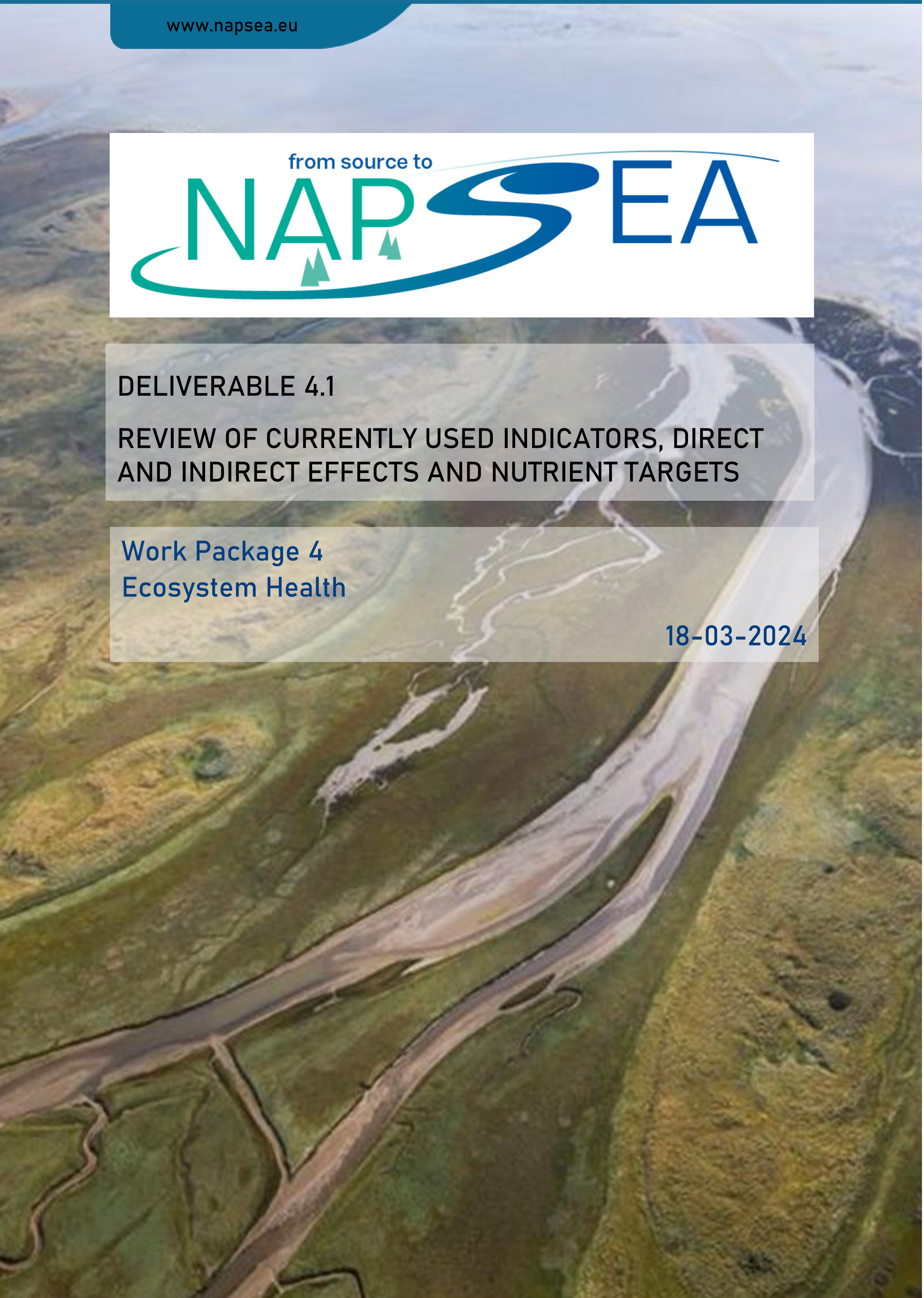

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from source to NAPSEA

DELIVERABLE 4.1

REVIEW OF CURRENTLY USED INDICATORS, DIRECT AND INDIRECT EFFECTS AND NUTRIENT TARGETS

Work Package 4
Ecosystem Health

18-03-2024

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Abstract	The deliverable investigates threshold values for eutrophication indicators in various water bodies, focusing on the limnic-marine gradient in specific regions. It highlights inconsistencies in assessment methods, notably reference conditions and threshold values, between directives and countries, emphasizing the need for understanding these differences to develop alternative assessment methods for ecological boundaries.
Keywords	eutrophication, threshold values, reference conditions, coherence, water framework directive, marine strategy framework directive, OSPAR, chlorophyll *a*, nitrogen

Contents

1. ACRONYMS

Abbreviation	**Explanation**
DIN	Dissolved Inorganic Nitrogen
EQRS	Ecological Quality Ratio Standardized (between 0 and 1)
MSFD	European Marine Strategy Framework Directive
OSPAR	Convention on the protection of the marine environment of the North-East Atlantic
QSR	Quality Status Report
TN	Total Nitrogen
TP	Total Phosphorus
WFD	European Water Framework Directive

2. EXECUTIVE SUMMARY

This deliverable (D 4.1) investigates the currently used threshold values for the assessment of eutrophication indicators in marine, transitional and freshwaters. It also investigates the rationales and methods to derive these threshold values, as an acceptable deviation from environmental conditions that are less impacted by human activity. The deliverable focuses on the limnic-marine gradient, specifically in the Rhine and Elbe catchments, the Dutch and German parts of the Wadden Sea, and the areas to the North of the Wadden Islands, *i.e.* the plumes of the rivers Rhine, Ems and Elbe. Three indicators are considered, *i.e.* concentrations of chlorophyll *a*, dissolved inorganic nitrogen (DIN), and total nitrogen (TN). These indicators were chosen because they are to some extent applied across the entire continuum from freshwater to the sea and by both Germany and the Netherlands.

The analysis shows that in general the threshold values decrease from source to sea, which is to be expected considering the dilution of nutrients released from land-based sources. However, inconsistencies appear, due to the different assessment methods used under OSPAR/Marine Strategy Framework Directive (MSFD) and the Water Framework Directive (WFD), that also consider waterbody-specific ecological conditions. In addition, the implementation of the WFD is to some extent country-specific, despite WFD intercalibration efforts. The deliverable presents a detailed description of these differences and how these evolved. This detailed understanding is a prerequisite for the next step under this work package, *i.e.* to develop alternative assessment methods to define safe ecological boundaries for the Wadden Sea and adjacent waters.

3. INTRODUCTION

The NAPSEA project investigates the effectiveness of measures aimed at reducing Nitrogen and Phosphorus loads from Source to sEA considering the effects of climate change (NAPSEA acronym). Its core objectives revolve around supporting national and local authorities in identifying potent strategies to mitigate nutrient loads and creating political support for their implementation. Employing a holistic approach, the project encompasses governance and policies, nutrient pathways and measures, and ecosystem well-being. Geographically, emphasis is placed on the Wadden Sea catchment area, with detailed case studies focusing on the Rhine, Elbe, Hunze, and the Wadden Sea itself. NAPSEA functions as a platform to highlight implementation practices that are socially acceptable, sustainable, and efficient. Furthermore, it considers the influence of climate change and the supplementary advantages of measures targeting the reduction of greenhouse gas emissions.

This report reviews the literature and available data on the currently used eutrophication indicators, including nutrient concentrations, direct and indirect eutrophication effects, as well as threshold values that are used in OSPAR and MSFD assessments, and in the WFD River Basin Management Plans.

4. METHODOLOGY

One of the tasks of WP 4, that will focus on ecosystem health, is defining safe ecological boundaries for different types of ecosystems along the continuum from catchment to coast. This deliverable (D 4.1) intends to show and explain the evolution of threshold values along this continuum for two parameters that appear in both WFD and OSPAR/MSFD assessments: nitrogen concentration (as winter DIN and/or annual or summer total nitrogen (TN)) and chlorophyll *a* concentration. This continuum crosses country borders (DE-NL) as well as legal frameworks (WFD-OSPAR/MSFD), which challenges comparability of assessment outcomes. One of these challenges relates to how threshold values have been defined and which philosophy or narrative has been used. Furthermore, the expression of eutrophication effects, as a response to increased nutrient loads, depends on local physical and biological characteristics such as light climate and the presence of filter feeders. Our analysis contributes to a better understanding of the observed discontinuities from source to sea.

