# Assessment of the eutrophication status of transitional, coastal and marine waters within OSPAR

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**Abstract** Eutrophication (nutrient enrichment and subsequent processes) and its adverse ecosystem effects have been discussed as main issues over the last 20 years in international conferences and conventions for the protection of the marine environment such as the North Sea Conferences and the 1992 OSPAR Convention (OSPAR; which combined and updated the 1972 Oslo Convention on dumping waste at the sea and the 1974 Paris Convention on land-based sources of marine pollution). OSPAR committed itself to reduce phosphorus and nitrogen inputs (in the order of 50% compared with 1985) into the marine areas and 'to combat eutrophication to achieve, by the year 2010, a healthy marine environment where eutrophication does not occur'. Within OSPAR, the Comprehensive Procedure (COMPP) has been developed and used to assess the eutrophication status of the OSPAR maritime area in an harmonised way. This is based on classification in terms of the following types of areas Non-Problem Areas (no effects), Potential Problem Areas (not enough data to assess effects) and Problem Areas (effects due to elevated nutrients and/or due to transboundary transport from adjacent areas). The COMPP consists of a set of harmonised assessment criteria with their area-specific assessment levels and an integrated area classification approach. The criteria cover all aspects of nutrient enrichment (nutrient inputs, concentrations and ratios) as well as possible direct effects (e.g. increased levels of nuisance and/or toxic phytoplankton species, shifts and/or losses of submerged aquatic vegetation) and indirect effects (e.g. oxygen deficiency, changes and/or death of benthos, death of fish, algal toxins). The COMPP also includes supporting environmental factors. It takes account of synergies and harmonisation with the EC Water Framework Directive, and has formed a major

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basis for the EC eutrophication guidance. Recently, additional components, such as total nitrogen, total phosphorus and transboundary transports have been included in the assessment of, e.g. the German Bight. The second application of the COMPP resulting in an update of the eutrophication status of the OSPAR maritime area will be finalised in 2008, and will include the agreed integrated set of Ecological Quality Objectives (EcoQOs) with respect to eutrophication.

**Keywords** Eutrophication · Assessment · OSPAR · Comprehensive procedure · German Bight · North Sea

## Introduction

Assessments of the eutrophication status of transitional, coastal and marine waters within OSPAR are performed for the Northeast Atlantic, including the Greater North Sea, the Celtic Sea, the Bay of Biscay and the Iberian Coast. A similar procedure is applied in the Baltic Sea by HELCOM.

The aim of the eutrophication strategy of OSPAR is to combat eutrophication in order to achieve and maintain a healthy marine environment where eutrophication, as anthropogenically caused nutrient enrichment and succeeding effects, does not occur past 2010.

For this reason (i) repeated assessments are performed to characterise the regional eutrophication status by the so called 'Common Procedure for the Identification of the Eutrophication Status of the Maritime Area of the Oslo and Paris Conventions', an internationally harmonised classification procedure and (ii) OSPAR has, as a first step, initiated measures to reduce the nutrient inputs to parts of the OSPAR Convention area by 50% compared to 1985 within 10 years where these inputs are likely, directly or indirectly, to contribute to inputs into eutrophication problem areas.

The COMP has been developed within OSPAR to allow the characterisation of the maritime areas with regard to their eutrophication status on a common basis. It includes (i) a screening procedure for mainly offshore water where anthropogenically induced eutrophication effects are obviously absent and (ii) the Comprehensive Procedures (COMPP) to be applied in more affected coastal waters. Both procedures were first applied in 2002 for the estuarine and marine waters of the OSPAR Contracting Parties.

A guideline for a harmonised holistic eutrophication assessment has been developed for COMPP, considering synergies and harmonisation with the EC Water Framework Directive (WFD), including a scheme of the main cause/effect relationships in the eutrophication process.

The main parts of this procedure and some selected examples are presented here briefly, considering that mainly the OSPAR Contracting Parties have free access to the OSPAR documents, including extended descriptions of COMPP and its applications.

## Interaction of eutrophication processes

The common procedure of OSPAR includes the main parameters involved in eutrophication processes. They are roughly differentiated into four categories (Fig. 1):

- Category I. nutrient enrichment,
- Category II. direct effects (e.g. algal blooms),
- Category III. indirect effects (e.g. oxygen deficiency) and
- Category IV. other effects (e.g. algae toxins).

The parameters are arranged according to their causal relationships. These are illustrated in an ecosystem flow diagram, which simplifies the possible interactions. Other flow diagrams, developed for the management of aquatic ecosystems, may be focussed on estuaries (De Jonge & Elliott, 2001, Bricker et al., 2003) or more complex systems and may also include socioeconomic responses as well as management options (Lundberg, 2005). The OSPAR conceptual framework focussing on the main eutrophication processes has also been transferred to activities in the implementation of the EC Water Framework Directive (WFD).

