OSPAR
COMMISSION

Eutrophication Thematic Assessment

OSPAR
QUALITY STATUS REPORT 2023

2022

OSPAR's Quality Status Report 2023

Eutrophication Thematic Assessment

Contributors

Lead authors: Michelle Devlin (UK), Hans Ruiter (NL), Philip Axe (SE), Wera Leujak (DE), Theo Prins (NL) and Birgit Heyden (DE)

Supporting authors: Hermann Lenhart (DE), Lasse Tor Nielsen (DK), Stiig Markager (DK), Francisco J. Gómez Jakobsen (ES), Jesús M. Mercado (ES), David Devreker (FR), Alain Lefevbre (FR), Robert Wilkes (IE), Garvan O’Donnell (IE), Lisette Enserink (NL), Rob Berbee (NL), Rob van der Veeren (NL), Federico Cornacchia (NL), Morten Skogen (NO), Marta Nogueira (PT), Emilie Brevière (SE), Liam Ferdinand (UK), Kate Collingridge (UK), Shannon White (UK), Eileen Bresnan (UK), Adrian Judd (UK), Jemma Lonsdale (UK), Bee Berx (UK), Stephen Dye (UK), Hjalte Parner (ICES), Alejandro Iglesias Campos, Eleanor Dening, Barbara Middleton, Lucy Ritchie, Chris Moulton and Julien Favier.

Supported by: OSPAR Hazardous Substances and Eutrophication Committee (HASEC), Intersessional Correspondence Group on Eutrophication (ICG-Eut), Intersessional Correspondence Group on Eutrophication Modelling (ICG-EMO), OSPAR Technical Group for the Common Procedure (TG-COMP), International Council for the Exploration of the Seas (ICES), Intersessional Correspondence Group on Ecosystem assessment outlook – Cumulative effects (ICG-EcoC), Intersessional Correspondence Group on Economic and Social Analysis (ICG-ESA), Climate Change Expert Group (CCEG).

Citation

OSPAR, 2023. *Eutrophication Thematic Assessment*. In: OSPAR, 2023: Quality Status Report 2023. OSPAR Commission, London. Available at: https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/thematic-assessments/eutrophication/

Contents

Executive summary

Nutrients, especially nitrogen and phosphorus, are essential for the growth of the aquatic plants that form the basis of marine food webs. Natural processes regulate the balance between nutrient availability and the growth of marine plants and animals in ecosystems. Excess nutrients introduced into the sea by human activities can disturb this balance, resulting in accelerated algal growth. This leads to adverse effects on water quality and marine ecology such as algal blooms, increased turbidity and eventually hypoxia, potentially causing fish and shellfish mortality **(Figure 1).** This process is known as eutrophication. Eutrophication harms water quality regulation and acts as a stressor on other ecosystem components. OSPAR works under its North-East Atlantic Environment Strategy (NEAES) 2030 to tackle eutrophication and to achieve a healthy marine environment.

This report describes the fourth application of the OSPAR Common Procedure for the assessment of eutrophication, which was conducted for the period 2015-2020. It identifies areas with eutrophication problems and where remediation measures are needed. Eutrophic areas were identified along the continental coasts from France to Denmark/Sweden and in river plumes of the Greater North Sea and the Bay of Biscay. Reanalysis of the previous three assessments shows a gradual improvement since 2000. However, the OSPAR 2010 objective "to *combat eutrophication, with the ultimate aim of achieving and maintaining a healthy marine environment where anthropogenic eutrophication does not occur*" has not yet been fully achieved.

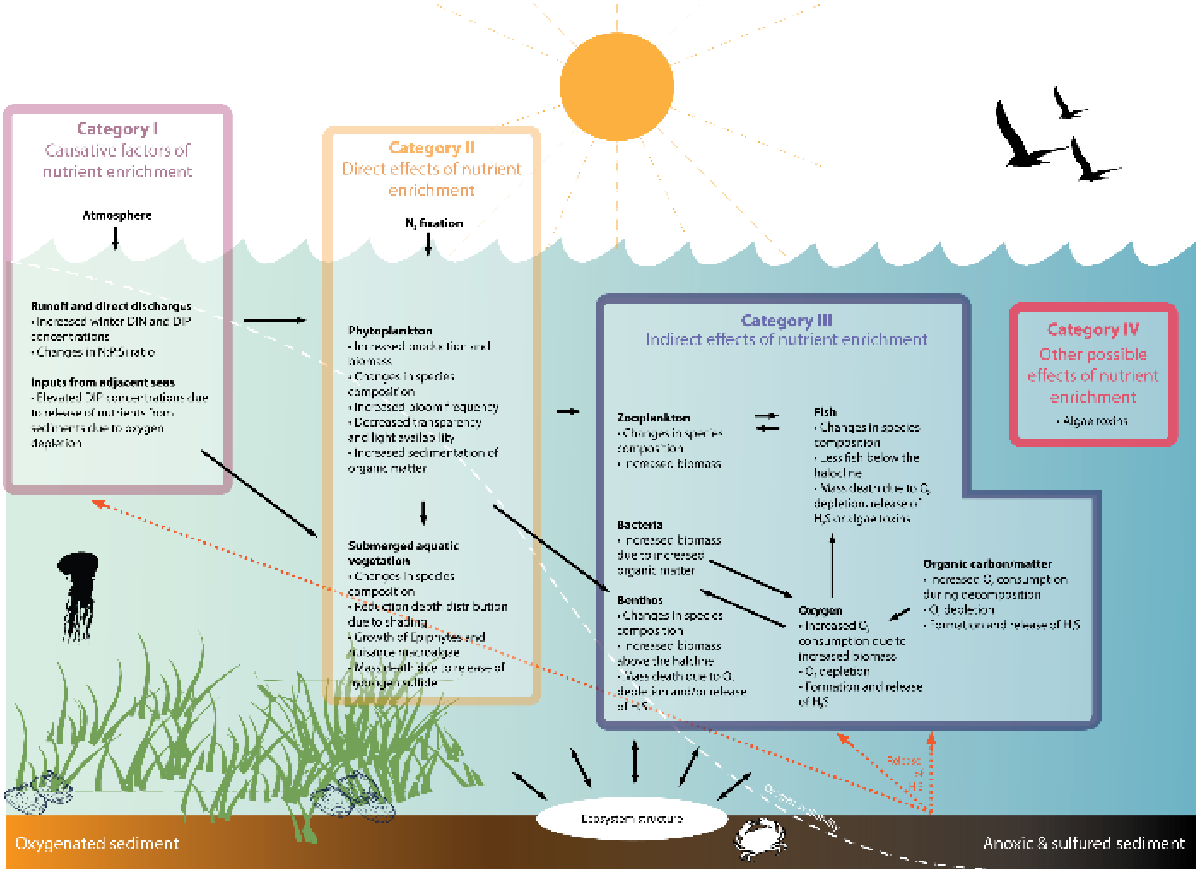


Figure 1: Schematic illustration of issues associated with eutrophication

During the industrial revolution, growing urbanisation in the OSPAR region, growing human populations and natural resource use, together with inadequately developed wastewater management, resulted in excess nutrients entering rivers and the sea. This caused historical eutrophication, particularly in shallower seas and coastal waters. Throughout the 20th century, while urban sewage management improved, the post-war need for food security and economic growth resulted in agricultural intensification and the use of vast amounts of mineral fertilizer to support this growth in output. The resulting nutrient discharges to waterways and estuaries led to large-scale marine eutrophication, particularly in the North Sea. In recent decades overall nutrient inputs have decreased. Fertilizer use has fallen significantly but nonetheless, agriculture remains a major nutrient source in our rivers and seas. Although industrial, agricultural, and domestic emissions of nitrogen into the air have also decreased substantially since 1990s, these sources still make up a third of the nitrogen reaching the sea. Future work to combat eutrophication in the OSPAR Maritime Area needs to further address these nutrient sources.

This application of the OSPAR Common Procedure differs from previous assessments, in that ecologically coherent assessment units and assessment thresholds have now been developed which reflect characteristics of the ecosystem rather than national boundaries. In addition, remote sensing and in situ data have been combined in an automated assessment tool, ensuring a genuinely "*regionally harmonised*" assessment.

Q1. Identify the problems? Are they the same in all OSPAR Regions?

OSPAR's overall strategic objective regarding eutrophication is to "tackle eutrophication, through limiting inputs of nutrients and organic matter to levels that do not give rise to adverse effects on the marine environment". To determine progress towards this objective, the OSPAR Common Procedure was revised and was applied for the fourth time in 2022 in OSPAR Regions II, III and IV **(Figure 2),** using data from 2015 to 2020. For the first time, the Common Procedure was based on ecologically relevant assessment areas and harmonised assessment thresholds, enabling a regionally coherent assessment outcome. Assessment areas have been defined by oceanographic criteria rather than international boundaries, so that assessments are now consistent across international boundaries, by contrast with previous practice. The use of OSPAR's Common Procedure Eutrophication Assessment Tool (COMPEAT) coupled with the refining of specific small-scale assessment areas (sub-area scale), has led to objective measures of eutrophication status which have a common scientific basis across the whole of the OSPAR Maritime Area. In addition, the thresholds for assessing status come primarily from an ensemble modelling approach or have been reported by the Contracting Parties for the assessment areas in which the modelling could not be applied, which provides a more objective measure for each assessment area than in previous assessments.

