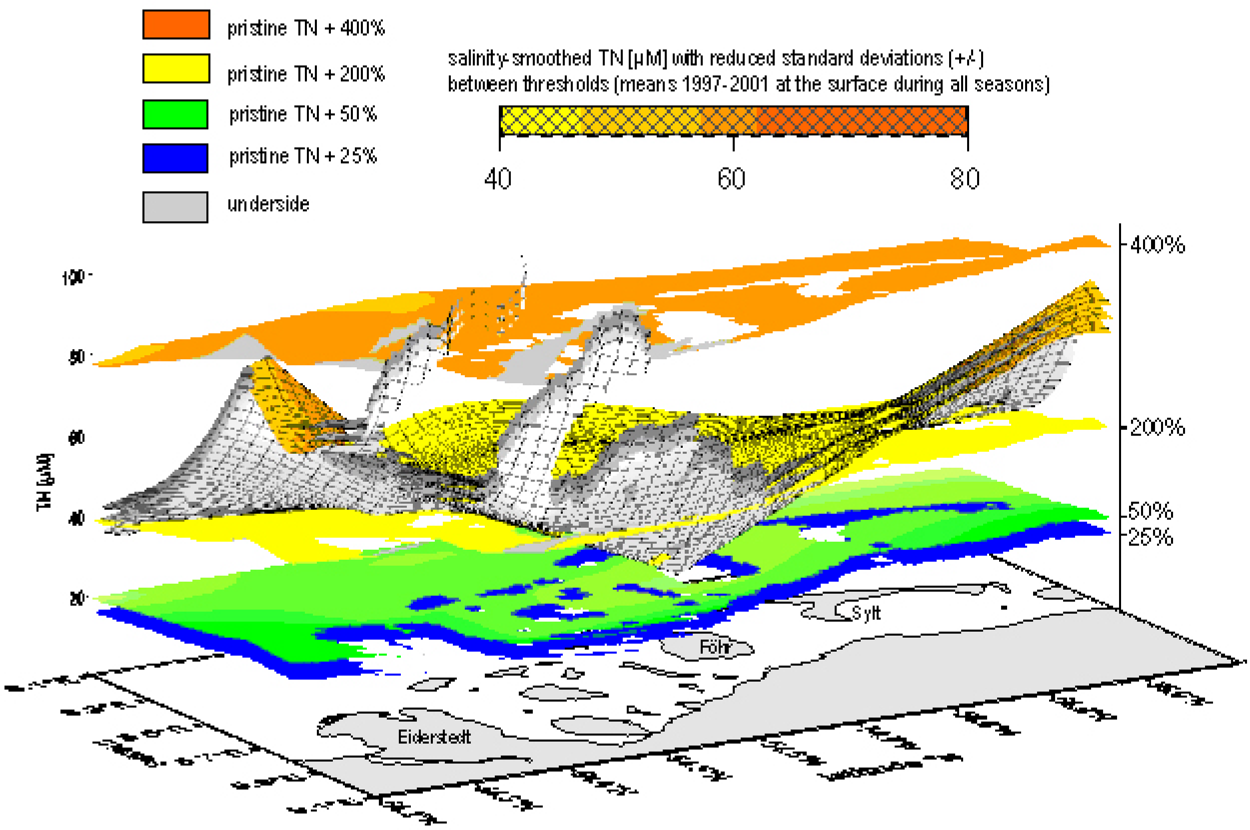


Figure 16. Salinity-smoothed TN (µM) with reduced standard deviations (+/-) between thresholds in the North Frisian Wadden Sea, map view to Northwest.

Tett et al 2003, Udy et al. 2005). However, it should be considered that also TN and TP show seasonal cycles, caused by denitrification or interaction with the sediment. For these reasons background concentrations and the deduced thresholds are reflecting always ranges.

Base of assessment

For the assessment the most recent 5-years time period was chosen for which data are available. A 5-year reporting schedule was proposed by OSPAR. The period between 1997 – 2001 has the advantage to perform an assessment without supplementary research data which have been used in the past to fill up data gaps (Brockmann et al. 2004). The restriction to monitoring data allows an evaluation of the ongoing monitoring in relation to the presented assessment.

The precision of any assessment is dependent on the quality of monitoring data which can be defined by the distance between sampling stations and frequencies. The quality of monitoring data should be considered for the scoring as well. By simple inventories the achieved resolution of present monitoring can be shown (Fig. 3 and 4). From these figures it can be estimated that the sampling is mostly restricted to the WFD-area, indicated by the black line on the map in Fig. 3 and 4, and that the chlorophyll sampling is performed only at a few stations. The same holds for the East Frisian coast where mostly only 10 samplings/5 years for TN, TP and chlorophyll have been performed between the islands. Only for the estuary of the Ems more than 200 TN and TP data were available and for the station at Norderney more than 180 chlorophyll measurements have been performed. For this reason the assessment is only locally valid and for larger areas the final classification must be assumed to be worse than deduced alone from the differences between recent data and historical background concentrations.