The nutrient concentrations and ratios are controlled by the different inputs, imports and exports and losses (e.g. denitrification), followed by the nutrient uptake by phytoplankton and macrophytes as direct effects. Transboundary fluxes include imports and exports as well which are controlling all pelagic parameters in open coastal waters in addition to nutrients form other sources.

All processes are influenced by environmental factors, such as stratification, residence time of water

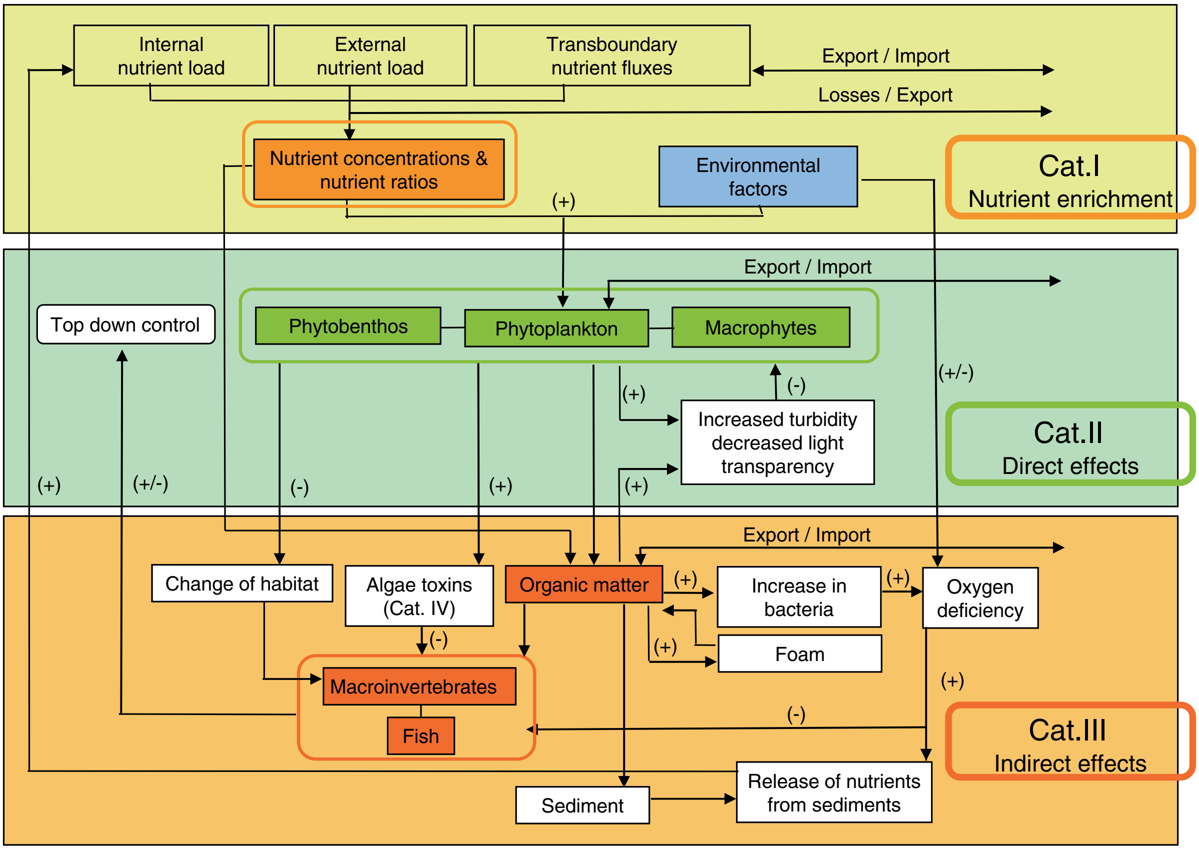



**Fig. 1** Interaction of eutrophication processes (Cat. = categories of the eutrophication processes, (+) = enhancement of process, (−) = inhibition of process)

masses and turbulence, forcing the resuspension of sediments and affecting the light climate which is also influenced by phytoplankton standing crops.

The indirect effects include the production of organic matter from different sources. This material serves as food for the zoobenthos and may give rise to oxygen depletion in estuaries or the bottom water of stratified areas, after accumulation and decomposition, possibly causing death of zoobenthos and fish.

All key parameters combined by these processes, have been involved in the assessment of OSPAR (Fig. 2): river inputs, winter dissolved inorganic nitrogen (DIN) and phosphate concentrations (DIP), chlorophyll *a* of phytoplankton species, shifts of macrophytes and, in relation to nutrient enrichment: organic matter, oxygen deficiencies and death of animals, caused by low oxygen levels or toxic phytoplankton species. Finally, the changes of the ecosystem structure are assessed within specified areas, which are characterised by salinity and specific environmental conditions, such as stratified and/or sedimentation areas.