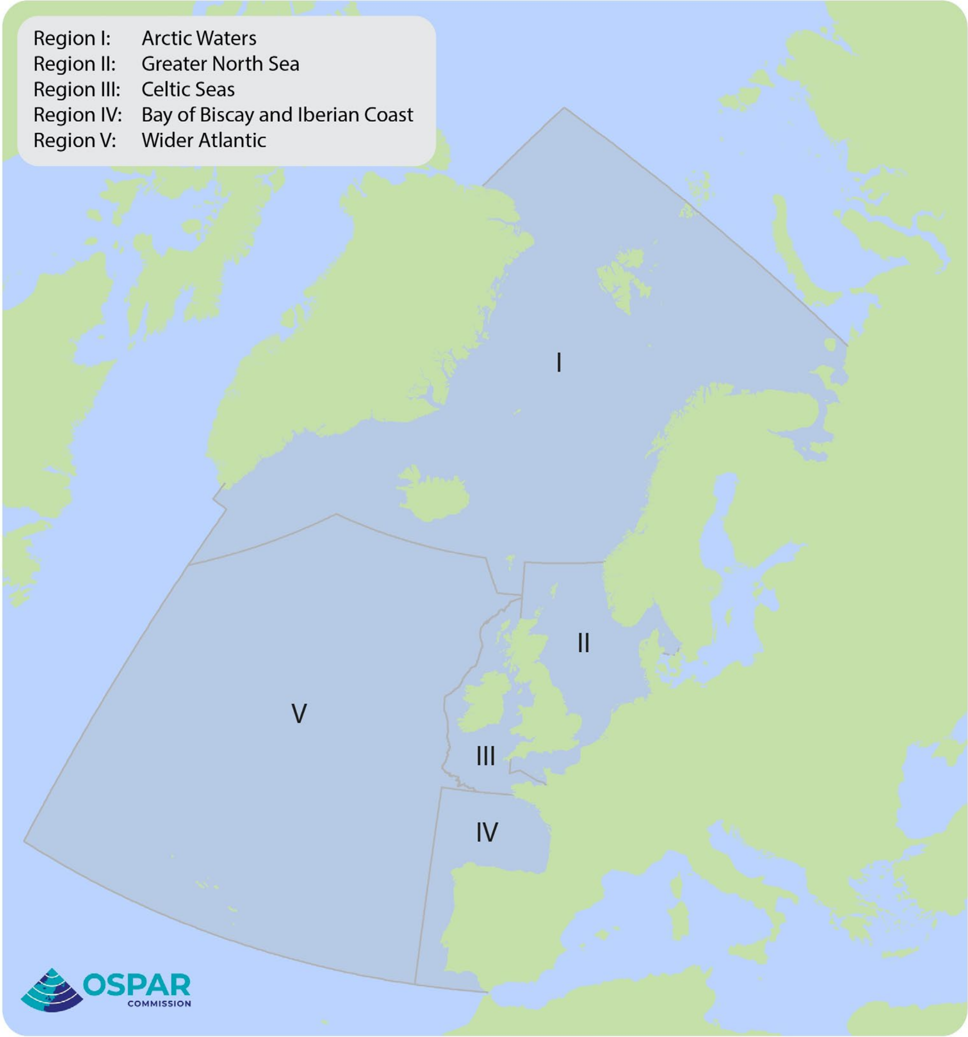


Figure 2: Location of the five OSPAR Regions comprising the OSPAR Maritime Area

The fourth application of the COMP indicates that eutrophication problem areas persist in particular along the continental coasts from France to Denmark/Sweden and in Regions II and IV. Mainly river plumes and coastal areas of Regions II and IV were affected by eutrophication, indicating that riverine nutrient inputs remain the major source.

Among the river plumes, 58% (15 555 km^2) did not achieve non-problem area status, while 22% (44 861 km^2) of the coastal areas and 10% (92 488 km^2) of the shelf areas did not achieve this status. The areas that are still eutrophic are Coastal French Channel, Scheldt plume, Meuse plume, Rhine plume, Ems plume, Elbe plume, German Bight Central, Outer coastal DEDK, Eastern North Sea, Kattegat Coastal and Kattegat Deep in Region II as well as Adour plume, Gironde plume, Gulf of Biscay coastal and Gulf of Biscay shelf in Region IV. By contrast, oceanic areas were not affected by eutrophication. Coastal waters subject to the EU Water Framework Directive were not assessed by OSPAR. Altogether, approximately 6% (152 904 km^2) of the OSPAR Maritime Area is eutrophic.

Since the QSR in 2010, the eutrophication status of the OSPAR Maritime Area has slightly improved. A change in status from problem to non-problem areas has been observed mainly offshore in the southern part of the North Sea (away from the coastal plumes), Belgian offshore waters, the former Dutch Southern Bight area and, partly, in Dutch coastal waters. These areas are now combined in the new transboundary area of Southern North Sea. A direct comparison of status assessment results in the different areas is difficult owing to change in the subdivision of assessment areas between QSR 2010 and QSR 2023. Several parts of the South-eastern North Sea and Kattegat remain classified as problem areas.

The main eutrophication effect that leads to classification as a problem area is elevated chlorophyll-a concentrations as a proxy for phytoplankton biomass. While winter concentrations of dissolved inorganic nitrogen (DIN) and phosphorus (DIP) have continued to decrease, mainly in coastal and some shelf areas of OSPAR Regions II, III and IV, this decrease has not resulted in a comparable decline in chlorophyll-a concentrations. The reason is that the phytoplankton biomass is controlled not only by nutrients but by a complex interplay of different processes including light limitation and grazing. However, chlorophyll-a concentrations show significant decreasing trends in the Coastal French Channel, Coastal DEDK, German Bight, Kattegat Coastal and Kattegat Deep. Nevertheless, there are also some non-problem areas that show significantly increasing concentrations. These are the Loire plume, the Liverpool Bay plume, and Gulf of Biscay coastal waters and shelf waters.

The second effect indicator assessed for all areas was dissolved oxygen concentrations near the seafloor. Oxygen depletion (concentrations <6 mg/l) was observed in seven assessment areas: Adour plume, Gironde plume, Gulf of Biscay coastal, Gulf of Biscay shelf waters, the Eastern North Sea, Kattegat Coastal and Kattegat Deep. The Atlantic region, Norwegian Trench, Scheldt plume, Meuse plume and Northern North Sea showed statistically significant decreasing trends and a deterioration of the oxygen situation. Concentrations in Kattegat Coastal and Kattegat Deep, while lower than 6 mg/l, have increased.

Considering the causative factors of eutrophication, namely the winter nutrient concentrations, DIN thresholds were more often exceeded (in 12 assessment areas) than DIP thresholds (in four assessment areas), indicating that stronger reductions of nitrogen inputs are necessary in the future.

The fourth application of the Common Procedure was conducted using the fully automated COMPEAT tool. As well as providing an assessment of eutrophication status and its confidence level, the tool enabled a retrospective assessment to be made through the re-running of COMP1 (1990-2000), COMP2 (2001-2006) and COMP3 (2006-2014), thereby delineating the history of eutrophication from 1990 until today in Regions II, III and IV. The use of COMPEAT coupled with the refining of specific small-scale assessment areas (sub-area scale) has led to an objective status assessment which has a common scientific basis across the whole of the region. Assessment areas have been defined by oceanographic criteria rather than international boundaries, and assessments are now therefore consistent across international boundaries, by contrast with previous practice.

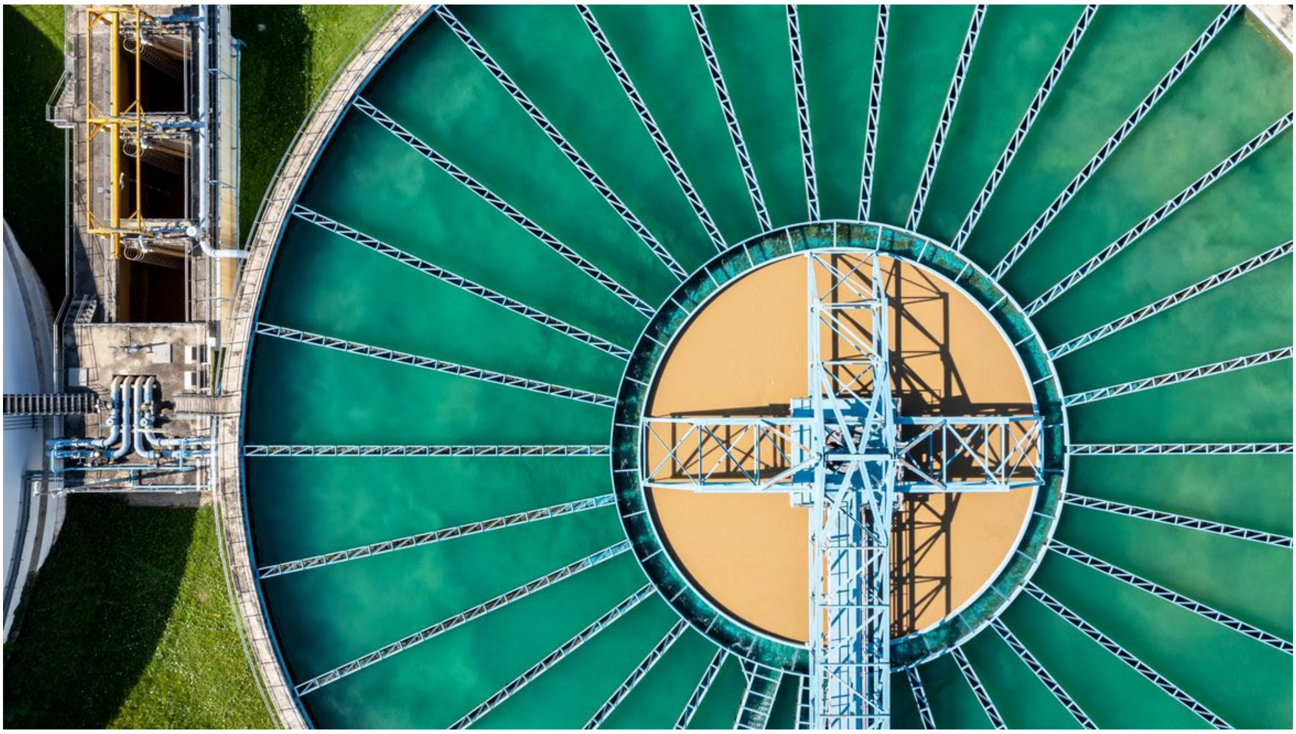
Q2. What has been done?

Nutrient input reductions

The OSPAR Contracting Parties have made significant efforts to reduce nutrient losses to the marine environment. As early as 1988, the Contracting Parties agreed to reduce nutrient emissions to the Greater North Sea by 50% (PARCOM 88/2). This commitment was reinforced by PARCOM 89/4, which introduced a coordinated programme to reduce nutrient inputs. PARCOM 92/7 introduced a range of measures which targeted agricultural practices that were causing excessive nutrient losses. These measures to reduce inputs have since been implemented, and in several cases augmented, by European Union directives covering wastewater treatment, nitrates in agriculture, industrial emissions and water and marine management.

Furthermore, atmospheric emissions are regulated through the Gothenburg Protocol of the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (CLRTAP), which is implemented by EU Member States through the National Emissions Ceilings Directive (2016/2284/EU).

As a result of these regulations and agreements, wastewater treatment and industrial point sources have reduced their discharges of both nitrogen and phosphorus. Riverine inputs of phosphorus have decreased significantly, as have atmospheric nitrogen inputs. Waterborne nitrogen inputs have not decreased as much. Waterborne inputs to the Arctic have increased substantially since the 1990s owing to a growing aquaculture industry. However, since this area has had no history of eutrophication, no assessment has been made this time.



Aerial view of purification tanks at a wastewater treatment plant. © Shutterstock

The most dramatic improvements have come in the form of atmospheric nitrogen input reductions and a reduction in fertilizer use, since 1990. Atmospheric nitrogen disperses far away from coasts, deposits directly onto productive surface waters and is completely bio-available. It accounts for approximately a third to a half of the nitrogen input to Regions II – IV. In Region I the atmospheric component is approximately 75% of the total nitrogen input. It has been reduced as a result of applying and reviewing the CLRTAP Gothenburg Protocol and incorporating those targets into legally binding EU directives. The transition to less combustion for power generation, transport, heating and cooking has not only improved air quality in towns but also enabled emissions targets to be met and inputs to the sea to be reduced.