The analysis focuses on the limnic-marine gradient, with the Wadden Sea as the ultimate receiving water body. This research partly builds on the work performed in the Interreg V A project “Wasserqualität – Waterkwaliteit” (Rönn et al., 2023; see Figure 1). However, the analysis also considers the areas to both the seaward and the landward sides of the WFD coastal water bodies (N-type), *i.e.* the river plumes as defined by OSPAR and WFD transitional and inland water bodies.

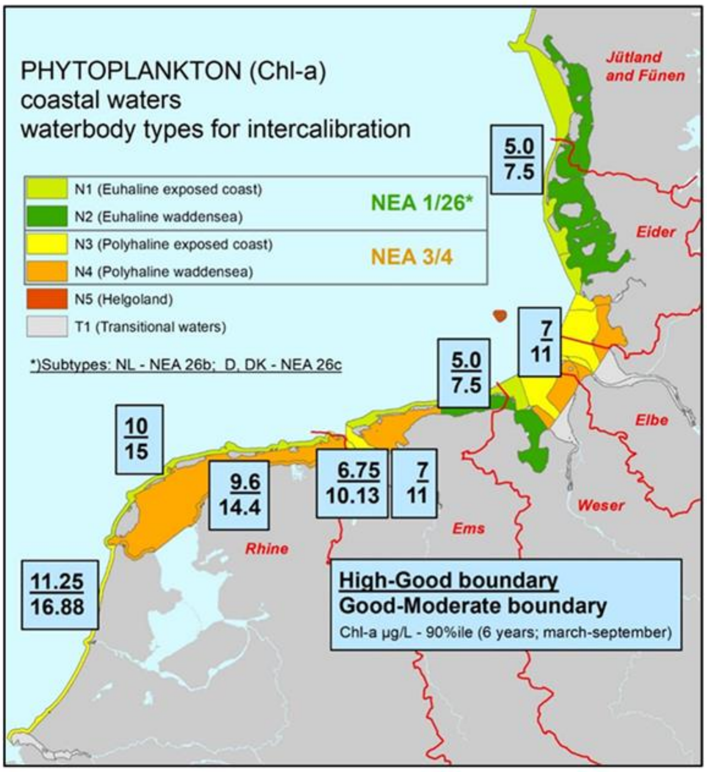


Figure 1. WFD-typology of coastal water bodies of the Netherlands and Germany, including the Wadden Sea, with current chlorophyll a threshold (EC 2018) for high/good and good/moderate boundaries, indicated as 90-percentile of chlorophyll a concentration (µg/l) of the growing season (March-September) over a six-year period. In: Rönn et al. (2023).

Ecological indicators such as phytoplankton composition, macroalgae and angiosperms, are used in WFD assessments of ecological status and OSPAR/MSFD assessments of biodiversity status including pelagic habitats. However, comparison of these indicators across the limnic-marine gradient is complex, since these are type or area-specific, including different taxa. Due to time constraints, we excluded them from our analysis. Nonetheless, these indicators are addressed in the upcoming case studies.

In the present deliverable, we focus on indicators of the good environmental/ecological status as proposed in the frameworks of the WFD, MSFD, and OSPAR. In the case studies, we will address safe ecological limits from a local perspective. Both viewpoints will then be synthesized to a coherent view on safe ecological limits in the river-sea continuum (cf. Gericke et al., 2024). In a final stage of WP4, we will discuss whether the proposed management goals to bring the nutrient loads to levels that achieve the good environmental/ecological status (according to the WFD, MSFD and OSPAR) enable the safe ecological limits as proposed within the NAPSEA project.

The information collected for this analysis is summarized in the Table in Annex I: NAPSEA Task 4.1 inventory of eutrophication indicator threshold values. The indicators selected for further analysis under this deliverable are presented in Table 1.

Table 1. Eutrophication indicators used across policy frameworks and countries. For these indicators the evolution across the limnic-marine border is analyzed.

Policy	**Water type**	**Country**	**Indicator**			
			DIN Winter	**TN Summer**	**TN annual**	**Chlorophyll *a* Summer**
OSPAR/ MSFD	river plume	NL	x			x
		DE	x		x	x
WFD	coastal	NL	x			x
		DE	x		x	x
	transitional	NL	x			x
		DE	x		x	
	river	NL		x		
		DE				x
	lake	NL		x		x

5. EUTROPHICATION REFERENCE AND THRESHOLD VALUES

In this chapter, the reference and threshold values for the eutrophication assessments used in OSPAR and MSFD assessments as well as in the WFD river basin management plans are described in more detail.

5.1 OSPAR

OSPAR’s Quality Status Report (QSR) 2023 for the first time presented a eutrophication assessment which is coherent across country borders (OSPAR, 2023a). This is the fourth application of the Common Procedure (COMP4). Previously, OSPAR has assessed eutrophication based on national assessment areas and disparate approaches lacking a transparent and comparable basis. A more harmonized approach has now been achieved through development of ecologically relevant assessment areas defined by oceanographic criteria rather than international boundaries, allowing for consistent assessments across exclusive economic zones and acknowledging that eutrophication is a transboundary problem. Thresholds that were specific for those harmonized assessment areas and eutrophication parameters have been derived primarily from an ensemble modeling approach to determine pre-eutrophic conditions. Common assessment areas and harmonized thresholds have enabled, for the first time, an objective and comparable assessment of the eutrophication status of the whole OSPAR Maritime Area. This establishes a level playing field for managing eutrophication and a solid basis for deriving OSPAR nutrient reduction targets as a prerequisite for targeted and successful regional eutrophication management (Devlin et al., 2023).

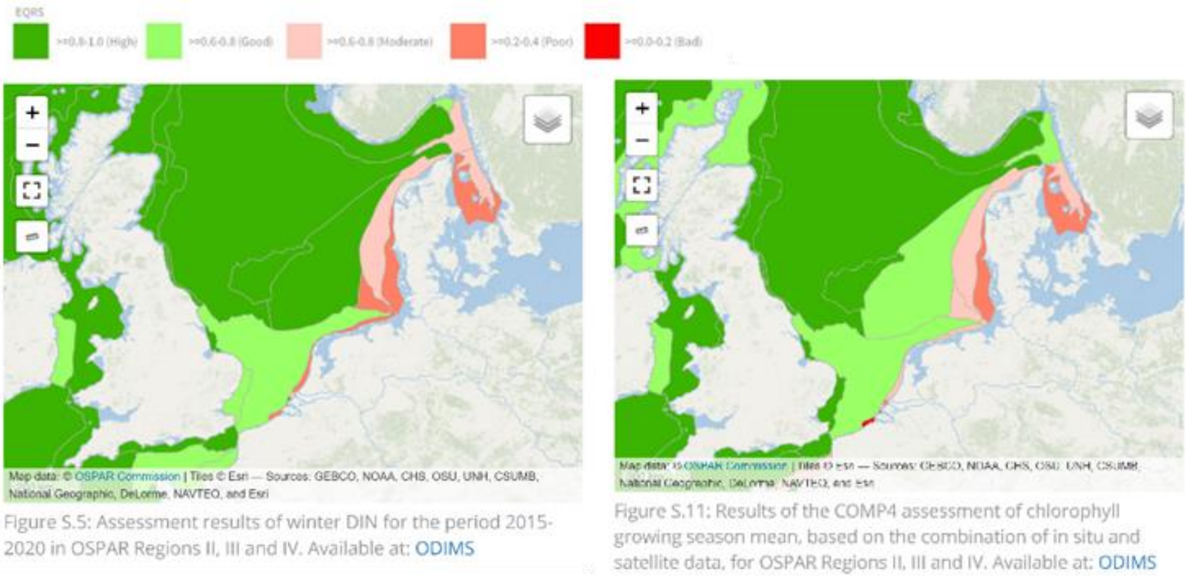
Indicators
The indicators involved in the OSPAR assessment of eutrophication are:

- *Winter dissolved inorganic nitrogen (DIN)*
- *Winter dissolved inorganic phosphorus (DIP)*
- Total nitrogen (TN)
- Total phosphorus (TP)
- *Growing season chlorophyll a*
- *Oxygen close to the seafloor*
- Secchi depth

The indicators in italics are common to all OSPAR contracting parties, the others are reported by Germany and Denmark, but not by the Netherlands.