Basic eutrophication assessment parameters are winter DIN and DIP concentrations. This season has been selected because during winter biologic activity (e.g. phytoplankton growth) is low. Therefore, highest nutrient concentrations can be expected and observed at that time of the year. This amount of nutrients is potentially available for the phytoplankton spring bloom. However, the winter nutrient concentrations at the specific monitoring site have mostly disappeared when eutrophication effects are observed in a specific area. For this reason, new assessment parameters have recently been introduced: total nitrogen (TN) and total phosphorus (TP) as annual means, thus combining seasonal processes to a large extent and allowing the combination of natural background concentrations from fresh water and sea water (Fig. 2).

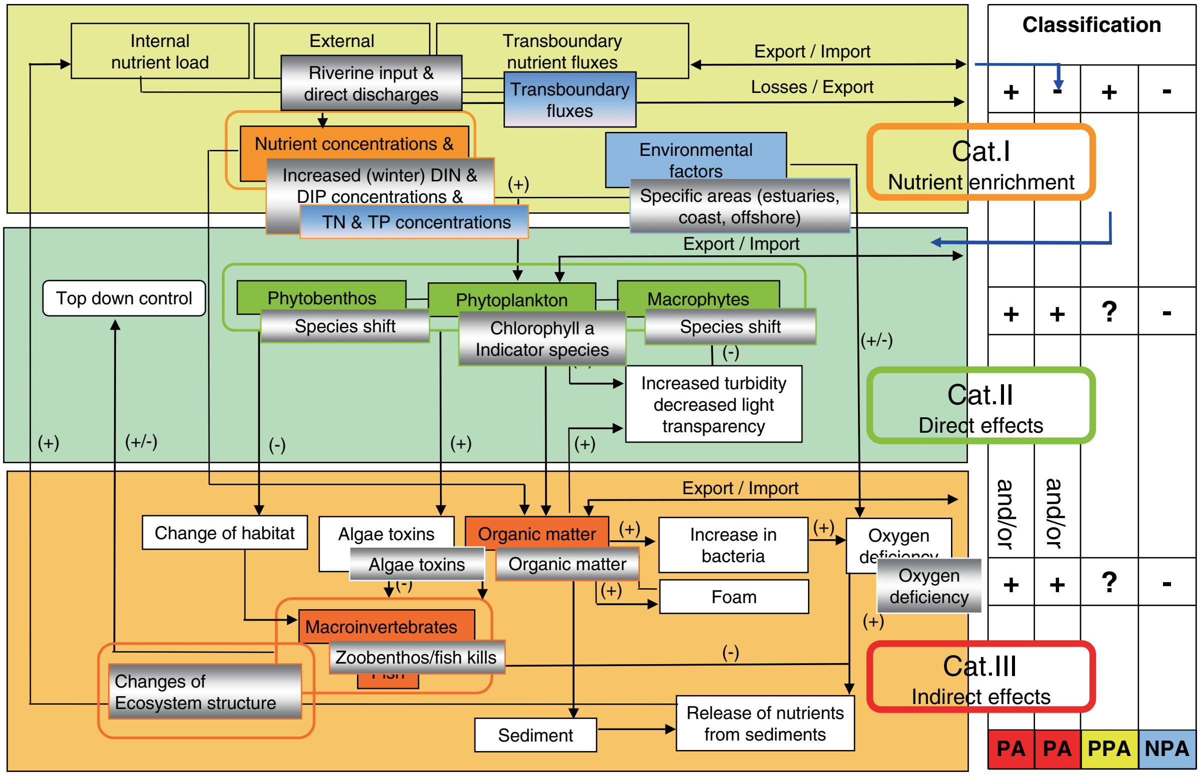



**Fig. 2** Interaction of eutrophication processes (background), assessed parameters (in *grey*) and classification: "+" = above elevated level, "−" = below elevated level, "?" = insufficient data; PA = Problem Area, PPA = Potential Problem Area, NPA = Non Problem Area

Since the nutrient gradients in the coastal water are not only influenced by river discharges and atmospheric deposition, but are mainly controlled by transboundary imports and exports, these transboundary transports have been added to COMPP as well.

Silicate concentrations will also be assessed in future, as background information for the possible shift in phytoplankton groups (from diatoms to flagellates) because many harmful species are flagellates and there are some indications for an increase of harmful blooms and flagellates abundances in connection with eutrophication (Radach et al., 1990, Cloern, 2001).

## Assessments and measures

The anchor of the OSPAR eutrophication assessment is the definition of natural background concentrations (or levels) which serve as reference levels. Their derivation follows similar rules as for the WFD. If, for a specific parameter, 50% of the area-specific natural background concentrations or conditions are surpassed the area is classified as "Problem Area" (PA), indicated by a [+] (Fig. 2). No effects meaning a derivation <50% are classified as "Non-Problem Area" (NPA) by a [−]. Within the four categories, the "one out—all out" principle is applied. If significant eutrophication effects are observed, a [+] will be scored for category II or III, resulting in a classification as "Problem Area".