Phosphorus fertilizer use is approximately a quarter of what it was in 1990 and nitrogen use has been reduced by approximately a third. The timing of the greatest reduction appears coincident with the introduction of the EU Nitrates Directive, but also with OSPAR's measures to tackle nutrient losses from agriculture. Over this period, while fertilizer use has decreased slowly, dairy and meat production continues to increase, creating growing demand for fodder crops and increasing the production of manure and urine. Increased protein consumption in society also leads to increased nitrogen excretion, and the management of manure, urine and human excreta remain significant challenges to the efforts to prevent eutrophication.

Q3. Did it work?

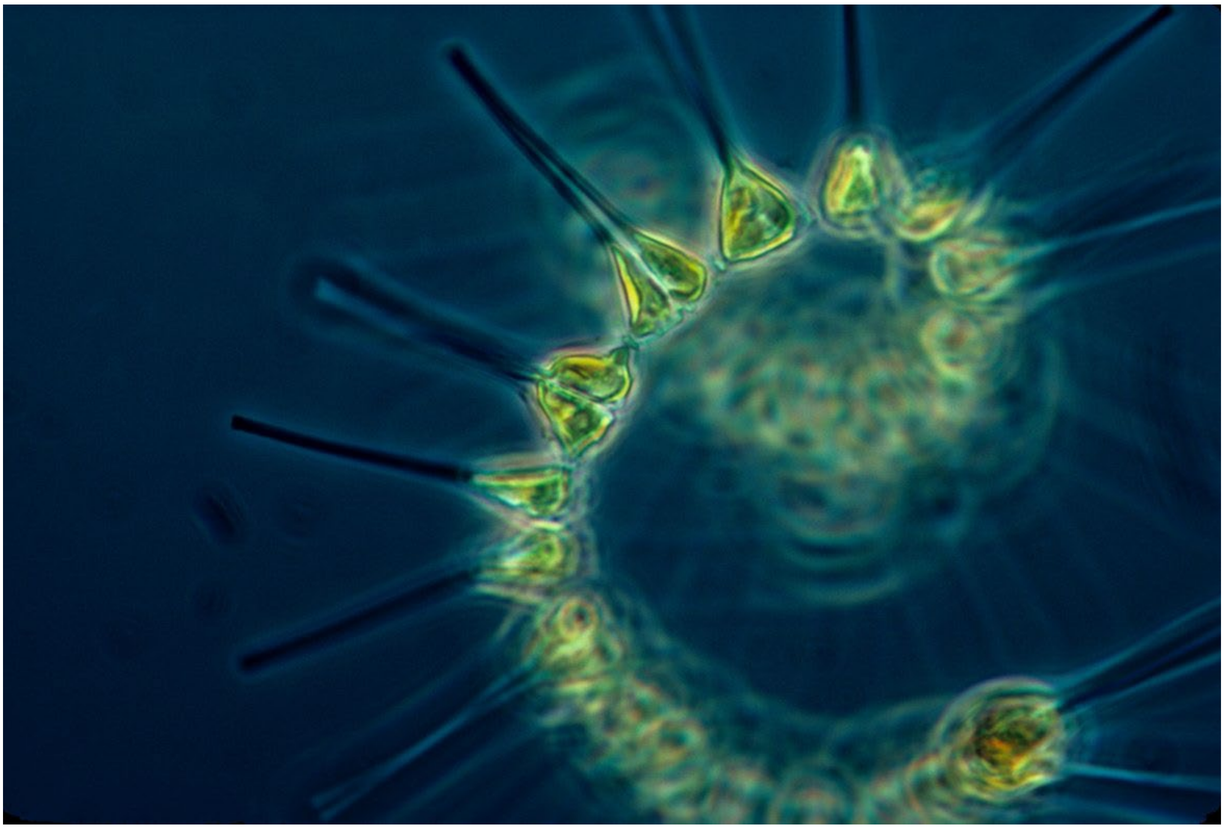
The four applications of the Common Procedure have revealed a steadily improving trend in the eutrophication status of OSPAR Regions II, III and IV**.** The first assessment covering the period 1990 – 2000 was characterised by *poor* conditions in much of the North Sea and *bad* conditions in the south-east and Kattegat. Later assessments show a contraction of eutrophication extending back towards the continental coasts. Eutrophication persists in the river plumes and in some coastal areas. The latest assessment shows areas of *moderate* status outside the Loire and Seine estuaries, along the Dutch and German coasts, the Eastern North Sea and in the deep Kattegat. *Poor* conditions occur in the coastal Kattegat and Elbe plume areas, and no areas are considered *bad*.

Q4. How does this field affect the overall quality status?

Interaction with other assessment themes (e. g. biodiversity, pelagic habitats)

The biodiversity outcomes show that the decreases in nutrient concentrations, particularly for phosphates entering the North Sea, may be driving downward trends in phytoplankton biomass across the Greater North Sea. Despite the efforts to reduce nutrient concentrations, the disequilibrium between nitrates and phosphates has increased, leading to an imbalance of nutrients. This imbalance has negatively affected phytoplankton biomass and is projected to continue owing to the success of phosphorus reduction compared with less successful nitrogen measures (Inputs of Nutrients Indicator Assessment). Nutrient imbalances can lead to a dominance of smaller taxa and potentially impact the plankton community. This situation corresponds with a general global decline in phytoplankton, with a pronounced decline at successively higher trophic levels. Such so-called “trophic amplification” of biomass decline has the potential to magnify the impacts on production from many of the services in pelagic environments, for example on fishery yields.

Future assessments must consider how to include plankton community indicators directly in the eutrophication assessment. The assessment needs to build evidence of how nitrate and phosphate ratios lead to changes in phytoplankton communities which negatively impact the efficiency of the ecosystem services those communities provide. An improved understanding of nearshore plankton dynamics and the influence of river flows can inform the measures required to manage the nitrogen inputs from sources such as urban wastewater and agriculture.



An improved understanding of nearshore plankton dynamics and the influence of river flows can inform the measures required to manage the nitrogen inputs from sources such as urban wastewater and agriculture. © Pixbay

The assessment areas developed for eutrophication and based on phytoplankton seasonal patterns and hydrological criteria were also adopted for the assessments of pelagic habitat and food web indicators, thereby facilitating comparison between these assessments. In addition to identifying areas where eutrophication is a problem, the information gathered also indicates spatial and temporal patterns for the primary producers (notably algae) that form an important basis for marine food webs. In the Greater North Sea (Region II), the "Not good" status of the coastal habitats under the PH2 – Changes in Phytoplankton Biomass and Zooplankton Abundance indicator, and of the shelf habitats under both the PH1/FW5 and the PH2 indicators, as well as the high number of significant trends with likely links to anthropogenic climate change, have resulted in the pelagic habitats being classified as "Not good". This is a different outcome from the eutrophication assessment in which parts of the Greater North Sea (Region II) achieved good status. This mismatch is likely due to the different datasets underlying these assessments, but also to the lack of plankton community measurements within the eutrophication assessment. Additionally, the biodiversity assessment discusses the impact of climate change and how temperature rises are likely to be impacting benthic-pelagic coupling in coastal and shelf areas, with rising sea surface temperatures linked to upward trends in the abundance of meroplankton and the larvae of benthic organisms, and to downward trends in holoplankton which spend their entire lifecycle as plankton.

Another important comparison is with the pilot assessment of primary productivity (FW2), which is strongly related to phytoplankton biomass and therefore chlorophyll-a. This assessment concluded that over the long term (1997-2019), primary productivity was stable in Regions II, III and IV. Significant decreases occurred in the majority of assessment areas, except for the Kattegat area, in 2015-2019, likely driven by de-eutrophication and climate change, which may disturb higher trophic levels. Since only long-term trend analyses were performed for the eutrophication indicator chlorophyll-a, a direct comparison is not straightforward, but the use of primary productivity should be considered as additional evidence in future assessments.

The assessment on Changes in Phytoplankton and Zooplankton Communities (PH1/FW5) looked into changes in functional groups in the current assessment period (2015 and 2019) compared with previous years. Changes in the abundance of diatoms and/or dinoflagellates were estimated to be driven by changes in nutrients in several coastal waters in the eastern part of the North Sea, the Channel, around the United Kingdom and Ireland and also in the area named Atlantic Seasonally Stratified. Nutrient imbalances are occurring in many coastal waters as a result of successful phosphorus management and less successful mitigation of direct and diffuse nitrogen. Nutrient imbalances and their impact on coastal plankton communities should be considered a key component of future assessments. The assessment on Changes in Biodiversity Index (PH3) also compared the current assessment period against previous years, focusing on diversity indices for phytoplankton and zooplankton. Significant changes in phytoplankton diversity were observed in only a small number of areas in the Celtic Seas and the North Sea. Nutrients were considered to be drivers of change mainly in coastal areas of the United Kingdom and Ireland, but also the Atlantic Seasonally Stratified area and along the Spanish and Portuguese coasts, and to a lesser extent in the eastern part of the North Sea.

Further harmonisation of data sources and assessment methods between the eutrophication and pelagic and food web assessments is expected to increase comparability. Moreover, further analyses of the relationships between these assessments will help improve understanding of how nutrient loads affect ecosystem functioning and at which nutrient concentrations the ecosystem can be considered healthy.

The Intergovernmental Panel on Climate Change (IPCC), through its Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) and subsequently its Sixth Assessment Report on Climate Change 2021, concluded that there is a growing consensus that between 1970 and 2010 the open ocean very probably lost 0,5-3,3% of its dissolved oxygen in the upper 1 000 m, and that oxygen minimum zones are expanding. In coastal ocean regions, anthropogenic eutrophication via continental run-off and atmospheric nutrient deposition, and ocean warming, are very likely to be the main drivers of deoxygenation. Future work should aim to decouple, where possible, the impacts of eutrophication on benthic ecology. Measures to reduce anthropogenic eutrophication need to be prioritised over those to mitigate the impacts of oxygen reductions in high-risk areas.

Q5. What do we do next?

In respect of eutrophication, the indications are that along the continental coast of Regions II and IV, further efforts to reduce nutrient inputs are necessary in order to achieve the strategic objective of the North-East Atlantic Environment Strategy (NEAES) 2030.

In parallel with the work “to determine the maximum inputs of nutrients for relevant assessment areas which prevent deterioration and enable the achievement of non-problem area status throughout the North-East Atlantic”, as foreseen in operational objective S1.O2 of the NEAES, it is important to align the threshold values for the dissolved nutrients and chlorophyll-a with an understanding of how a healthy ecosystem functions, in order to establish an ongoing scientifically sound narrative for deriving threshold values from reference conditions that does not require individual Contracting Parties to adjust those values.

OSPAR's eutrophication modelling group (ICG-EMO) needs to begin the work of determining maximum nutrient inputs according to objective S1.O2, with this work paving the way for agreement on the nutrient reduction needs that enable each Contracting Party to stay at or below the maximum input levels (objective S1.O3). This work needs to give adequate consideration to transboundary nutrient transports, both between Contracting Parties and from outside the OSPAR Maritime Area. While deriving nutrient reduction needs is scientifically challenging and requires some time, it is important to undertake immediate measures in catchments where nutrient inputs are increasing, or eutrophication effects are deteriorating. This includes selected catchments in OSPAR Regions II and IV, as well as the overall waterborne nutrient inputs in Region I caused by intensive marine aquaculture.