Reference and threshold values
OSPAR agreed to use the pre-eutrophic conditions around the year 1900 as a reference for winter DIN and DIP and for chlorophyll *a* concentrations. These conditions were modelled using information on land use, human population size and wastewater treatment. A set of (partly overlapping) eco-hydrodynamic models estimated the distribution of resulting nutrient inputs in the sea and the chlorophyll concentrations as they would have occurred around 1900 (OSPAR, 2022). In order to allow for natural variability, and in the absence of more specific information, the assessment level was defined as the concentration 50% above the salinity-related and/or area-specific background concentration in the first application of the Common Procedure (OSPAR, 2003).

The threshold values are area-specific, taking into account e.g. the dilution of river water flowing into the sea. Many areas are shared by neighboring countries, however some smaller ones, e.g. river plumes, do not cross national borders. Figure 2 shows the so-called COMP4 assessment areas relevant for this deliverable, including the outcomes of the assessments of Winter DIN and chlorophyll *a*. The WFD (coastal) water bodies were not assessed by OSPAR.



Map data: © OSPAR Commission | Tiles © Esri — Sources: GEBCO, NOAA, CHS, OSU, UNH, CSUMB, National Geographic, DeLorme, NAVTEQ, and Esri

Figure 5.5: Assessment results of winter DIN for the period 2015-2020 in OSPAR Regions II, III and IV. Available at: ODIMS

Map data: © OSPAR Commission | Tiles © Esri — Sources: GEBCO, NOAA, CHS, OSU, UNH, CSUMB, National Geographic, DeLorme, NAVTEQ, and Esri

Figure 5.11: Results of the COMP4 assessment of chlorophyll growing season mean, based on the combination of in situ and satellite data, for OSPAR Regions II, III and IV. Available at: ODIMS

Figure 2. COMP4 assessment areas and the results of the COMP4 assessment of winter DIN (left panel) and chlorophyll a (right panel). The colors refer to EQRS classes, see legend on top of the Figure (OSPAR, 2023a).

5.2 MSFD

The OSPAR COMP4 assessments are used for the 2024 MSFD Article 8 reporting by most OSPAR contracting parties that are also EU member states, including Germany and the Netherlands and rely on the same indicators as listed above and the same threshold values.

Germany
Germany reports the coastal waters including the Wadden Sea as a part of the MSFD area and recalculates the eutrophication status using OSPAR's COMP4 assessment rules. The indicator assessments follow the WFD methodology and are using WFD thresholds.

Netherlands
Under the MSFD the Netherlands report the status of the coastal and open sea waters to the seaward side of the 'basiskustlijn'. Hence, the Netherlands do not report the Wadden Sea under the MSFD and use the WFD 2021 assessment for the coastal water bodies Ems-Dollart, Waddencoast, Dutch coast ('Hollandse kust'), Northern Deltacoast ('Noordelijke Deltakust') and Zeeland coast ('Zeeuwse kust'). The OSPAR COMP4 results are used for the areas to the seaward side of the coastal WFD water bodies (Figure 3).

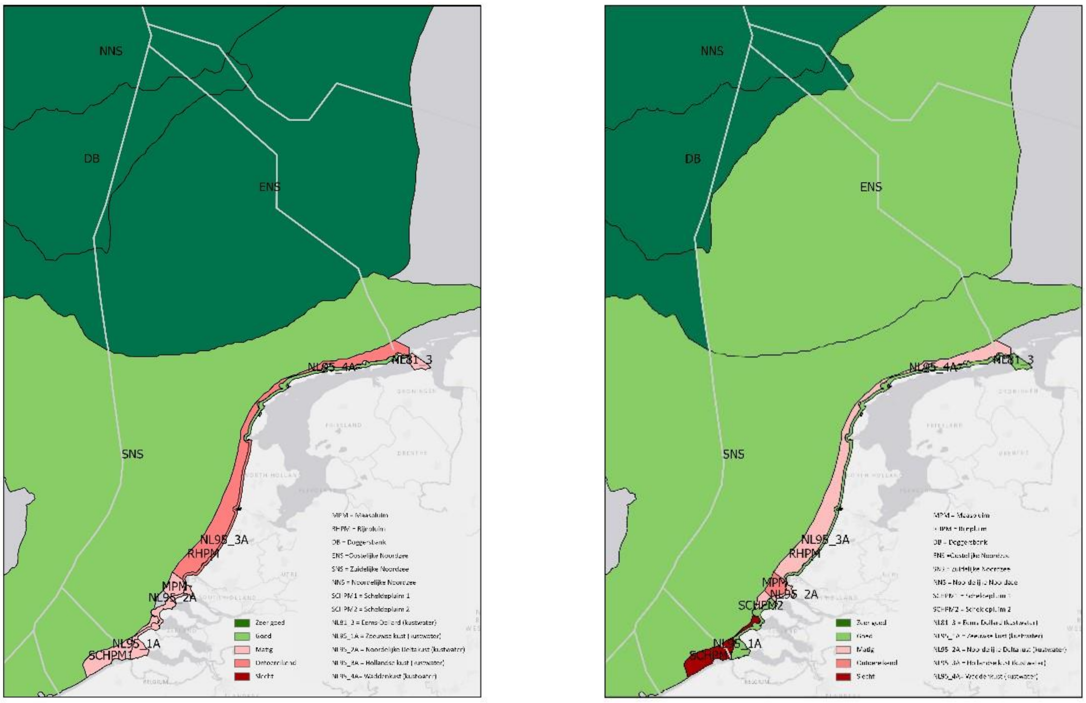


Figure 3. Assessment of the present winter DIN (left) and chlorophyll a (right) according to OSPAR and WFD for the Dutch coastal zone. The Dutch assessment areas for OSPAR are adjacent to the WFD coastal water bodies. Color codes are according to OSPAR: dark green = high, green = good, light red = moderate, red = poor, dark red = bad status (Ministry of Infrastructure and Water Management, in prep.)

5.3 WFD

Netherlands

As in OSPAR/MSFD, chlorophyll *a* is a proxy for phytoplankton biomass under the WFD. This indicator (or quality element) is applied in the water body categories lakes, transitional waters and coastal waters, not in rivers.

The definition of Dutch WFD reference conditions and threshold values for *coastal and transitional* water bodies goes back to the 1990's, with amendments following the intercalibration process (Carletti & Heiskanen 2009), expert judgment and work in OSPAR.

In the framework of the "Watersysteemverkenning" (Water System Exploration), so called reference values, representing the upper boundary of the good status, for a number of functional groups and individual species (including chlorophyll *a*) were calculated (Baptist & Jagtman 1997). For the calculation of these reference values the year 1930 was chosen as being illustrative for a situation with limited anthropogenic disturbance and some availability of historical data (Baptist & Jagtman 1997). The natural reference loads were derived from multi-annual average river discharges combined with estimates of the range in natural background concentrations for total-N and total-P. Ranges for natural background concentrations had been established in an international workshop on background concentrations of natural compounds in the North Sea. The lowest value represents the estimated upper limit for pristine conditions, whereas the highest value represents the upper limit for unpolluted conditions (Laane 1992, Wulffraat et al. 1993, Ahl 1994).