If there are effects but no elevated nutrient concentrations, transboundary imports may be assumed. Areas without visible effects but with elevated nutrient concentrations are classified as "Potential Problem Areas" (PPA) because monitoring may have failed to detect effects, e.g. due to complex hydrodynamic conditions. However, nutrients may be exported from these areas causing transboundary effects in adjacent regions. PPA are indicated by "?".

These classifications have been applied for the OSPAR maritime area by the Contracting Parties, resulting in national reports on more or less extended "Problem and Potential Problem Areas". Based on the national information, OSPAR produced an "Integrated Report 2003 on the Eutrophication Status of the OSPAR Maritime Area based upon the First Application of the Comprehensive Procedure". Figure 3 shows the eutrophication status for the Greater North Sea for that assessment. Whereas along the continental coast from Belgium to Denmark large areas are classified as Problem Areas, along the coasts of the United Kingdom only estuaries are classified as Problem Areas. Along the steep Norwegian Skagerrak coast offshore areas are mainly classified as Potential Problem Area, contrary to the Danish coast and the Swedish Kattegat coast and despite the fact of frequent occurrence of harmful blooms along the Norwegian Coastal Current. These classifications, compiled by the OSPAR secretariat, are based on national reports.

As an example for one of the newly introduced parameters, an assessment of Total Nitrogen (TN) (means calculated from all seasons) is compared at different scales (Fig. 4). Determination of total nutrient concentrations includes all nutrient fractions (inorganic dissolved, organic dissolved and particulate) and is less affected by seasonal nutrient conversion processes than the inorganic nutrients which are seasonally replaced by organic compounds (Butler et al., 1979). Annual means of TN can be assessed through all seasons, and thereby bridging the seasonal and regional developments. Additionally, significant correlations between TN and chlorophyll have been found in many areas (Smith, 2006) indicating quantitative relationships between these parameters. However, it has to be acknowledged that TN is a parameter that can be used on a voluntary basis to obtain an improved insight into its possible value for the eutrophication assessment. For TN to be included into the core set of harmonised OSPAR COMPP parameters further work is necessary.

For TN in coastal waters, natural background concentrations have been derived by modelling based on literature data for pristine German rivers (Behrendt et al., 2003) and extrapolated historical coastal concentrations (Van Raaphorst et al., 2000) for the German Bight. Differences between recent concentrations and the natural background were calculated as percentage of reference values. Regions, where