The extent of the growth in aquaculture within the OSPAR Maritime Areas is striking. Region I was alone in showing significant increases in waterborne nutrient inputs. Analysis of the changes in direct discharges to the OSPAR Convention area has shown that almost all the improvements in industrial discharges and wastewater treatment have been cancelled out by the increases from marine aquaculture. Although OSPAR has issued Recommendation PARCOM 94/6 concerned with reducing the input of toxic substances from aquaculture and requiring national reports on best environmental practices and water quality, reporting under the Recommendation was suspended in 2006. Moreover, marine aquaculture is not covered by either the EU Industrial Emissions Directive or its associated BREF documents. A gap therefore exists concerning the agreement of minimum environmental standards for aquaculture across the OSPAR Maritime Area, but also - since the COMP analysis did not cover Arctic waters – there is a knowledge gap as to whether the substantial increase in nutrient inputs is causing eutrophication in OSPAR Arctic waters.

Lastly, climate change leads, among other effects, to floods and droughts which cause stronger variations in nutrient inputs. More investigation is needed in order to understand the ecological effects of this greater variability and how to adequately monitor and assess such increasingly prevalent events for the purposes of future eutrophication assessments.

D - Driver(s)

Social and economic drivers for activities affecting eutrophication

The main driver of eutrophication historically has been urbanisation, which concentrated the human population in urban centres and led to problems with the disposal of human and animal excreta. These problems reduced with the development of increasingly effective wastewater management systems, so that food security became the main driver of eutrophication. Arguably, modern agricultural production is driven by the need for trade and economic development as much as food security. Burning fuel for heat and transport also remain important drivers.

All social and economic drivers have the potential to influence eutrophication status. However, the rapidly increasing global population and the infrastructure and resources needed to support it stimulate many of the drivers that link to eutrophication, for example food; trade and movement of goods; materials; stable economies; industrial processes; health and wellbeing; and climate change mitigation, adaptation and resilience.

The need for food security

Population growth can lead to increased demand for food, which in turn can lead to changes affecting diet, global food chains, regulation, innovation, international trade, political stability, culture, international collaboration and food prices. Europe is the third most populous continent behind Asia and Africa. Its population in 2016 was estimated at 738 million, which accounts for 11% of the world's population. The continent is currently growing at a rate of 0,3% per annum.

Agriculture and aquaculture help to meet the demand for food security, but agricultural run-off and waste products from aquaculture can introduce nutrients and organic matter into the marine environment, leading to eutrophication effects. Increasing demands for nitrogenous fertilizers for use in agriculture (Lu and Tian, 2017), and particularly urea in recent times, are largely responsible for the rapidly increasing discharge of nitrogen to the marine environment (Jickells and Weston, 2011).

Agriculture is the biggest user of nitrogen in the world (EU Nitrogen Expert Panel, 2015). Run-off from agricultural land has been identified as the predominant source of the nitrogen discharges to the aquatic environment over the last two decades (EC, 2018; see also EEA, 2005, 2012, 2018a). Nitrogen consumption in agriculture has now levelled off in Europe, – although rates of change will vary significantly between OSPAR Contracting Parties – as a result of improved fertilizer application and the onset of the EU Urban Wastewater Directive.

From 2000 to 2015, the gross balance between nitrogen added to and removed from agricultural land in the EU showed an improving trend **(Figure D.1)**, signifying that the gap between inputs and outputs was closing and the potential nitrogen surplus decreasing. This is more likely related to efficiency gains than to any reduction in agricultural effort. Efficiency gains have likely been achieved through adapted nitrogen management practices such as changes in fertilizer application techniques (Eurostat, 2015) and may have been driven by the implementation of other specific measures under the Common Agricultural Policy and EU legislation, such as the Nitrates Directive and the Water Framework Directive (WFD). However, this trend also reveals that since 2010 the nitrogen balance has not improved, i.e. the surplus of nitrogen from agricultural land has not declined further since 2010. Assessments for the year 2010 suggest that, for the EU, the average reference values for critical nitrogen loads were exceeded, underscoring that fertilizer applications in agriculture continue to drive eutrophication issues.

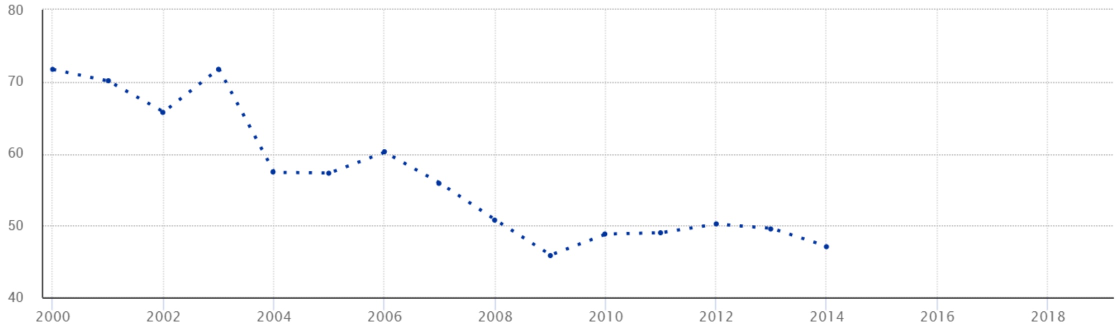


Figure D.1: Gross nutrient balance on agriculture land by nutrients for EU countries. Source: Eurostat 2019

An additional, important driver of nutrient increase is the expansion in meat consumption across European countries. The bulk of European crop production is now used to feed animals and create biofuels. Of all the cereal crops used in Europe in 2016, the majority (59%) went to feed animals, with only 24% used to feed people. Of the protein-rich pulses and soy used in Europe, 53% (2016) and 88% (2013), respectively, were used for animal feed. At the same time, Europe is overproducing meat and dairy products, with EU production of beef, pork and poultry 4%, 16% and 8% higher than consumption, respectively, and production of dairy 14% higher than consumption. Over 71% of all agricultural land in the EU is dedicated to feeding livestock.

This rise in easily accessible, cheap meat products can also be measured from the rise in protein consumption across the OSPAR countries **(Figure D.2).** An average EU citizen consumes more than 80 kg of meat every year. The recommended amount of meat and cold cuts amounts to approximately 70 g of meat per day, which is slightly less than 26 kg per year. An average EU citizen is thus consuming well above recommended amounts, but this is expected to decrease. The price of beef is expected to remain fairly constant until 2025 and per capita meat consumption is expected to continue to increase worldwide by 2030.

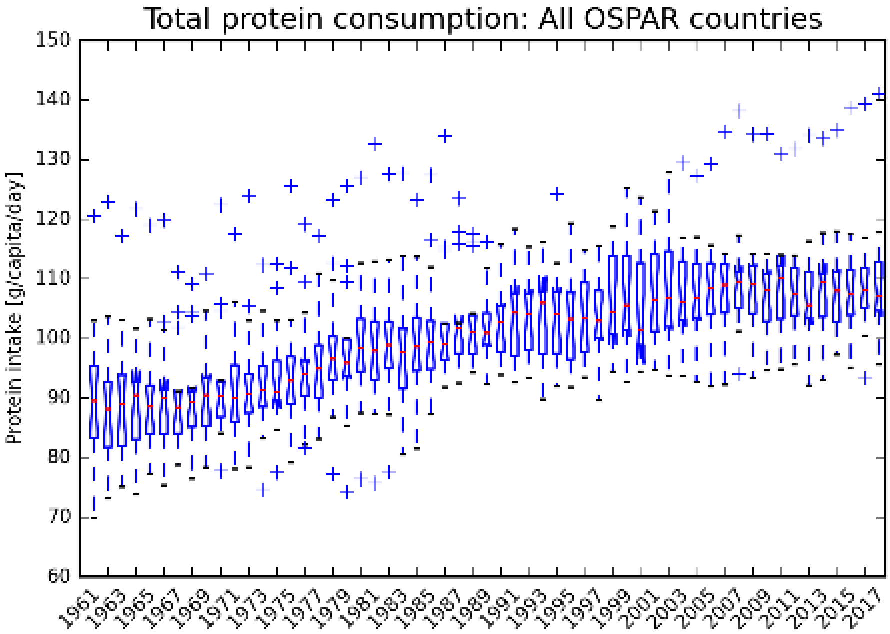


Figure D.2: The increase in total protein consumption. Source: Our World in Data

Additional sources of nutrients include nitrogen and phosphorus discharges to coastal seas from domestic wastewater and groundwater inputs, driven by human population growth and lack of the infrastructure needed to deal with increasing sewage and stormwater discharges.

The need for construction

Demand for materials (marine aggregates), growing population with demand for housing and infrastructure (e.g., roads, shops, houses, towns), and increase in utilities (e.g., sewerage, power networks).

The growing global population and improvements to societal health and wellbeing are increasing the demand for housing and utilities, and thus for materials and their processing. One of the main challenges confronting agriculture in Europe is land take, namely the conversion of land to, for example, settlements and infrastructure (EEA, 2017a). The proportion of total land accounted for by agricultural land is shrinking and the sector is affected by land take. Independently of this, the number of farms is decreasing and the average farm size increasing. All three factors — land take, intensification and extensification — lead to loss of high nature value (HNV) farmland.

Construction often leads to an expansion of sealed surfaces, which affects stormwater management and run-off. Nutrient and water retention mechanisms such as wetlands compete for space, and rapid run-off from hard surfaces increasingly overloads combined sewerage systems, resulting in discharges of untreated wastewater. Proper design and integration of water management in construction is essential.

The need for societal wellbeing

Cost of living, environmental awareness, health of population, demands for goods and services, accessibility of goods and services (convenience), communications, socio-economic status (regional / national differences), culture, historic environment, tourism and recreation, pandemics.

Over 40% of European land is given to agriculture in order to meet these societal demands for food production, pollination and energy. Society is becoming increasingly better informed about the environment and the need for sustainable land use. This has led to some improvements in land use including decreases in greenhouse gas (GHG) emissions and less pesticide use, but excess nutrient discharges, diffuse water pollution and loss of grassland biodiversity still persist.

The need for economic development

Political and economic autonomy, international trade (goods and services) - imports and exports, foreign aid, tariffs and grants, international agreements, stocks and market prices, tourism.

Paradoxically, strategies to improve agricultural sustainability may hinder the achievement of overall sustainability goals. For example, efficiency gains are effective in reducing crop and nutrient losses, but solely focusing on system optimisation at the farm level may lock agriculture into a cycle of unsustainability (EEA, 2022). Since the 1950s, traditional farm management, which favoured a range of landscapes, habitats and plant and animal species, has been replaced by the rapid industrialisation of agriculture characterised by widespread intensification of subsidised farming methods. This has resulted in farm specialisation and increased use of chemical inputs and homogeneous landscapes, in turn leading to wider socio-economic changes in rural communities.

Europe's agriculture has received sustained support under the Common Agricultural Policy (CAP) over the last 50 years, evolving over time in growing recognition of agriculture's impacts on the environment. Unfortunately, the CAP has not changed sufficiently to reduce nutrient inputs below an acceptable level.