Using specific models for the various water systems chlorophyll *a* (90-percentiles) for the year 1930 was calculated (Baptist & Jagtman 1997; Lorenz et al. 2004). For a 50-km wide zone of coastal waters in the North Sea, the calculated reference value was 14.3 µg/l. The Dutch coastal water bodies were divided into two groups. Water bodies 'Holland coast' and 'Northern Delta coast' near the mouth and downstream from the main outflows of Rhine and Meuse have larger salinity ranges and lower salinities and belong to the polyhaline type (NEA-GIG type NEA3). The other water bodies in the coastal waters (Zeeland coast, Wadden coast, Ems-Dollart coast) have smaller salinity ranges and are of the euhaline type (NEA-GIG type NEA1/26b. As the Wadden Sea (NEA-GIG type NEA4: sheltered, polyhaline coastal water) also was characterized by large freshwater discharges and reduced salinities, it was concluded that it could have the same reference values as NEA-GIG type NEA3. Therefore, the 90-percentile of chlorophyll *a* in the growing season as calculated by Baptist & Jagtman (1997) for the Dutch coastal zone (14 µg/l) was used for both water types (Prins et al. 2017).

The model estimates of Baptist & Jagtman (1997) were considered the boundary between high and good Ecological Status in the WFD, consistent with the definitions of ecological status in the WFD, where the reference represents undisturbed conditions (high status) and good status is characterized by “a slight deviation from reference conditions”. The good/moderate boundary is 1.5 times the high/good boundary (Carletti & Heiskanen 2009).

After intercalibration (EC 2018) with Germany, the good/moderate boundaries for coastal water bodies were set to the values shown in Figure 1. See also van den Berg (2004), van den Berg & Pot (2007), van der Molen et al. (2018).

Chlorophyll *a* threshold values for *lakes* are based on background concentrations for phosphorus. The boundary between reference conditions and good status depends on the water type as a consequence of differences in hydromorphology and water bottom type. In the present study large, deep and buffered lakes are taken into account, which are classified as type M21. The boundaries of the five WFD quality classes have been calibrated internationally. These boundaries are given in “Referenties en maatlatten voor natuurlijke watertypen voor de Kaderrichtlijn Water 2021-2027” (STOWA, 2020). For lakes, such as Markermeer and Lake IJssel, that are defined as ‘heavily modified’, the boundary between good and moderate shifts proportionally towards the boundary between moderate and inadequate as defined for natural water bodies.

Phytoplankton growth in lakes of type M21 is limited by the concentration of phosphorus. The boundary between good and moderate status is based on observations made in Lake Peipsi (Estland) that is regarded as a reference for this lake type. WFD threshold values for phosphorus (total P) and nitrogen (total N) are given in STOWA (2020).

In the present study, slow flowing rivers and tributaries on sand or clay (R7 type) have also been considered. Chlorophyll *a* is not part of the assessment for these water bodies. Phosphorus is regarded as the limiting nutrient for plant/algal growth. Nitrogen threshold values cannot be derived from the characteristics of the water type, since these rivers are heavily modified. Therefore, the threshold value for coastal waters has been extrapolated to this type of rivers (STOWA, 2020).

Germany

Reference concentrations of chlorophyll *a* and nutrients were estimated for different water bodies by Topçu et al., (2006). They used modeled riverine nutrient inputs based on the nutrient model MONERIS (Behrendt et al., 2003) and present-day correlations between TN and chlorophyll *a* to estimate the historical reference (pristine) concentrations of chlorophyll *a*. The reference 90-percentiles are 3.3 µg/l for euhaline water bodies (water-body types N1 and N2) and 4.8 µg/l for polyhaline water bodies (water-body types N3 and N4, Brockmann and Topçu, For the nutrient reference and orientation values, Germany has used the approach as described for Chlorophyll-a above, but realized over time that the resulting nutrient orientation values were too low and unrealistic to achieve since they are based a pristine nutrient input scenario with unrealistic assumptions (Germany without any population and fully forested). Therefore, a later version of the MONERIS model (Venohr et al., 2011) was used to re-calculate the riverine nutrient loads into the German North Sea for the reference year 1880 (Gadegast and Venohr, 2015). A similar approach was applied to the German Baltic Sea (Hirt et al., 2014) originally to the Oder basin (Gadegast et al., 2012). The reference values for the different water bodies were interpolated along the salinity gradient into the German Bight between the reference values for the riverine input and assuming recent measured conditions for the outer open sea waters (Topçu et al. 2006). For N, 50% N retention in estuaries was assumed (EUNÄP, 2015; LAWA-AO, 2021).

For rivers, the WFD threshold values for different river types were derived from modelled of reference conditions with MONERIS (based on Behrendt et al. 2003) and statistical and regression analyses of monitoring data. The threshold values for mean chlorophyll *a* between March and October were only determined for suitable river types based on their response to TP. The monitoring data was grouped by the (preliminary) TP status (e.g. Mischke et al. 2011, Mischke & Behrendt 2005). The boundary for high-good was set to 0.05 mg/l – derived as reference condition based on the MONERIS results (Mischke and Behrendt 2005). The boundary poor-bad was set at the point of saturation point, i.e. the point of no further response to increasing TP. The remaining boundaries (good-moderate, moderate-poor) were derived by fitting regression models to the TP range and dividing it into equal parts (e.g. Mischke et al., 2011). The chlorophyll *a* assessment is part of the PhytoFluss assessment for phytoplankton in rivers – a multi-metrics assessment which also considers algal groups, and type-specific indicator lists (Mischke et al., 2022). The other metrics were derived from statistical and regression analyses using monitoring data for (preliminary) status classes based on TP and chlorophyll *a*. The assessment was continuously further developed and extended to other river types. For instance, PhytoFluss uses maximum chlorophyll *a* as metrics since v4.0 (cf. Rohlaufs et al., 2020).

The thresholds for nutrients were derived with statistical and regression analyses based on monitoring data and the status according to different biological quality elements. The most sensitive element was selected (Halle & Müller 2014).

Realizing that waterborne nutrient inputs should be managed using nutrient targets that enable the achievement of good status for all surface water bodies, including rivers, lakes, coastal and marine waters, Germany has set a “management target” for the concentration of total nitrogen at the limnic-marine border in rivers that allows the achievement of good status in transitional, coastal and marine waters. This target concentration of 2.8 mg/l TN at the limnic-marine border was derived from the load reduction relative to 2005/6 needed to achieve a good ecological status of the Wadden Sea. For the Rhine the target concentration of 2.8 mg/l is set at the Dutch-German border. A summer concentration of 2.5 mg/l for the Rhine at Bimmen/Lobith was calculated from the (then) Dutch working standard of 0.46 mg/l DIN for the Wadden Sea. The summer concentration was found to correspond to a mean annual concentration of 2.8 mg/l TN (ICPR 2009). The threshold was later extended to other German rivers flowing into North Sea out of ecological considerations of the eutrophication of the North Frisian Wadden Sea, assuming a molar silicate-total nitrogen ratio in rivers of 1:1 (BLMP 2011). Germany has extrapolated the target concentration at the limnic-marine border upstream using the catchment model MONERIS and by considering in-stream retention. Maximum allowable total nitrogen concentrations upstream have been calculated and are considered in the River Basin Management Plans. Under the MSFD, the achievement of 2.8 mg/l TN serves as an environmental target under Article 10 of the Directive. Currently, work is underway in Germany to investigate whether there is a need to set a corresponding “management value” for TP as well. So far, it is assumed that the riverine orientation values for TP are sufficient to achieve the good status of transitional, coastal, and marine waters.

WFD fitness check

The focus of OSPAR so far has been on improving the coherence in eutrophication assessments of marine waters on the seaward side of the WFD coastal waters. The WFD Fitness Check has clearly shown that the WFD’s objectives have not been reached fully yet due to insufficient funding, slow implementation, and poor integration of environmental objectives in sectoral policies, and not due to a deficiency in the legislation. However, the Fitness Check did not look at all nutrient emission-related legislation and there is a need to work further on improving the coherence between WFD and other relevant policy frameworks, such as the Common Agriculture Policy, the Nitrates Directive, Urban Waste Water Directive, National Emissions reduction Commitments (NEC) Directive, MFSD, the Habitats Directive and the new OSPAR Northeast Atlantic Environment Strategy in particular when it comes to implementing measures (see EU DG Environment, 2019).