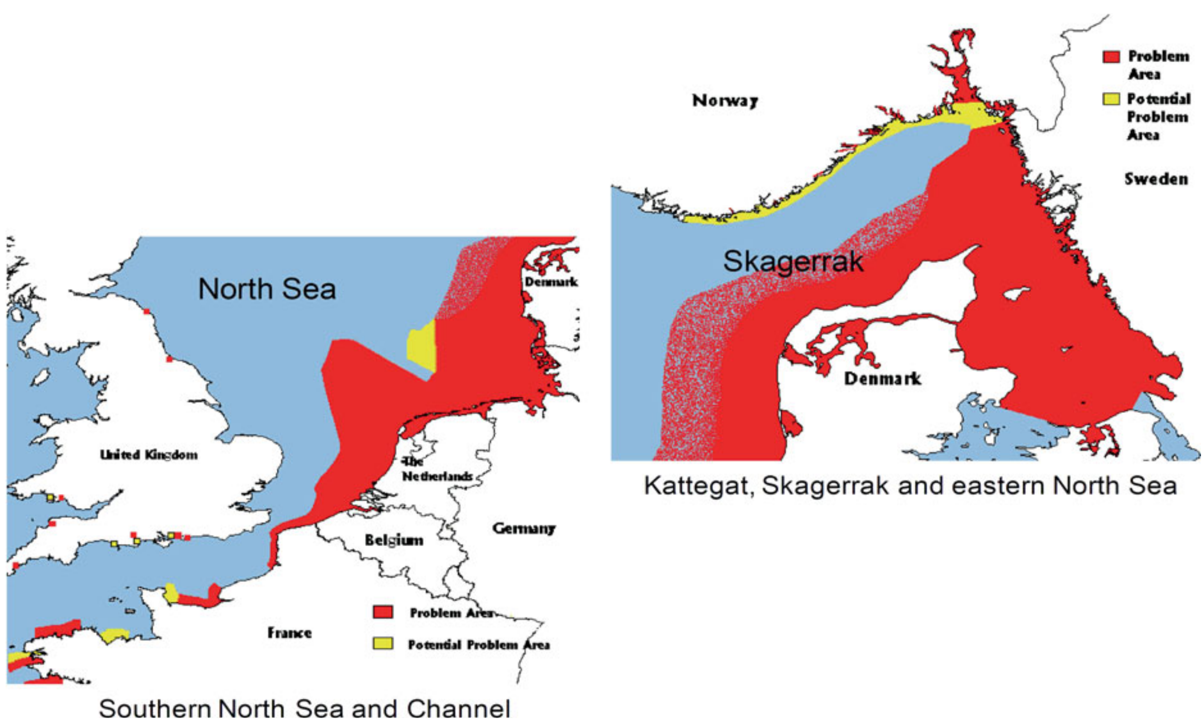



**Fig. 3** Eutrophication status in 2002 of selected OSPAR areas

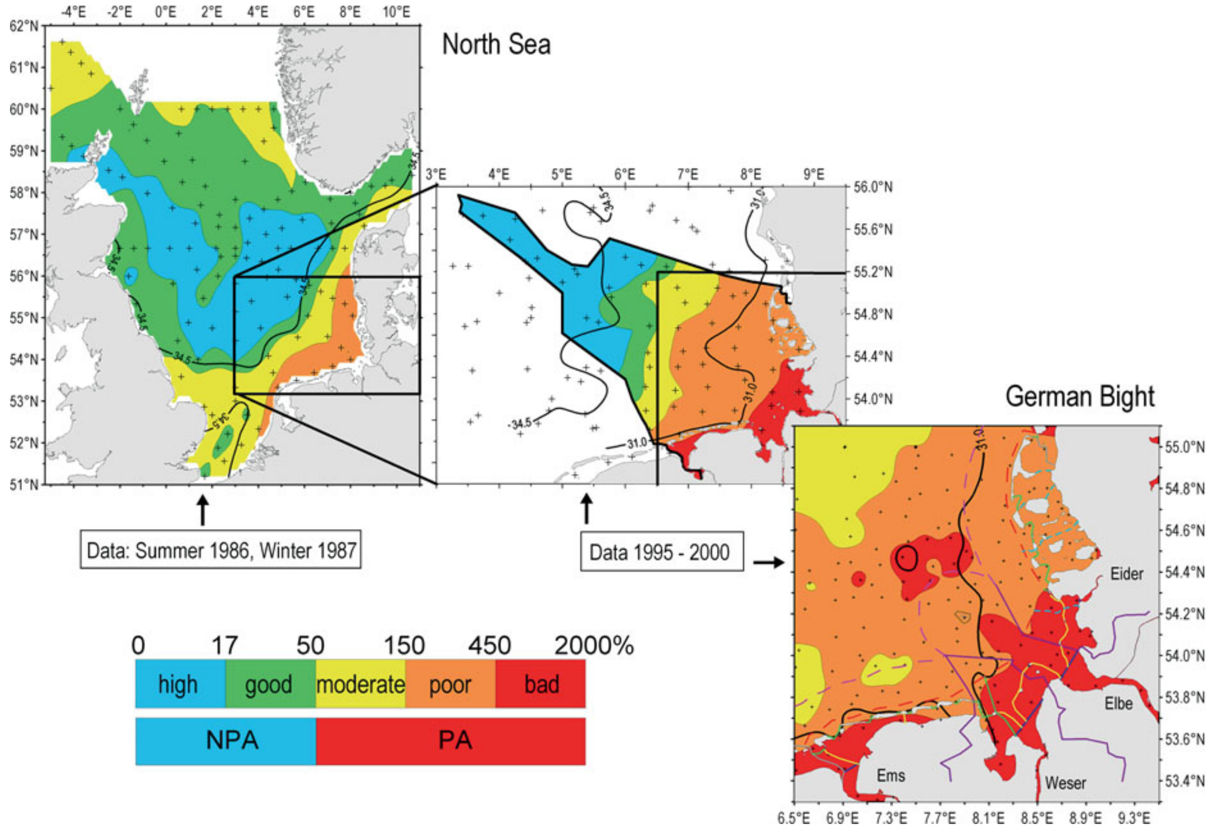



**Fig. 4** Differences between pristine and recent TN in % of pristine values, which were developed for the German Bight and transferred to the whole North Sea as a test