Increased competition for land is expected to influence European agriculture. For example, the production of renewable energy and biofuels also influences the conversion of natural or semi-natural ecosystems, whether for the production of biofuel feedstock or for the production of other crops such as animal feed.

The need for trade and transport

Supply and demand of goods and services, national and international targets, tourism.

The need for trade and transport has resulted in a society dependent on the movement of products across national and international boundaries (**Figure D.3**). In 1990, the most significant sources of NOx emissions from OSPAR Contracting Parties were 'Road transport' (41%), 'Stationary combustion, including energy production' (32%) and 'Shipping' (15%). However, emissions of nitrogen oxides (NOx) in OSPAR countries decreased by 54% between 1990 and 2019. By 2019, shipping had become the major source of NOx emissions (31%) overtaking road transport (28%) (Gauss and Klein, 2022). The introduction of exhaust gas cleaning scrubbers also results in a direct waterborne input of nitrogen into marine waters, estimated at 1 281 kilotonnes / year (Jalkanen *et al.*, 2022).

While agriculture is a major driver in respect of the need for food security, it also plays a large part regarding the need for trade and transport. In 2021, additional trade in agricultural products accounted for 8,1% of total additional EU international trade in goods, and between 2002 and 2021, EU trade in agricultural products more than doubled, equivalent to average annual growth of 4,8%.

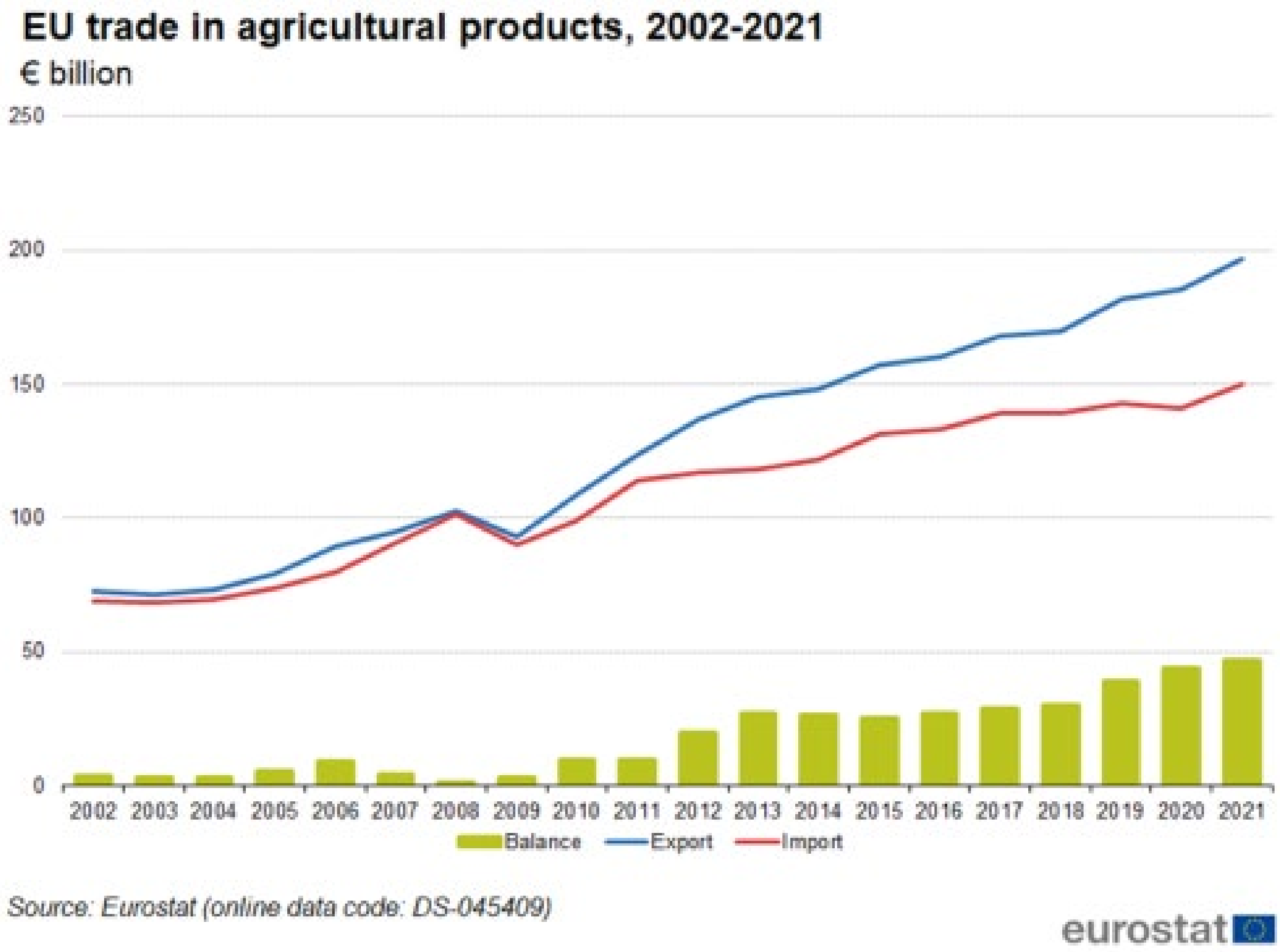


Figure D.3: Increase in trade of agricultural products, concentrating on exports and imports between the European Union (EU) and all countries outside the EU (extra-EU)

This growth in production is not only a response to a growing population. Between 2005 and 2016 the EU lost up to 4,2 million farms, while the amount of land that was used for agricultural production remained largely the same. In animal farming, there is a clear trend of concentration and industrialisation. Between 2007 and 2016, EU exports of beef and pork nearly doubled, with exports of dairy products and poultry meat increasing by 35% and 43%, respectively.

Maritime transport of goods involves maintaining the navigability of waterways and therefore dredging of the seabed, which can release nutrients and other pollutants into the water column. Shipping can also result in the introduction of non-indigenous species through ballast water discharge, whose spread and associated problems can be exacerbated by eutrophication. The introduction of infrastructure to marine and coastal environments in order to meet society's need for economic development (e.g., ports, housing, tourism and leisure, coastal protection) can alter hydrological and hydrodynamic conditions and thereby influence nutrient inputs.

A – Activities

Human activities with the potential to affect eutrophication

The most significant human activity with the potential to affect eutrophication is agriculture. Agricultural activities dominate nutrient discharges to water, while animal husbandry and the use of machinery also lead to significant losses into the air, which can then be deposited directly onto the sea. Wastewater, particularly in large urban centres, has been historically significant. Since the introduction of treatment standards in the 1980s and 1990s the scale of this problem has been reduced. Industrial releases into water have also decreased substantially. In the Arctic Waters (Region I), aquaculture has emerged as the most significant direct input of waterborne nutrients, although in the Region as a whole, nitrogen inputs have decreased owing to the reduction of emissions to the air.

Main activities	**Arctic Waters**	**Greater North Sea**	**Celtic Seas**	**Bay of Biscay and Iberian Coast**	**Wider Atlantic**
Agriculture					
Intensity	L	H	M	M	L
Trend since QSR2010	↔	↔	↔	↔	↔
Trend to 2030	↔	↔	↔	↔	↔
Aquaculture					
Intensity	H	H	M	M	L
Trend since QSR2010	↑	↑	↔	↑	↑
Trend to 2030	↑	↑	↑	↑	↑

Table A.1: Regional summary of main activities leading to eutrophication pressures, including an estimate of past and future trends. While agriculture is expected to remain at a similar level to today, the pressure from agriculture on eutrophication needs to decrease in order to achieve the goal of no anthropogenic eutrophication

Nutrients enter the OSPAR Maritime Area via waterways and atmospheric deposition. Natural processes such as the weathering of rocks lead to small quantities of nutrients being released, while combustion, such as wildfires, creates oxidised nitrogen compounds which can be deposited on the sea surface. Nutrient leaching from natural soils and soil transport by erosion also introduce nutrients into the marine environment. These natural processes seldom cause eutrophication problems, however. Instead, eutrophication has occurred because of the introduction of large quantities of reactive nitrogen and phosphorus into the marine environment by human activities. The key human activities affecting eutrophication are:

- **Agriculture (Cultivation of living resources):** Society's need for food drives the need for agriculture. Agricultural run-off can lead to the input of substances to the environment, including nutrients. Agriculture also contributes significantly to atmospheric emissions of nitrogen. (Agriculture Feeder Report)

Around 34% of the land in the OSPAR Contracting Parties is given over to agriculture. This extensive land use has a significant impact on biogeochemical cycles. As point sources of nutrients have been mitigated, agriculture has become the most significant activity leading to nutrient losses to the environment. At the cessation of reporting under Recommendation PARCOM 88/2 and 89/4, published in 2008, approximately 84% of reported diffuse nutrient losses came from agriculture or agricultural land, although reporting definitions vary between Contracting Parties, making the exact contribution difficult to assess.

Among anthropogenic sources, agriculture was responsible for more than half of nitrogen losses and about a third of phosphorus losses **(Figure A.1)**. Since 1990, phosphorus inputs from OSPAR Contracting Parties have halved, while waterborne inputs of nitrogen have remained steady. Atmospheric inputs have almost halved, resulting in a roughly 25% reduction in nitrogen inputs to the OSPAR Maritime Area as a whole. (Inputs of Nutrients Indicator Assessment)

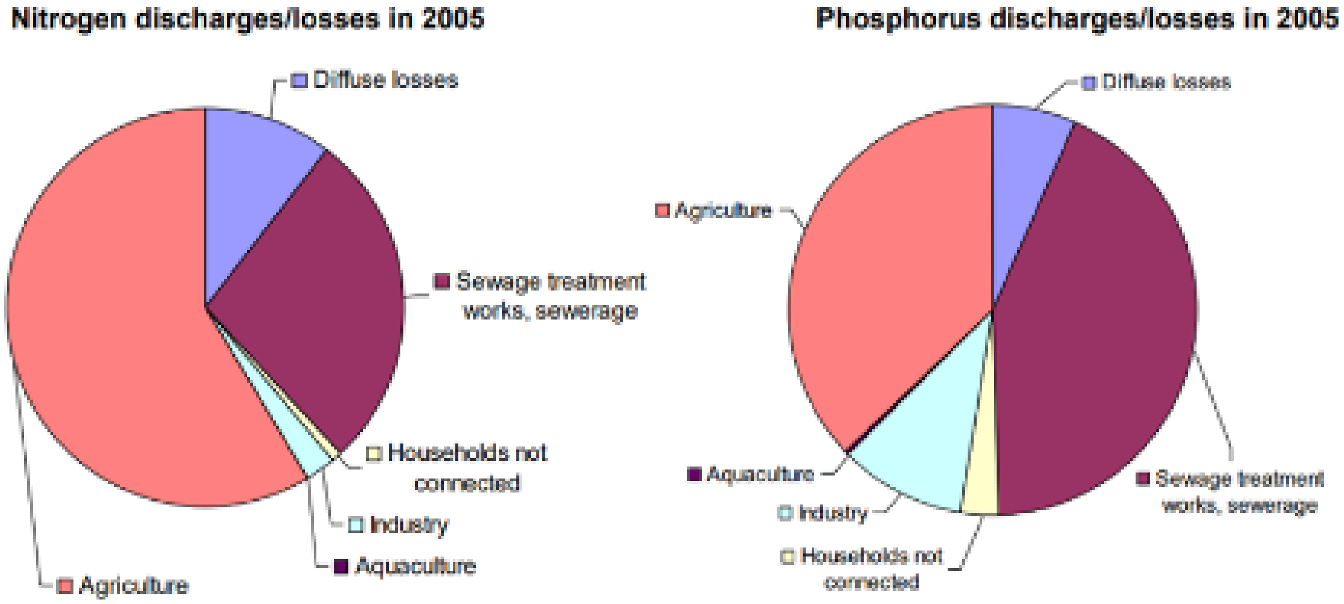


Figure A.1: Contribution by different *anthropogenic* sources to total losses and discharges of nutrients in 2005, from OSPAR 2008