6. COMPARISON OF THRESHOLD VALUES IN THE CATCHMENTS OF THREE CASE STUDIES

6.1 Introduction: the catchments

The catchment-estuary-sea continuum responds differently to nutrient pressures across its subsystems. Freshwater systems are more impacted by phosphorus (P) availability, while marine waters are typically limited by nitrogen (N) availability for phytoplankton growth. However, this paradigm was challenged in the German Project Nitrolimit showing N limitation especially in shallow lakes (Nitrolimit, see Wiedner et al. 2016). Recent observations in the Elbe also point at a possible N limitation during low flow conditions (Gesa Schulz, unpublished results, cf. Schulz et al., 2023). Estuarine and coastal waters may be influenced by both nutrients. Silicon (Si) also plays a crucial role, particularly in limiting diatom growth under eutrophic conditions. The specific impacts of eutrophication on ecosystem health and safe ecological limits vary depending on the ecosystem type, and the feasibility and effectiveness of measures, as well as local socio-economic factors and stakeholder involvement. Therefore, three out of four NAPSEA case studies were included in the present study to illustrate various scales of impact and different eutrophication symptoms for each water type (catchment, estuary, coastal sea):

- Rhine basin: Focuses on oligotrophication due to damming and phosphorus deficiency in water systems like Lake IJssel, emphasizing the need for natural solutions and management of nutrient fluxes;
- Elbe Estuary: Addresses organic matter accumulation, hypoxia, and greenhouse gas release due to excess nutrients and ship fairway deepening;

- Wadden Sea: Discusses the impacts of nutrient influx from various river catchments, highlighting differences in ecosystem responses and drivers of primary production, and other eutrophication indicators like nutrient ratios, (N:Si:P), macroalgae blooms, and seagrass.

The fourth case study (Hunze catchment) was not included since it covers a relatively small catchment area, with a limited limnic-marine gradient.

This present report evaluates local ecosystem functioning and indicators of eutrophication effects across these case studies. Existing model results reveal that the relative importance of nutrient pathways and sources varies in space and depend on the specific model (setup). The overall picture remains however consistent: the intensive agriculture with its high N surplus on agricultural soils causes high N inputs via tile drainage and subsurface flow, while for P urban sources including wastewater treatment are at least equally important as the agricultural input. Given the larger area of surface waters, the share of atmospheric N deposition is higher in the Netherlands than in Germany (cf. Deliverable D 2.2 and the references therein).

6.2 The Rhine catchment

The total length of the river Rhine is 1230 km. The river begins in the Swiss canton of Graubünden in the south-eastern Swiss Alps, forms part of the Swiss-Liechtenstein, Swiss-Austrian, Swiss-German and then the France-German border, then flows in a mostly northerly direction through the German Rhineland and the Netherlands and empties into the North Sea. Near Cologne, the river Rhine changes from a typical gravel-dominated river of the German *Mittelgebirge* (type 10 according to the German typology) to a sand-dominated river of the lowlands (type 20). Given its high discharge, the water bodies along the river are assigned the sub-type 10.1 and 20.1 (in contrast to river Elbe).

The catchment has a total area of 200000 km^2, which flows in the branches of Haringvliet, Nieuwe Waterweg, Noordzeekanaal and Lake Ijssel into the North Sea and the Wadden Sea (Figure 4). The Rhine has an average discharge of 2300 m^3/s (OSPAR, 2023b). After the strong decline during the 1990s, the changes in TN and TP concentration and load are small. The river Rhine currently achieves the nutrient targets according to WFD and MSFD at the German-Dutch border (cf. Figure 3 in Deliverable D 2.2).

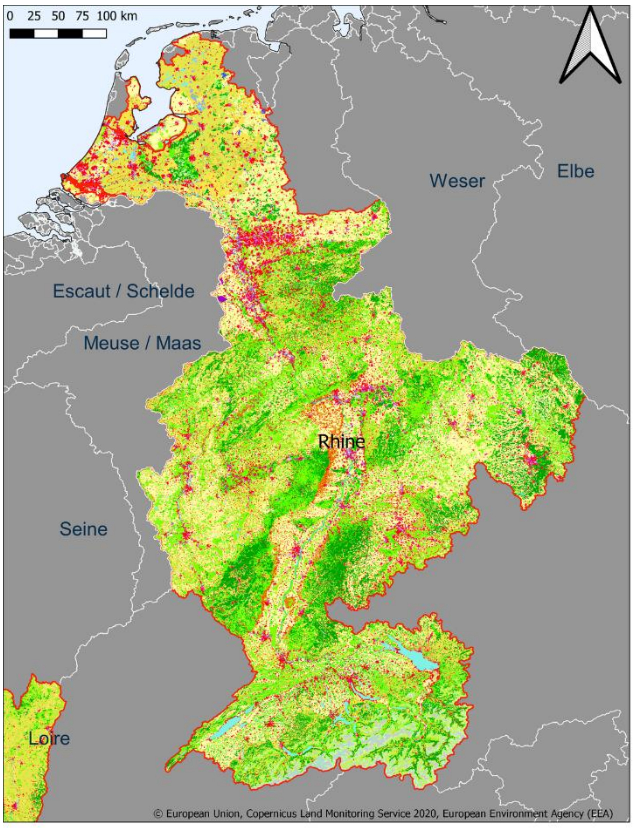


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Figure 4: Map showing the extent and land use in the Rhine basin (OSPAR, 2023b)

For this deliverable the focus is on the gradient of threshold values for the German and Dutch parts of the Rhine itself, but also including the WFD water bodies via which the Rhine discharges into the sea:

- R-type (river) water bodies: German parts along river Rhine, Nederrijn-Lek, Bovenrijn-Waal, Ijssel, Boven- en Beneden Merwede, Oude Maas, Nieuwe Maas;
- M-type (lake) water bodies: Amstelmeer, Ijsselmeer, Ketelmeer;
- O-type (transitional) water bodies: Nieuwe Waterweg;
- K-type (coastal) water bodies: Waddenzee, Waddenzee vastelandskust, Hollandse Kust, Waddenkust.

Next to the WFD water bodies, the COMP4 area Rhine Plume, which is adjacent to the WFD water bodies to the seaward side, is also included in our analysis.

6.3 The Elbe Catchment

The total length of the river Elbe is 1094 km from its source in the Krkonoše Mountains to its estuary, the North Sea. The area of the Elbe river’s drainage basin covers about 150000 km^2. About two thirds of the catchment belongs to Germany and represents about 27% of the total German land area. Around one third of the Elbe catchment belongs to the Czech Republic. Austria and Poland have almost the same small shares in the catchment area. Usually, the Elbe is subdivided into three parts: the upper Elbe (from the spring to Elbe km 96 – Schloss Hirschstein, 54170 km^2), the middle Elbe (from km 96 to Elbe km 585.9 – weir Geesthacht, 80843 km^2) and the lower Elbe (from Elbe km 585.9 to the North Sea, Elbe km 727.7 – Cuxhaven Kugelbake, 13255 km^2). Near the city of Hamburg, the Elbe divides into two branches: the Norderelbe and Süderelbe, encompassing the harbor. Here, the depth of the Elbe strongly increases due to dredging activities. Downstream of the weir at Geesthacht (upstream of Hamburg), the river forms an estuary with a width of 1.5 km downstream of Hamburg and 18 km near Cuxhaven. With a length of 90 km, the Elbe estuary is connected to the Wadden Sea – German Bight (OSPAR, 2023b).

The middle and lower sections of the river Elbe are typical for lowland river with an average discharge below 10 l s^{-1} km^{-2} at the limnic-marine border. The water bodies are classified as type 20.2 (sand dominated) according to the German typology. In the mountainous upper part, the river is gravel dominated (type 10.2). While the change in the main class implies different thresholds for nutrient concentrations along the river according to the German legislation, the sub-types result in different thresholds for chlorophyll *a* between river Elbe and Rhine.