In the Wadden Sea which is frequently interacting with the water masses offshore (Dick et al. 1999, Pohlmann et al. 1999), the few samples which have been taken are not representative. Especially for the WFD-assessments of the small defined Waterbodies indicated by dotted lines on the maps in Fig. 3 and 4, the sampling coverage is not sufficient. On the other hand, for the assessment of the larger Types (Eider 1 – 4), the resolution may be representative due to the fast exchange of water masses between the tidal basins.

The frequencies of chlorophyll sampling with more than 20 data/month, aimed for the detection of nuisance species within the combined Types Eider 1 and 2 from May to September, are providing a good data base also for the general assessment of phytoplankton biomass (Fig. 12). However, the sampling during March and April, when the phytoplankton spring bloom is occurring, was less frequent and probably significant maxima have not been detected. Maximum chlorophyll values are assessed by OSPAR because they reflect bloom events. However, it must be considered that the chlorophyll data do not reflect the phytoplankton biomass directly (i) due to the different relationships between chlorophyll and biomass (carbon) of different species and of the same species at different physiological state (Brockmann et al. 1999b) and (ii) due to the large amount of chlorophyll that can originate from microphytobenthos in the Wadden Sea (Cadee 1984). A differentiation can only be performed on the base of species quantification and parallel biomass estimation. Additionally, the maximum chlorophyll values are dependent from the number of available data. For this reason the estimated maxima represent probably too low values.

Besides of frequent measurements at the stations on the islands of Norderney, Helgoland and Sylt (List), also between Helgoland and the coast frequent measurements have been performed. But this is not the case for all discussed parameters. Generally this combined sampling strategy of data, frequent measurements at some points combined within areas which are less frequent sampled but with a sufficient spatial resolution, can provide significant data sets which allow assessments of processes in space and time. However, the representativity of the key station for the surrounding area and the connections with the gradients and events in the station net has to be evaluated. This has mostly not been done.

Assuming a sufficient intercalibration and good data quality, which has not been checked by this study, it is very helpful for a roughly check of data quality by correlation analyses when all basic parameters (salinity, temperature, nutrients, chlorophyll, suspended matter, secchi depth) are estimated parallel. This allows establishing relationships in time and space for the different interfering hydrological and biogeochemical processes. Since the correlations between salinity TN and TP as well as between TN and DIN, TP and phosphate, TN and chlorophyll were highly significant, it can be assumed that the data quality was sufficient.

Classification

The proposal for the thresholds between the classes defined by OSPAR and WFD was made on the basis of (i) the suggestions by OSPAR (EUC 2005), allowing "elevated" concentrations of 50% above background, (ii) a sufficient differentiation of WFD-values (0.25 – 0.8, corresponding to 400 – 25% deviation from background) which were calculated by division of 100% as background by values, expressed as achieved levels (%), and (iii) considering the range of surpassing the background concentrations by modern data (Fig. 14). The thresholds in relation to background conditions may be changed in the future, because opposite to the scientifically based estimation of natural background data, the definition of thresholds includes also political elements considering the costs of possible measures to reduce eutrophication.

Even the OSPAR threshold of 50% above background is under discussion, because serious effects have been observed already by nutrient values at only 25% above background concentrations (Andersen et al. 2004). For the differences of effect-levels different regional hydrodynamic conditions are responsible, such as light conditions and residence times. These facts have to be considered within harmonised international assessments.

For the assessment according to the WFD, nutrients have only to be considered, if the biological elements are classified at least as "moderate" (COAST 2002, ECOSTAT 2004). However, nutrients are the causative factors, generating eutrophication and affecting all biological elements. Any measure to improve the trophic state of the ecosystem has to start with reduction of nutrients. For this reason nutrients are important assessment parameters for the Wadden Sea, too, and nutrients are assessed similarly to chlorophyll. This parallel assessment allows a direct comparison of scores.

Since the scores, indicated by the colours blue to red, are for the different parameters generally similarly distributed along the coastal water (Fig. 6 – 11), the assessment appears to be consistent and similar to that performed in 2003 for the German Bight during 1985 – 1998 (EUC 2003). However, for a final classification of the recent time period (1997 – 2001) the uneven distribution of data has to be considered for regional scoring. Indeed there are some discrepancies between the means of different seasons. For instance, TN was scored as moderate in a part of North Frisian area during all seasons, whereas DIN during winter was scored as poor (Fig. 6 and 8). The reasons are probably the high river loads of DIN during winter with extended plumes reaching at dominating westerly wind forces also the North Frisian Wadden Sea. Differences between scores of phosphate concentrations at the coast of Schleswig-Holstein for the period 1996 – 2001 are caused by the data from 1996, originating from a research project, by which during winter a local bloom event around the island of Föhr was detected (Brockmann et al. 2004).

The largest differences were observed between scores of TP and phosphate (Fig. 7 and 9): For the North Frisian area TP was generally scored as moderate during all seasons and phosphate during winter as poor. In the opposite, in the East Frisian area TP was scored between poor and bad and phosphate only as moderate. The nutrient loads from the Rhine include in this latter area less phosphate which has already been converted to phosphoric compounds like dissolved organic phosphorus and particulate phosphorus. The particulate material is kept close to the coast by the estuarine circulation (Postma 1984), resulting in high contributions to TP during spring (Brockmann et al. 1999a). Generally TP concentrations were higher along the East Frisian coast during spring and summer. In the opposite, during winter the contribution of phosphate to TP was only around 50% in this area.