Historically, land was drained to increase the availability of high-quality agricultural fields. To keep these areas from returning to marshland, extensive drainage systems were constructed. The resulting arable areas, while highly productive, frequently had poor water and nutrient retention, increasing the risk of nutrient losses. These areas also emit large amounts of CO_2 and should therefore be turned into wetlands in order to achieve the goals in the Paris Agreement. In other areas, surface water run-off and resulting soil erosion is problematic, resulting in the loss of particle-bound nutrients. Ploughing and the production of a homogenous surface soil layer have been associated with surface run-off, as has the soil compaction associated with some crop types and the use of heavy machinery.

A range of measures has been developed to mitigate these losses. They include: restrictions on the amounts and timing of nutrient fertilization including balanced fertilization plans; winter plant coverage and riparian buffer strips to reduce surface run-off to streams and rivers; techniques such as cross-slope (rather than down-slope) ploughing to reduce run-off in furrows; no- or minimal-till approaches to reduce soil compaction and disturbance to top layers; removal of land from production – including land swaps – to increase the distance between agricultural land and waterways, and the reestablishment of wetland/wet meadows to obtain natural nutrient removal/retention processes.

Animal husbandry is also a significant source of nutrient losses **(Figure A.2)**. Manure and urea lead to significant emissions to both air and water. Manure has long been used as a fertilizer but increasing awareness of eutrophication problems has led to restrictions on spreading (volumes, timing and techniques) and the requirement for adequate manure storage capacity at farms for when spreading is not permitted. In OSPAR Contracting Parties, animal husbandry for both dairy and meat production has increased steadily since

2007. Production increases do not have to cause a rise in eutrophication pressures in themselves if the atmospheric emissions are trapped and the manure is managed well; however, the increase in dairy and meat production is likely matched by an increase in demand for animal feed, which places more pressure on arable production.

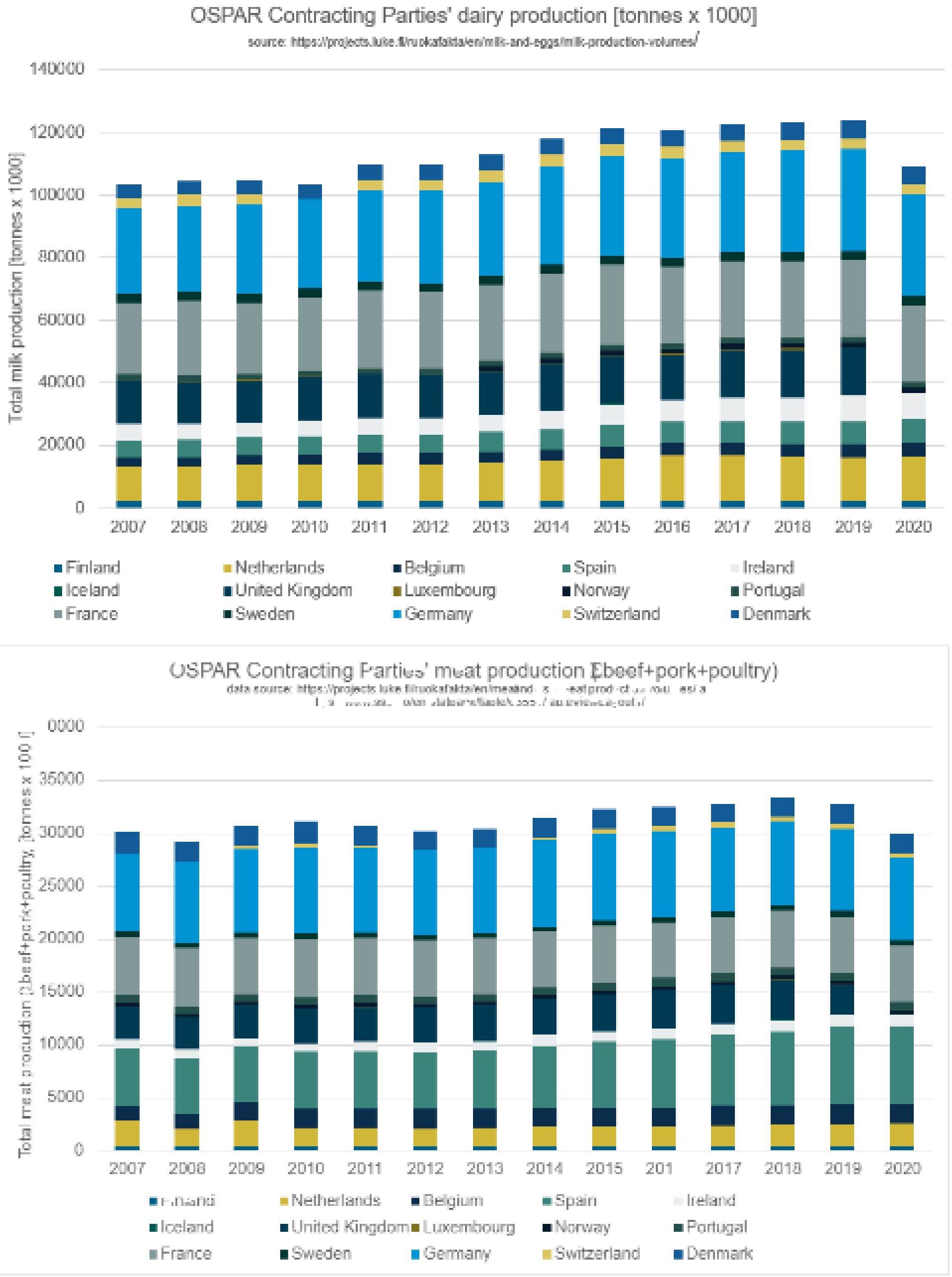


Figure A.2: Time series of dairy and meat production in OSPAR Contracting Parties (tonnes x 1 000). Data from the Natural Resources Institute, Finland and Statistics Norway. The United Kingdom did not submit data for 2020

Arable crop production in the OSPAR Contracting Parties has long been dependent on the availability of mineral fertilizers to ensure and improve yields of both food and fodder crops. **Figure A.3**, produced by the European Fertilizers Manufacturing Association (now Fertilizers Europe), records the rapid increase in

European fertilizer use after 1945, reaching a plateau for phosphorus at the end of the 1970s and a peak for nitrogen fertilizer use at the end of the 1980s.

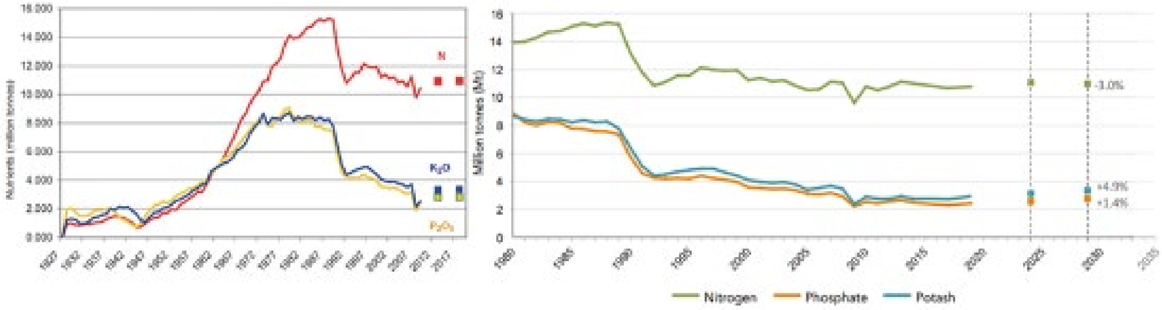


Figure A.3: Historical and predicted fertilizer use in the EU27, from EFMA 2009 (left) and Fertilizers Europe, 2019 (right)

The rapid reduction in fertilizer use at the start of the 1990s coincided with the onset of binding environmental legislation under European directives, but also with an economic downturn **(Figure A.4).** A similar drop in fertilizer use is apparent in 2009, coinciding with the impact of the 2008 financial crash. Based on data reported to Eurostat, the OSPAR Contracting Parties appear to account for just over half of total EU nitrogen fertilizer consumption – about 7 million tonnes of nitrogen - and about a third of phosphorus fertilizer consumption – about 800 000 tonnes against an EU27 total of 2,4 million tonnes. As for the EU27, OSPAR fertilizer consumption appears stable between 2010 and 2020.