For the Elbe, the TN goal is set at an annual mean of 2.8 mg/l. Originally, the value was set for winter concentrations and represents a 1:1 molar ratio of Si and N. It was intended to be used as a minimum goal and could be interpreted as the transition between the moderate and good status.

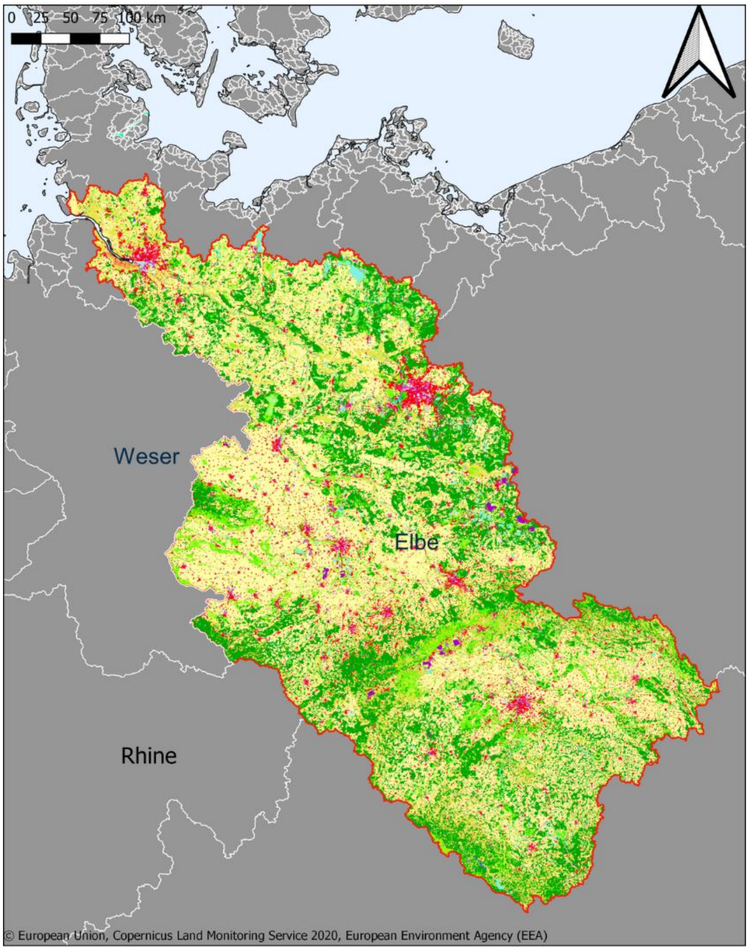

Figure 5: Map showing the extent and land use in the Elbe basin (OSPAR, 2023b).

Similar to river Rhine, the TN and TP concentration and load declined strongly during the 1990s with negligible changes since then. However, the discharge significantly decreased during the last decade. Currently, river Elbe does not meet the nutrient targets at the limnic-marine border according to WFD and MSFD (cf. Figure 3 in Gericke & Leujak, 2023).

6.4 The Wadden Sea

The Wadden Sea is a large intertidal coastal sea along the continental European North Sea coast (see Figure 1). It is impacted by direct discharges from the large tributaries, *ie*. Lake IJssel, Ems, Weser, and Elbe as well as small rivers and sluices. The combined Rhine/Meuse discharge indirectly impacts the Wadden Sea mainly by supporting the high primary production of the coastal phytoplankton. Part of the offshore primary production is imported into the Wadden Sea supporting the high local primary production. Therefore, the Wadden Sea eutrophication is not locally driven but to a major part by nutrient inputs from the European continent (van Beusekom et al., 2019).

6.5 Comparison of threshold values

Here, we focus on the indicators that are used for both WFD and OSPAR/MSFD reporting, *i.e.* winter DIN, TN and chlorophyll *a*. Figures 6 to 8 below demonstrate how the threshold values change from land to sea, across the limnic-marine boundaries. Further details can be found in the Excel matrix ‘NAPSEA task 4.1 inventory indicator threshold values (TVs)'.

Winter dissolved inorganic nitrogen (DIN)

Figure 6 depicts the evolution of threshold values for winter DIN along the rivers Rhine and Elbe. Since winter DIN is only used for transitional and coastal WFD water bodies and for the OSPAR COMP4 areas (here the Rhine and Elbe Plumes) a comparison across the limnic-marine boundary is not possible. In German freshwaters, nitrogen is not expressed as DIN but as the inorganic N components except nitrate (NH_4-N, NH_3-N, and NO_2-N). In Dutch fresh waters nitrogen is only expressed as TN (see Figure 7).

However, the threshold values decrease from land to sea, with higher values for transitional waters. For the Rhine, the lowest value is in the Rhine Plume, which is to be expected given the dilution of river water flowing into the sea. For the Elbe Plume, the threshold value is slightly higher than the threshold value for the water body “Helgoland”. Looking at the outcomes of the area-specific assessments, the transitional and coastal waters in the Elbe catchment, including the Elbe Plume are all assessed as ‘not good'. For the Rhine catchment, the coastal waters to the North of the Dutch Wadden Islands (water body ‘Waddenkust’) are assessed as ‘good', while the Rhine Plume adjacent to this area is considered ‘not good'.

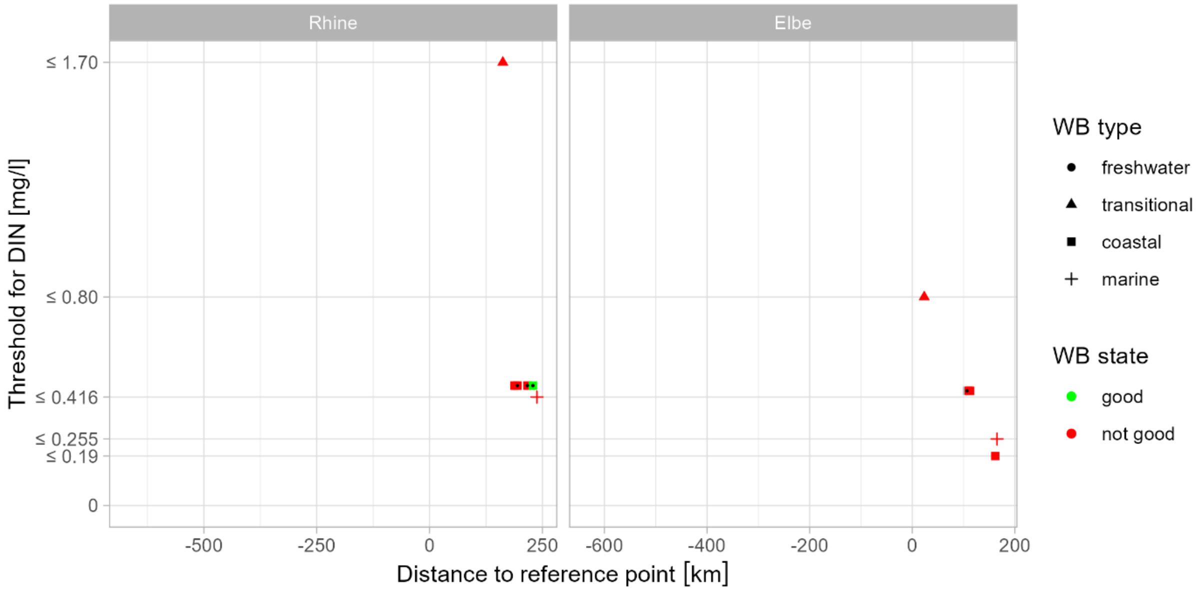

Figure 6. Threshold values and states for dissolved inorganic N (DIN) of different types of water bodies belonging to rivers Rhine (left) and Elbe (right). The two river plumes (marine areas, crosses) are linked to OSPAR (MSFD), the remaining water bodies along the main rivers (arms) to the WFD. The reference points (x=0 m) are located at the German-Dutch border (r. Rhine) and the limnic-marine border (r. Elbe). The x value approximates the flow distance along the linear water bodies (rivers) extended by the shortest Euclidean distance between the endpoints of the river network and the centroid of the other water bodies. Points with a black dot refer to the Wadden Sea. The threshold values refer to the average winter DIN between December and February (OSPAR, NL) and November and February (DE). The state of German WFD water bodies refers to nitrogen.