Especially the estuaries have bad scores regarding nutrients, with concentrations surpassing mostly 400% of estimated background concentrations. For chlorophyll there are no data in the estuaries, but using the correlation between chlorophyll and salinity, "salinity-smoothed data" have been calculated for the measured salinity means (Fig. 3 and 10). Since the differences between the measured and calculated smoothed data were not significant in the coastal water, the more extended smoothed data have been presented.

Since for the calculation of smoothed data, light limitation and effects to the phytoplankton by salinity gradients were neglected, especially for the estuaries this scoring is questionable and has not been involved in the final compilation of classification (Fig. 15). This example shows again how important consistent data sets are for all assessed areas.

Due to the limitation of chlorophyll data only a restricted assessment for chlorophyll maxima could be performed. This resulted to some extent in a similar assessment as for mean chlorophyll (Fig. 10 and 11). It is remarkable that at locations with a high sampling activity (Fig. 3, at Norderney 185 samples were processed) the scoring of chlorophyll maxima resulted in poor (Norderney) or bad scores (Sylt). This indicates an insufficient frequency of sampling at most of the other locations where phytoplankton bloom events may not have been detected properly. Especially, for chlorophyll maxima it is evident that the scoring results depend on the frequency of sampling.

Opposite to the significant reductions of nutrient loads in the river discharges and concentrations within the estuaries,(ETG/MON 2004) there are no significant indications from the available data for changes in the well sampled North Frisian Types Eider 1 and 2 for the mean concentrations of TN, TP and chlorophyll (Fig. 12 and 13). Similar findings were also produced by ecosystem modelling, showing that only minor changes have been occurred in the coastal water in spite of significant nutrient reductions (Lenhart 2001). The reason is obviously the buffering capacity of the system, including the nutrient reservoirs of the sediment (van Beusekom et al. 1999), besides of the ongoing precipitation of nitrogen from the atmosphere which is especially high near the coast (Schulz et al. 1999). However, for some areas of the Wadden Sea and the TN load of Rhine and Meuse significant correlations have been identified with mean summer chlorophyll concentrations (van Beusekom et al. 2001, 2005). Also for the Sylt Römö Bight a decreasing trend of summer chlorophyll correlates with TN loads of Rhine/Meuse and Elbe/Weser (van Beusekom et al. 2005).

Due to the limitation of available data, environmental factors have mostly been neglected for the assessments of the single parameters. Only the variability, mainly caused by changing extensions and directions of river plumes, coupled with changing salinities, has been excluded. The spatial differences between original data and salinity-smoothed data are relatively small and caused only at some locations different classifications. However, the original hydrodynamic controlled variability destroys nearly every clear assessment result, if not only the means are considered. Since the natural hydrodynamic variability has not to be assessed, the procedure of "salinity-smoothing" was applied and is recommended.

This procedure, considering salinity related means and the remaining residual variability (Fig. 5), results in a clear separation between thresholds and recent data (Fig. 16). The distances between recent data and thresholds are made visible by this 3D-plot which results correspond to Fig. 6. The standard deviations for the thresholds, which may be transferred from the background values, were also mostly below 10% and were not considered in the figure for simplification. The original standard deviations for the modern TN data with ranges of 30 – 100% in the Wadden Sea (Fig. 5) would cause a strong overlapping with thresholds between the whole scale from high to low scores.

From the classification results some suggestions for the monitoring may be deduced: Assuming a precision of 10%, monitoring distances should generally cover this range in space and time. This means that (i) equidistant sampling within a station grid should maintain distances of 10% of the maximum extension of the area to be assessed or (ii) 10% of regular sampling times within a time period of 100% possible dates for events. However, for small areas, like the WFD-types or WFD-water bodies in the Wadden Sea, the limitation of minimum distances may be in the range of the extension of tidal tracks within the tidal channels, which are in the range of 10 nm. (Dick et al. 1999).

Since this would require an increase of monitoring activity, some reasons to reduce frequencies or to increase the necessary distances are mentioned:

- if the data are below the background level, only low monitoring activities are required,
- if the concentration differences between stations (gradients) are < 10%, a less spacial resolution is needed,
- if the differences with thresholds are high, a less sampling resolution is possible, as long as the the differences allow a significant classification,
- another impact is the residence time, if this is low, as is the case in many tidal basins (Dick et al. 1999), the spacial resolution of sampling may be reduced in favour of an increased frequency.

However, short time and small-scaled events should be considered for the monitoring design as well. Any evaluation and change of monitoring programmes should be accompanied by research activities, providing information about the representativity of locations and time sequences, according to the nesting principle (Brockmann et al. 1997).

The improvement of assessments is mainly based on a sufficient or better monitoring. The progress of both is an iterative process.

For a final classification the different representativities of regional data or parameters should be considered by weighting the scores. Insufficient data may be a reason to reduce the original scores following the precautional principle, because events with strong effects (e.g. nuisance blooms) may have been missed.

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