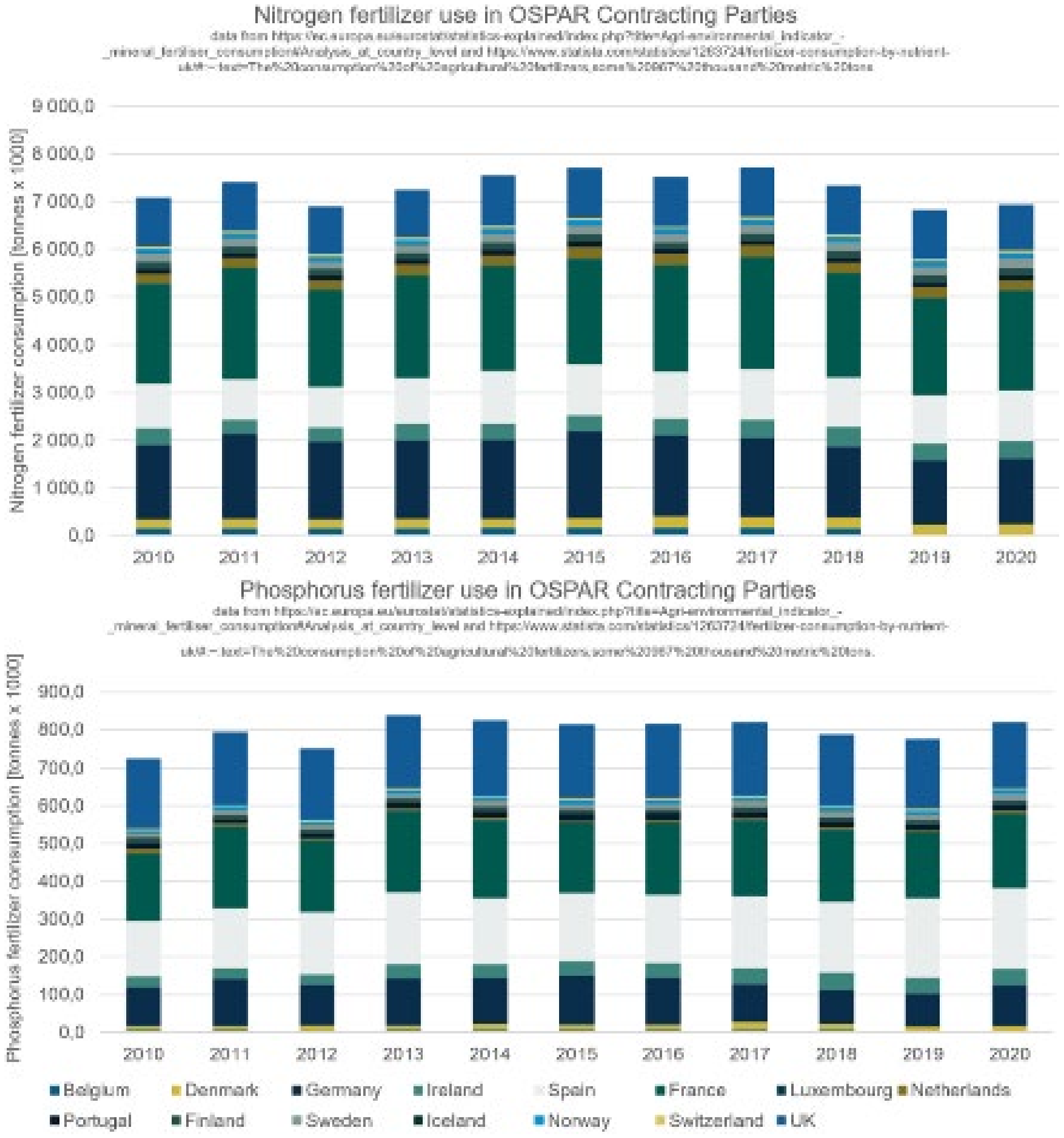


Figure A.4: Fertilizer use in OSPAR Contracting Parties 2010 - 2020

Source:
https://ec.europa.eu/eurostat/databrowser/view/AEI_FM_USEFERT__custom_2754449/default/table

The EU Nitrates Directive introduced the concept of nitrate vulnerable zones and codes of good agricultural practice, affecting both arable and meat/dairy producers. Under OSPAR Recommendation 92/7, the Contracting Parties agreed to reduce the nutrient load from agriculture through a range of different measures. The EU Common Agricultural Policy and other national schemes include support for environmental measures to reduce agricultural emissions.

Codes of good agricultural practice typically limit animal numbers based on the availability of land, so as to spread the manure generated. Several EU Member States and OSPAR Contracting Parties have implemented exceptions to these levels however, leading to even greater amounts of manure being produced. Increasing specialisation in agriculture has led to the separation of arable land from animal production, resulting in manure being produced in areas where it cannot be used as fertilizer. Precision fertilization techniques have also reduced the attractiveness of manure as a fertilizer compared to mineral sources that can be applied exactly with a known nutrient content. This results in a mismatch between where manure is generated and where it can be used as fertilizer. High transport costs have been a barrier to the re-use of manure as fertilizer although market volatility associated with phosphorus rock extraction and natural gas supply (used in nitrogen fertilizer production) should stimulate further development to address this problem.

Atmospheric ammonium emissions come overwhelmingly (> 90%) from agriculture. Ammonia is a component of dissolved inorganic nitrogen that is considered to be immediately available to marine phytoplankton. Ammonia releases depend on diet, on how animals are kept (free-range, in barns or a mix), how manure and urea are managed around the animals and how these are stored prior to spreading. Even techniques such as cast-spreading in place of soil injection and immediate ploughing-in can result in significant losses to the atmosphere. Atmospheric ammonium typically does not travel great distances but instead is deposited relatively close to the source (**Figure A.5).** OSPAR waters, particularly in the Eastern North Sea, Celtic Seas and eastern Bay of Biscay, are recipients of significant amounts of atmospheric ammonium, and while oxidised nitrogen emissions and the resulting deposition have reduced significantly since 1995, ammonium deposition to the respective OSPAR Regions has decreased at only about one-seventh of that rate **(Figure A.6** and **Figure A.7).**

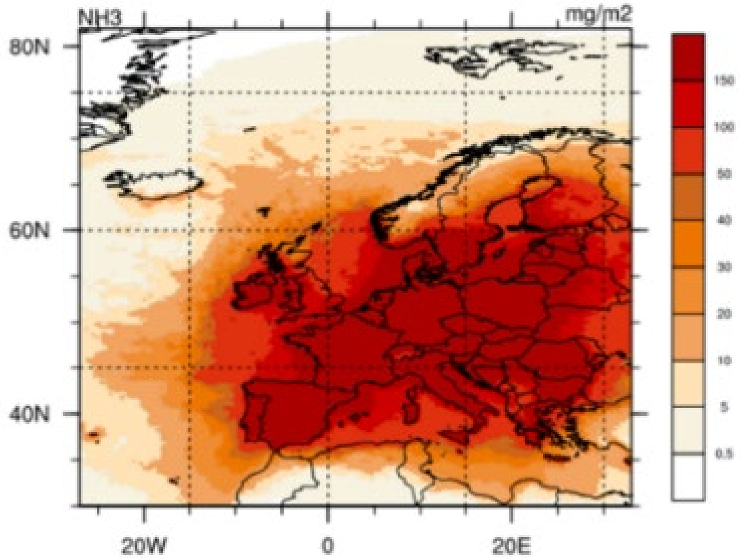


Figure A.5: Deposition of reduced nitrogen (ammonium) originating in EU member states (Klein *et al.*, 2022)

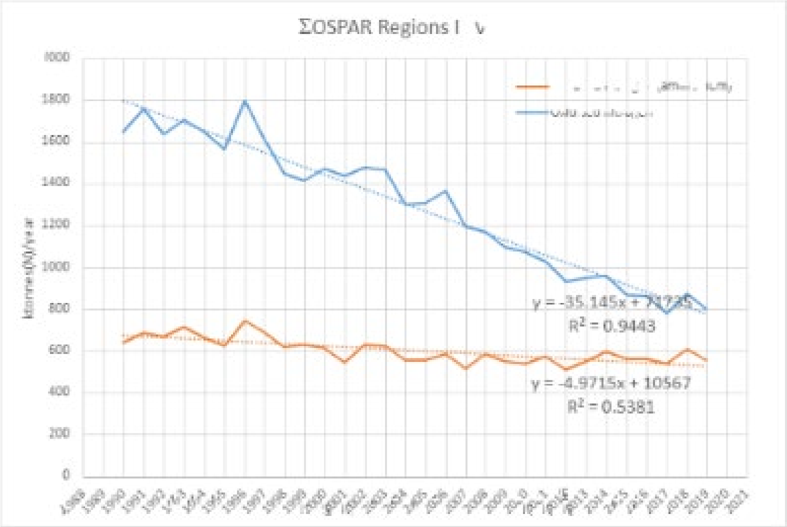
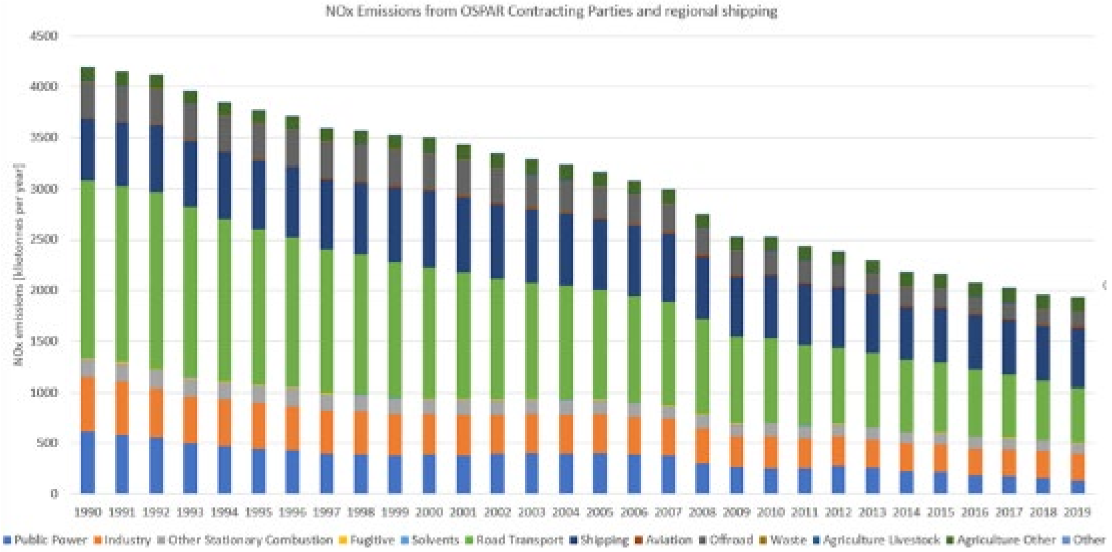


Figure A.6: Time series of oxidised (blue) and reduced (orange) nitrogen deposition to all OSPAR Regions, showing small reductions in reduced nitrogen (ammonium) deposition compared with oxidised nitrogen (from Gauss *et al.*, 2020)



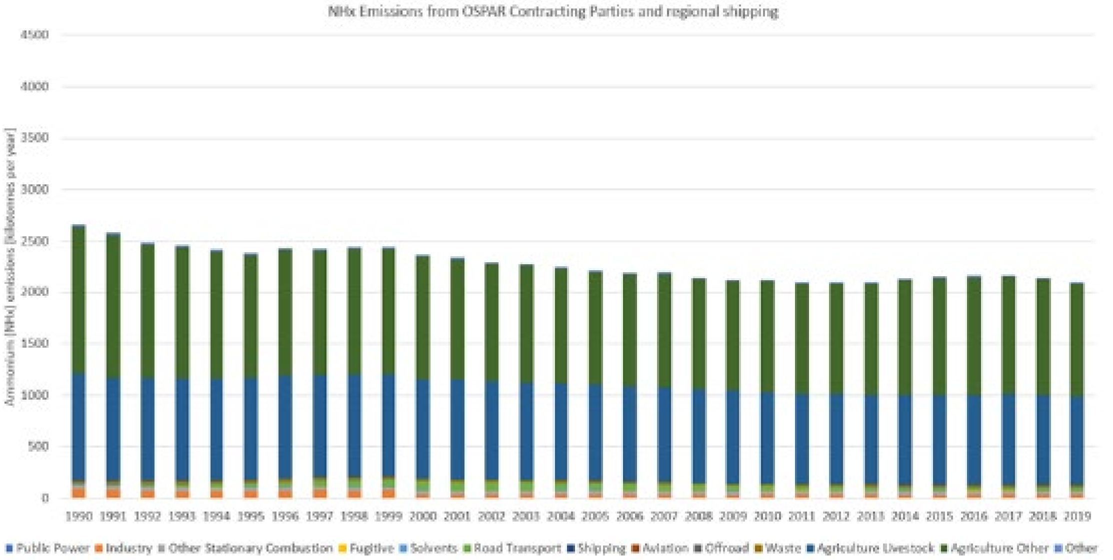


Figure A.7: NO_x (top) and NH_4 (ammonium; bottom) emissions to the air from OSPAR Contracting Parties and international shipping in the Atlantic and the North Sea, arranged by industrial sector. NO_x emissions show a strong downward trend and in recent years have been lower than ammonium emissions. Data collated from Gauss and Klein, 2022. Ninety per cent of the reduced nitrogen is emitted by agriculture