Total nitrogen (TN)

Figure 7 shows the changes in threshold values for TN along the river Rhine and Elbe. Since TN is only used for fresh WFD water bodies in the Netherlands, comparison across the limnic-marine boundary of the Rhine catchment is not possible. In German freshwaters, nitrogen is expressed as separate components (NH_4-N, NH_3-N and NO_2-N). However, Germany uses a TN threshold value for the national (Rhine) and limnic-marine borders and reports TN for transitional, coastal and marine (OSPAR) water bodies/assessment areas. For the Elbe catchment a decrease in threshold values is shown from land to sea, which is consistent with the dilution of river water when it flows into the sea. The outcomes of the assessments are consistently ‘not good’ for the Elbe catchment, while a mixed pattern is seen in the Rhine catchment. In Dutch transitional and coastal waters nitrogen is expressed as winter DIN (see Figure 6) and therefore cannot be compared to the freshwater threshold values.

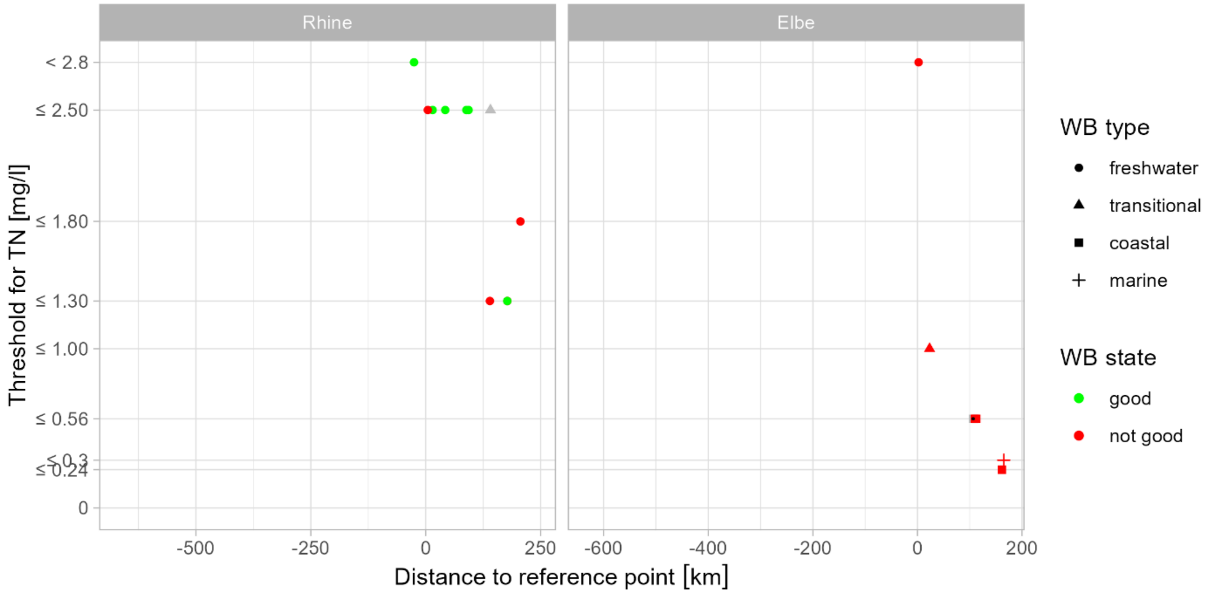

Figure 7. Threshold values and states for total N (TN) of different types of water bodies belonging to rivers Rhine (left) and Elbe (right). The two river plumes (marine areas, crosses) are linked to OSPAR (MSFD), the remaining water bodies along the main rivers (arms) to the WFD. The reference points (x=0 m) are located at the German-Dutch border (r. Rhine) and the limnic-marine border (r. Elbe). The x value approximates the flow distance along the linear water bodies (rivers) extended by the shortest Euclidean distance between the endpoints of the river network and the centroid of the other water bodies. Points with a black dot refer to the Wadden Sea. The threshold values refer to the average annual TN. The state of German WFD water bodies refers to nitrogen.

Chlorophyll a

Figure 8 shows the changes in threshold values for chlorophyll *a* along the river Rhine and Elbe. The indicator chlorophyll *a* is used across most of the river catchments, enabling comparison across the limnic-marine border. As an exception this indicator is not applied to the Dutch R-type water bodies, which creates a gap between the German-Dutch border and the more downstream water bodies in the Netherlands (Figure 8, left panel). In the case of the Rhine, the threshold values do not decrease consistently from land to sea as a number of (heavily modified) lakes have higher threshold values, probably due to their high retention of nutrients. Furthermore, the threshold value for the Rhine Plume is higher than the adjacent (landwards) WFD coastal water bodies. This is not the case for the Elbe, where OSPAR threshold values were adjusted to ensure a decrease from coastal WFD water bodies to the Elbe Plume.

Regarding the outcome of the assessments, the more upstream part of the German Rhine is in a ‘good’ state, while the more downstream part is ‘not good’ anymore. The German water bodies along river Rhine have the same threshold value. From the German-Dutch border, good and not good status both occur and there is no distinct pattern across the limnic-marine border. For the Elbe catchment, most of the areas are assessed as being in ‘not good’ status, although some, more downstream freshwater water bodies are 'good'.

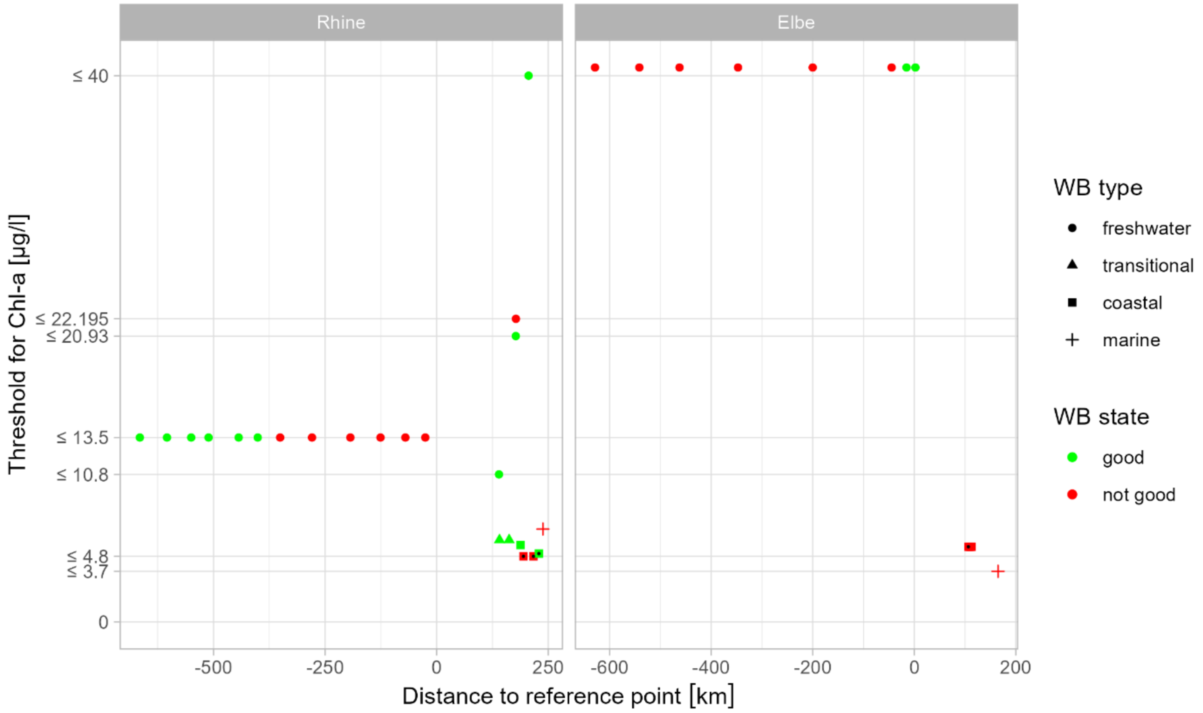

Figure 8. Threshold values for chlorophyll a and phytoplankton states of different types of water bodies belonging to rivers Rhine (left) and Elbe (right). The two river plumes (marine areas, crosses) are linked to OSPAR (MSFD), the remaining water bodies along the main rivers (arms) to the WFD. The reference points (x=0 m) are located at the German-Dutch border (r. Rhine) and the limnic-marine border (r. Elbe). The x value approximates the flow distance along the linear water bodies (rivers) extended by the shortest Euclidean distance between the endpoints of the river network and the centroid of the other water bodies. Points with a black dot refer to the Wadden Sea. The threshold values refer to the growing season between March and September (OSPAR, NL, transitional and coastal areas in DE) or October (rivers in DE) based on 90- percentiles divided by two to approximate the seasonal mean value.