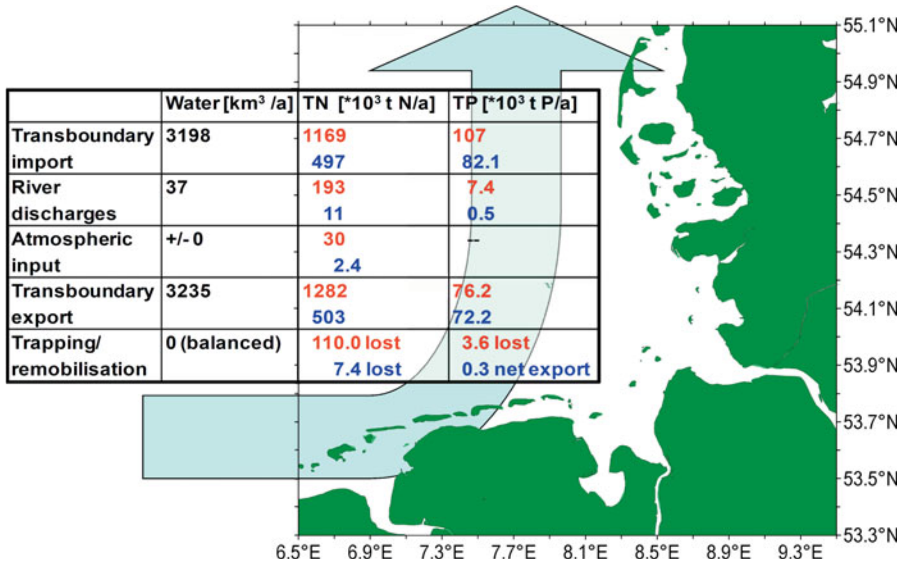
150% of reference conditions (=100%) were surpassed, were classified as Problem Areas. This was the case for the whole German Bight, the Continental Coastal Water, loaded with about 20–30 μM TN, as well as small strips of Norwegian Coastal Water. The German approach was extended to the whole North Sea as a test, showing also the high nutrient loads of the Atlantic inflow affecting the shallow North Sea which is a sink for nitrogen (Seitzinger & Giblin, 1996). Due to the lack of data it was not possible to assess the same time period for all areas.

The open coastal waters receive and export most of the nutrients by transboundary transports. This process is also relevant for the WFD-areas because particulate material will be trapped partly in estuaries and tidal flats by the estuarine circulation and asymmetric tides.

Based on the simple assumption of a constant coastal current transport (Mittelstaedt et al., 1983), imports and exports of the German Bight were calculated from recent (1995–2000) mean and pristine offshore concentrations (TN: 11 μM, TP: 0.72 μM) (Fig. 5). The borders for the in- and outflow were closed to get a balanced budget of water masses. Recent data, necessary for budget calculations, are very scarce due to missing seasonal representative sampling and rare complete analyses of TN and TP. The river Rhine input is included within the import.

The transported water masses through the German Bight area, containing 476 $km^3$ water, were balanced by different in- and outflow velocities through the defined boundaries with their different cross-section sizes (west: 5.59 $km^2$; north: 3.42 $km^2$): 1.8 cm/s inflow, 3 cm/s outflow (946 km/y). Across the north-western edge the entering water will leave the area soon. The water masses will be exchanged about 7 times/year.

The atmospheric input into the area of the German Bight contributes with about 30,000 t/y nitrogen to the budget (Bartnicki & Fagerli, 2003, Rendell et al., 1993). Historically, 1 kg N/ha deposition is assumed (Nixon, 1997). About 110 * $10^3$ t N/year are lost in




| | Water [km³ /a] | TN [*10³ t N/a] | TP [*10³ t P/a] |
|---|---|---|---|
| Transboundary import | 3198 | 1169<br>497 | 107<br>82.1 |
| River discharges | 37 | 193<br>11 | 7.4<br>0.5 |
| Atmospheric input | +/- 0 | 30<br>2.4 | – |
| Transboundary export | 3235 | 1282<br>503 | 76.2<br>72.2 |
| Trapping/ remobilisation | 0 (balanced) | 110.0 lost<br>7.4 lost | 3.6 lost<br>0.3 net export |

**Fig. 5** Annual budget of TN and TP in the German Bight for pristine and mean recent (1995–2000) concentrations. The *arrow* indicates the residual current. The borders for the budget correspond to those of the map

the German Bight, corresponding to 36 μM/m$^2$ h which is in the range of estimated denitrification rates (Lohse et al., 1996). Also 3,600 t/y phosphorus are lost, which is equivalent to 4.7 μM/m$^2$ y for the whole area. However, most of the particulate fraction was probably trapped in the Wadden Sea and estuaries due to the estuarine circulation (Postma, 1984). It must be assumed that also nitrogen was partly trapped in the sediments, at least transitionally.

Beddig et al. (1997) assumed transboundary transports of about 900–1,000 * 10$^3$ t N/year within a nitrogen budget of the German Bight in 1990 and 1991, which is in the same range of the presented recent calculation.