7. DISCUSSION

Although a large set of indicators for the assessment of eutrophication status and the status of pelagic or benthic habitats is available across the legal assessment frameworks WFD and OSPAR/MSFD, only a limited selection is comparable across these frameworks and across the German-Dutch border. The only parameter that allows such a comparison is chlorophyll *a*, although this indicator is not applied to the Dutch R-type water bodies. The narratives behind the threshold values also vary. OSPAR uses modelled reference values around the year 1900 with an acceptable deviation of +50%, while for the WFD different approaches are used in Germany and the Netherlands. These are not necessarily the same as the '1900' reference plus 50% and vary across water body types, see column G in the Excel matrix presented in the Annex. Therefore, expecting a consistent gradient of threshold values from land to sea is difficult.

This lack of harmonization seriously hampers further analyses. This problem was also encountered by Poikane et al. (2019) who reviewed nutrient criteria for surface waters under the European WFD and came to similar conclusions. They suggest that further development of nutrient criteria should be based on relationships between ecological status and nutrient concentrations, taking into account the need for comparability between different water categories, water body types within these categories, and countries.

One of the problems in setting thresholds is related to the underlying ecological problem. Depending on which problem is encountered, different goals can be formulated to mitigate the problems (Boers *et al*., 1995; see Table 2).

Table 2: A list of possible environmental goals in the coastal North Sea and target concentrations of TN in the river Rhine to encounter these environmental problems (from Boers et al., 1995)

Objective	Rhine, mg/l N	North Sea (coastal area), mg/l N
Coastal waters		
Natural concentration	0.6	0.34
50% biomass reduction in Spring	1.8	0.6
25% reduction of annual mean biomass	3.0	
No oxygen depletion in stratified parts	3.0	
Max. biomass of Phaeocystis < 5 µg/l	1.8	
N-limited growth	1.8	N:P < 7 g/g
Lake IJssel		
No dominance of blue-green algae	1.4	
River Rhine		
Natural N:P ratio (0.15 mg/l TP)	1.9	
N-limited algal growth	1.0	
50% reduction of emissions	2.7-3.0	

The comparison of the threshold values shows a variety of patterns, as described in section 5.6, although a general decreasing trend is seen from land to sea. The variability in patterns is partly related to the encountered environmental problems. For instance, in the inner Elbe estuary, chlorophyll *a* levels are good, but oxygen levels are not good. This is linked to extremely high phytoplankton biomass in the riverine part of the Elbe, low primary production in the inner estuary but ongoing high levels of grazing leading to severe oxygen depletion. In other words, we have to be aware of the environmental bottlenecks in the land-river-ocean continuum leading to a discontinuity in the gradients of certain environmental indicators.

Different narratives in setting threshold values may also add to the observed discontinuities. As an example, we show recent values of chlorophyll *a* (summer values; May-September) from the Wadden Sea (Figure 9). The selected stations are all in or near the tidal inlet. Large differences exist between the northern and southern part of the Wadden Sea, probably due to a stronger import of organic matter and nutrients from the coastal zone to the southern Wadden Sea (NL, Lower Saxony (DE-NI) in DE) than in the northern Wadden Sea (Schleswig-Holstein (DE-SH) in DE, DK; see van Beusekom et al., 2019). The status of water bodies in the Elbe catchment (DE-SH) is generally 'not good', while for the Rhine a more mixed status is found. This contrasts with the ecological status being that seagrass recovered in the northern Wadden Sea, which is influenced by the Elbe, to pre-eutrophication levels but not in the southern Wadden Sea, which is influenced by the Rhine. The green bar in Figure 9 shows the range of chlorophyll *a* levels prevailing when seagrass recovery accelerated. Both in the western Dutch Wadden Sea (WDWS in Figure 9) and in the Lower Saxonian Wadden Sea between the Ems and Jade (EJWS), chlorophyll *a* levels approach these conditions. This is in line with first signs of recovery, but additional reduction measures are needed for a full recovery of seagrass. Details will be elaborated a.o. in the case study Wadden Sea.

Conclusion and Outlook

The review of threshold values highlights the inconsistency of (inter)national policies. Furthermore, the review highlights apparent discontinuities in the indicators and threshold values. These discontinuities occur partly due to the fact that environmental indicators and assessments reflect the local conditions whereas overarching (downstream) factors are not always taken into account. One of the remaining challenges in the project will be to further develop an integrated view on eutrophication including both terrestrial, limnic, estuarine and marine aspects. As example we will use our case studies. Elements considered are the conditions, including nutrient loads and chlorophyll *a* concentrations, that enable seagrass recovery and suppress oxygen problems in the Elbe estuary.

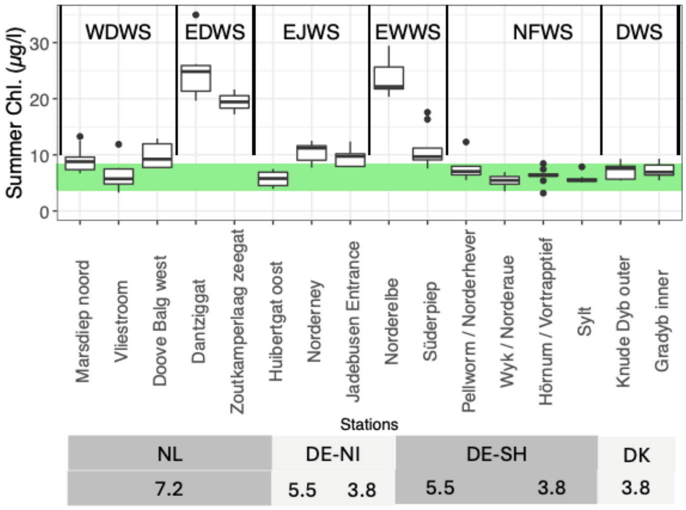

Figure 9: Present average summer chlorophyll a values (May – September; 2008 – 2016). The values in the grey box at the bottom show the good-moderate boundary by assuming that the 90-percentile is twice the average. The green box denotes the range of chlorophyll a values (3.8 – 8.2 µg/l) prevailing in the northern Wadden Sea when seagrass return accelerated (van Katwijk et al., in revision). Note that the threshold values apply to the entire growing season (March – September).

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ANNEX

- The basis of the inventory of eutrophication indicators and related reference conditions and threshold values is summarized in a matrix containing:
    - Tables for German and Dutch assessment areas/water bodies under OSPAR/MSFD and the WFD: OSPAR_MSFD (NL and DE together), WFD NL Marine waters (K and O-types), WFD DE Marine waters (N and T-types), WFD NL Fresh waters (R and M-types), WFD DE Freshwater (R-type);
    - A Readme page containing legends/explanations and references.
- Each Table presents for relevant assessment areas/water bodies:
    - Description of the indicator
    - Season taken into consideration
    - Unit (e.g. mg/l) and how it is derived (e.g. annual mean or P90)
    - Threshold value narrative
    - Threshold value for each assessment area/water body
    - Assessment outcome for each assessment area/water body
- The matrix is available on the NAPSEA website: https://napsea.eu/wp-content/uploads/2024/03/NAPSEA-task-4.1-inventory-indicator-TVs_forpublication.xlsx