Reacting to the observed eutrophication problems, the nutrient discharges from anthropogenic sources have been reduced significantly within the OSPAR Convention Area, stimulated by the agreement to reduce the loads of N and P by 50% compared to 1985 discharges. The achieved reductions between 1985 and 2003 show that this goal was generally met for phosphorus discharges (Fig. 6). For Germany the

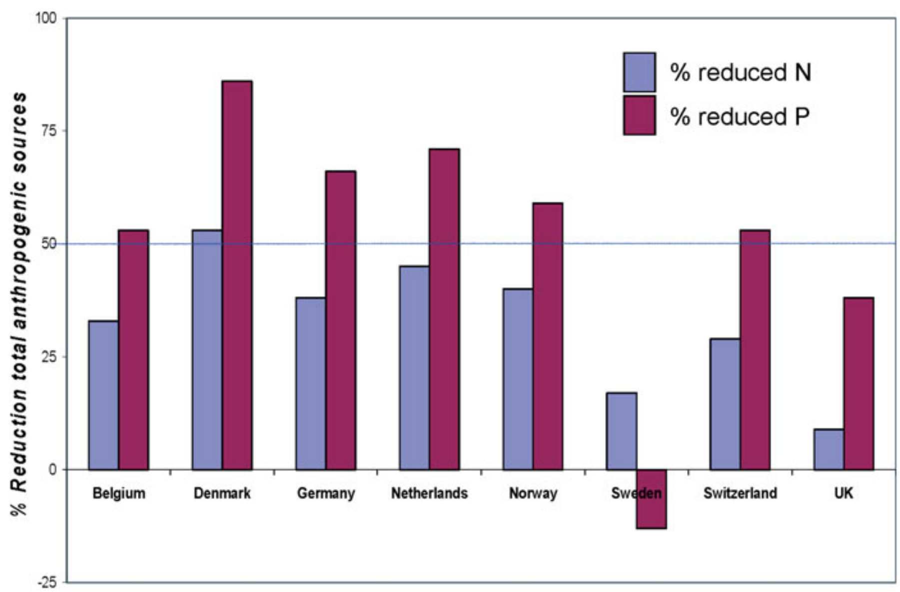



**Fig. 6** Total percentage reductions of anthropogenic discharges between 1985 and 2003

data are limited to 2000, and UK estimates for inputs from aquacultures are not included. For nitrogen discharges significant reduction could also be achieved in the order of 10–50%. However, the river discharges are very variable, especially for nitrogen, dependent on the amount of freshwater run-off. Therefore, long time periods and concentrations should be considered for trend analyses.

## Towards a pan-European assessment strategy

The second application of the COMPP will result in an updated assessment of the eutrophication status of the OSPAR maritime area in 2008 and will include the agreed integrated set of Ecological Quality Objectives (EcoQOs) with respect to eutrophication.

Many of the parameters assessed by OSPAR are also considered within the WFD, which can be seen by comparison (Fig. 7). These especially are the biological quality elements phytobenthos, phytoplankton, macrophytes and macrozoobenthos, supplemented by assessment-supporting physico-chemical parameters like nutrients, oxygen conditions and transparency.

These synergies have been addressed by OSPAR including the "translation" of thresholds (Table 1). Non Problem Area (NPA) is corresponding to high and good scores, Problem Area (PA) to moderate and worse scores. However, the appropriate OSPAR threshold between NPA and PA, allowing a surplus of 50% of natural background concentrations, can lead to misclassifications according to the WFD which defines the "good status" by only "slight differences" from "high status" (=reference).

First steps of harmonisation between the different assessment methods have already been realised, by utilisation of central COMPP parts. An interim document "Towards a guidance document on eutrophication

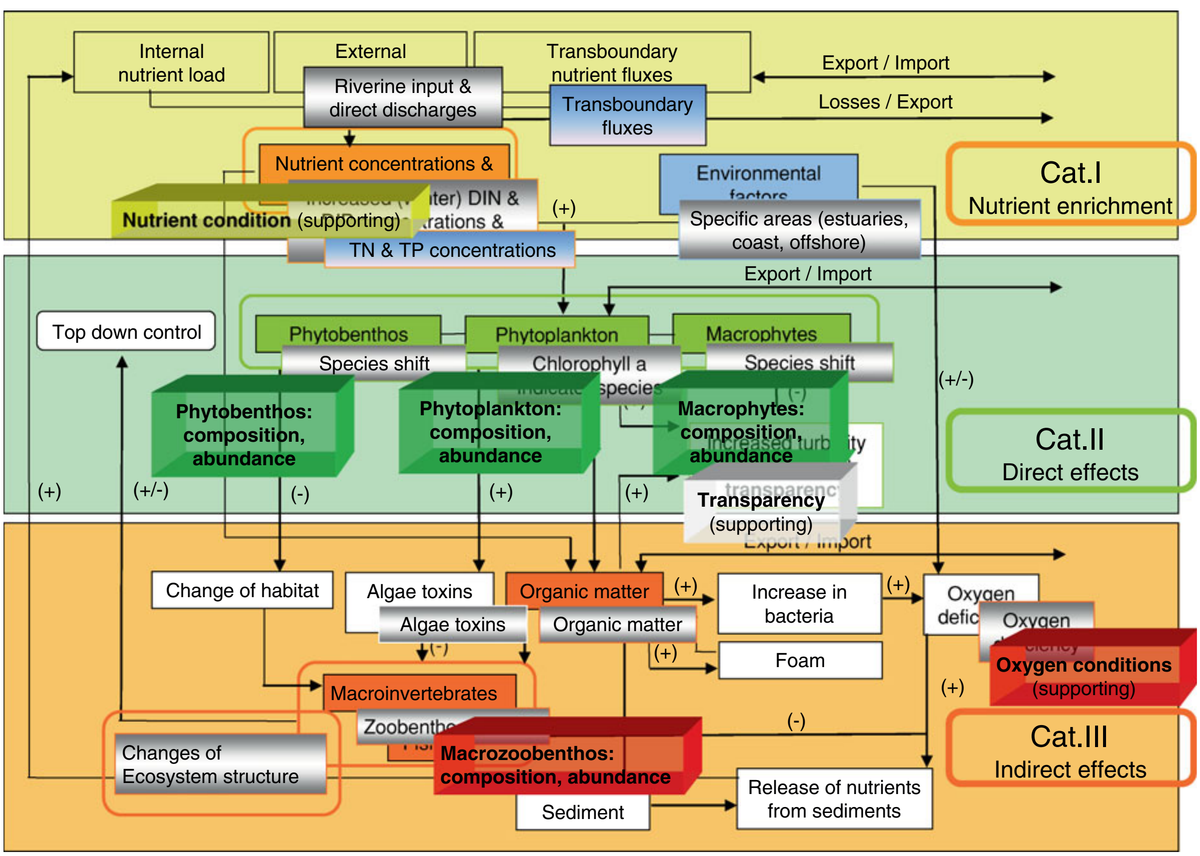



**Fig. 7** Interaction of eutrophication processes: assessed OSPAR and WFD parameters. Background: interaction of eutrophication processes (Fig. 1); Second level: assessed parameters (Fig. 2), Surface level (in *bold*, 3-D-boxes): assessed WFD parameters

**Table 1** Relationship between OSPAR COMPP, EcoQOs and WFD classification

| | | | | | | |
|---|---|---|---|---|---|---|
| OSPAR COMPP | Further Application | Non-Problem Area | | Problem Area | | |
| | Initial Application | Non-Problem Area | | Potential Problem Area | | Problem Area |
| WFD | | High | Good | Moderate | Poor | Bad |
| | | OSPAR Background | ↑ | | | |
| | | | | | | |
| EcoQOs | | % Ecological Quality Objectives Eutrophication<br>% OSPAR Assessment Level<br>(reflecting natural variability and (slight) disturbance<br>(OSPAR Background + 50 %)) | | | | |

assessment in the context of European water policies" has been developed as part of the implementation of the EC Water Framework Directive. It is based on work of a "eutrophication steering group" led by DG Environment and on two workshops with experts for all water categories (lakes, rivers, transitional and coastal water) from all EU Member States and the Joint Research Centre. This guidance document includes a conceptual framework for eutrophication assessment based on the OSPAR conceptual framework but adapted to a pan-European perspective. In this document the different relevant European directives are considered, such as the Urban Waste Water Treatment Directive, the Nitrates Directives, and especially the Water Framework Directive. Key terms are compared, as well as the possible assessment results for waters responding to nutrient enrichment.

However, in comparison to OSPAR only the biological quality elements are considered with the same meaning. Nutrients, the main origin of anthropogenic eutrophication processes, which are fully assessed by OSPAR, are only considered as supporting parameters for the WFD assessments.

In addition to the European assessment methods, an assessment method has also been developed and broadly applied for estuaries in the United States (Bricker et al., 2003) which has many similarities to the methods of OSPAR and the WFD. Therefore, other developments and experiences should also be considered for the further development of a common assessment strategy. This integration of different assessment methodologies should be continued by harmonisation of:

- Area specification and typing (natural interfering processes),
- Determination of quantitative causal relationships for specific regions and tests of generally applicable correlations,
- References and thresholds,
- Supplementary parameters,
- Monitoring resolutions and requirements of precision,
- Development of classification tools,
- Reporting formats and time periods,
- Modelling of transboundary transports, residence times and reduction scenarios,
- Most effective reduction measures.

Climate changes, causing, e.g. longer seasonal stratification, may increase eutrophication effects, e.g. by extending oxygen depletion in enclosed bottom waters or supporting seasonal dominance of dinoflagellates. OSPAR is addressing these processes by assessment of combined effects of nutrient offshore transports, riverine discharges, atmospheric deposition, trapping and conversions processes, considering influences of hydrodynamic factors and their possible changes.

Improvements of transitional and coastal waters will result from implementation of the WFD, but they cannot be properly managed without considering imports of particulate matter by estuarine circulation and asymmetric tides. These are affected by transboundary fluxes of nutrients and organic matter. The complex eutrophication processes at the sea/shore transition zone are addressed by OSPAR, supplementing WFD and the new European Marine Strategy Framework Directive.

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