- **Forestry** satisfies society's need for materials as well as being a process that mitigates climate change. Nutrient leakage from forested areas is generally considered to be a natural process although in some commercial plantations artificial fertilizers are used to increase growth rates, while large-scale felling, particularly near water courses, leads to nutrient losses (Copernicus, 2018).
- **Transport – shipping:** Society's need for trade and movement of goods and for national security are drivers of shipping activity. The combustion processes associated with shipping emit nitrogen to the atmosphere and, more recently, directly to the marine environment through open- and hybrid scrubber systems. Shipping emissions to the atmosphere from the Atlantic and the North Sea changed only marginally between 1990 and 2019 but are expected to decline with the implementation of the Nitrogen Emission Control Area (NECA) in the North Sea. This differs from the global shipping dataset published in Fagerli *et al*., 2022, which suggests a roughly 20% decrease between 2000 and 2019.
- **Transport – land:** Society's need for trade and movement of goods are drivers of land transport activity. Combustion processes associated with transport emit nitrogen to the atmosphere. Road transport was the largest emitter of oxidised nitrogen to the atmosphere in OSPAR Contracting Parties in 1990. Emissions are still significant – second only to shipping – but are less than a third of the losses recorded in 1990.
- **Wastewater treatment and disposal:** Society's need for health and wellbeing and for industrial processes are drivers of waste treatment and disposal. Direct discharges can lead to the input of substances to the environment, including nutrients.

Wastewater treatment plants discharging directly into the OSPAR Maritime Area were responsible for about 10% of the total waterborne nitrogen input and 16% of the total waterborne phosphorus input. Nutrient inputs through direct discharges are reported annually to OSPAR as part of the Riverine Inputs and Direct Discharges component of the Joint Assessment and Monitoring Programme. Between 1990 and about 2005, the amount of nitrogen discharged increased, but since then the inputs have decreased to less than half of the 2005 value **(Figure A.8).** Total phosphorus inputs from wastewater treatment plants (WWTPs) have decreased more steadily and are now less than half of the 1990 level.

- **Industrial uses:** Society's need for trade and movement of goods, stable economies, industrial processes, materials, and health and wellbeing, are drivers of industrial uses. Industrial atmospheric emissions and direct discharges can lead to the input of substances to the environment, including nutrients.

The reduction of nitrogen and phosphorus discharges from industry has been more successful than that from wastewater treatment. Nearly half of direct nitrogen inputs in 1990 were from industry – approximately 60 kt from a total of 150 kt. This may not only reflect better removal but the fact that a lot of industries have been connected to WWTPs and therefore no longer count as direct industrial inputs. The contribution from industrial direct discharges is now some 10 kt. A similar, though less marked decrease has occurred in phosphorus direct discharge, which is approximately half of the 1990 level.

- **Aquaculture - marine, including infrastructure:** Aquaculture is driven by society's need for food. This activity can result in the input of substances to the environment, including nutrients. Cultivated non-fed organisms (e.g., filter feeders) may improve water quality.

Reported inputs from aquaculture have increased significantly since OSPAR RID (Riverine and Direct Discharges) reporting started in 1990. Aquaculture is now the primary source of direct nutrient inputs to the OSPAR area, contributing approximately as much nitrogen as industry and wastewater treatment combined. Phosphorus inputs from aquaculture exceed those from all other point sources. As a result of the growth of aquaculture, there was no decrease in total direct discharges of nitrogen to the OSPAR Maritime Area between 1990 and 2019, while phosphorus inputs only decreased by approximately a sixth, despite industrial and wastewater inputs having together decreased by two-thirds since 1990. The inputs from aquaculture are suspected to be an underestimate as not all Contracting Parties have reported aquaculture inputs from all their territories.

The shift in nutrient supply from industrial and wastewaters to aquaculture also involves a geographical shift, as the most significant source is no longer the major coastal/industrial conurbations in Regions II and IV, and the pressure has moved to the Atlantic margins of Regions I and III.

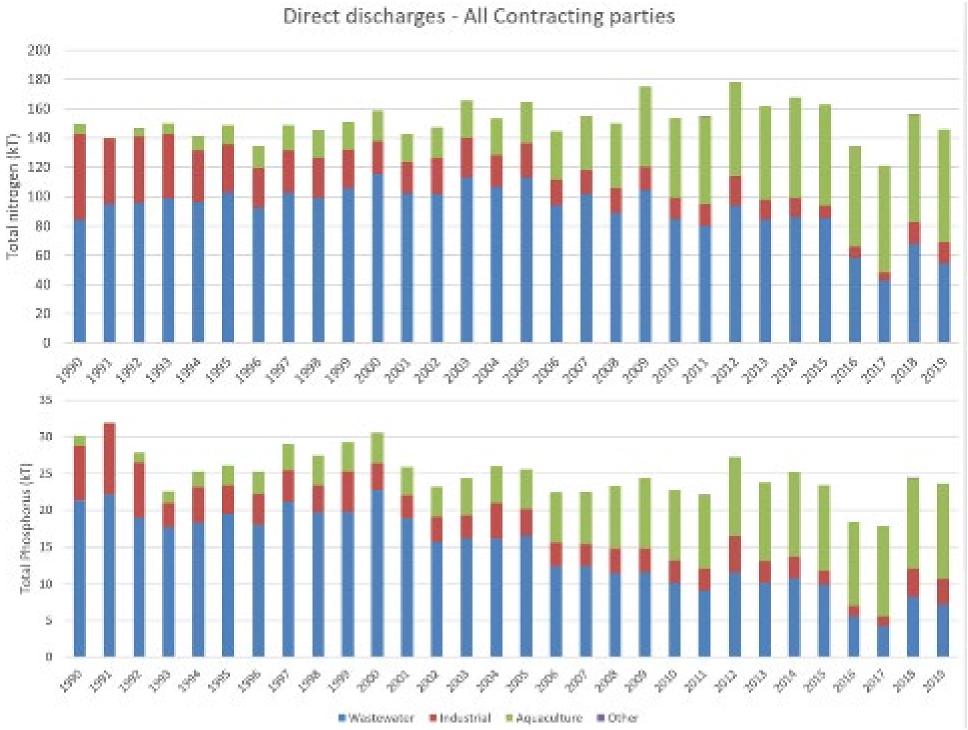


Figure A.8: Nutrient inputs from point sources (direct discharges) into OSPAR Regions I - IV (data from OSPAR RID database). Figure shows total nitrogen (top) and total phosphorus (bottom) inputs

- **Climate change (see corresponding thematic assessment and Ocean Acidification 'other assessment'):** Numerous drivers and activities (e.g., burning of fossil fuels, agriculture, deforestation) contribute to climate change, with a number of associated pressures potentially link to eutrophication.

The reader is referred to the thematic assessment on climate change. In brief, climate change is expected to alter land use patterns and agriculture, resulting in changes in nutrient discharges. Episodic events such as flooding are expected to increase suspended sediment and nutrient inputs. Whether this cancels any general decrease in run-off is unclear. Changes in stratification, mixing and temperature will have profound biogeochemical effects and therefore change the sensitivity of the system to eutrophication pressures.

Adaptation to climate change, for example by switching from combustion sources for power generation and transport is producing significant decreases in NOx emissions to the atmosphere, which in turn lead to less atmospheric nitrogen deposition on the sea surface and reduce eutrophication pressures, particularly away from coasts.

- Restructuring of seabed morphology, including dredging and depositing of materials **[Physical restructuring of rivers, coastline or seabed (water management)]:** Society's need for trade and movement of goods is a driver for dredging, and disposal and dredging can cause localised increases in nutrients.

Restructuring of the seabed by dredging, depositing or bottom trawling is expected to have a local impact on eutrophication. Traditionally it has been considered that organic material resuspended in disturbed sediment gives increased local oxygen demand. This may become problematic in an already oxygen-stressed environment such as the Kattegat. An additional problem is the destruction of habitat for seaweeds, seagrasses and filter feeders which are long-term stores of nutrients and signs of a healthy environment unaffected by eutrophication.

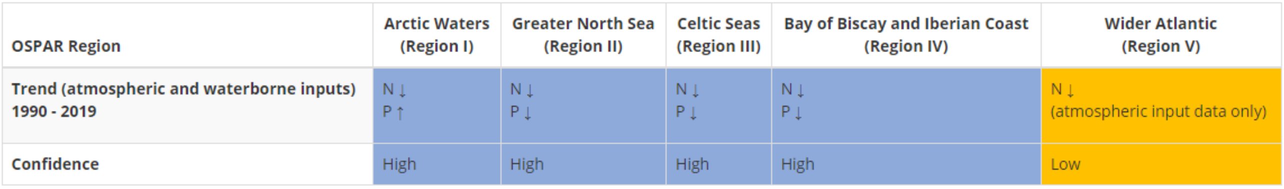
- Aquaculture - freshwater **[Cultivation of living resources]:** Aquaculture is driven by society's need for food. This activity can result in the input of substances to the environment, including nutrients.

In most OSPAR countries, freshwater aquaculture discharges enter the marine environment as part of the diffuse load measured at river mouths, and therefore separate data are not available. Recent developments with land-based recirculating aquaculture systems (RAS) have the potential to significantly reduce nutrient inputs. However, RAS are still in an early stage and have difficulty competing with open cage production, in which wastewaters are discharged untreated.

P – Pressure(s)

Pressures associated with eutrophication

Inputs of nutrients constitute the main pressure with respect to eutrophication. Region I has significantly increasing pressures in coastal waters, although the total nitrogen input pressure across the whole Region is decreasing. Regions II, III and IV show decreasing pressures when considering both atmospheric and waterborne inputs together. Changes in the ratios of nitrogen to phosphorus in the inputs – owing to greater success in reducing phosphorus loads – are likely exerting an additional pressure on species composition.



OSPAR Region	Arctic Waters (Region I)	Greater North Sea (Region II)	Celtic Seas (Region III)	Bay of Biscay and Iberian Coast (Region IV)	Wider Atlantic (Region V)
Trend (atmospheric and waterborne inputs) 1990 - 2019	N ↓ P ↑	N ↓ P ↓	N ↓ P ↓	N ↓ P ↓	N ↓ (atmospheric input data only)
Confidence	High	High	High	High	Low

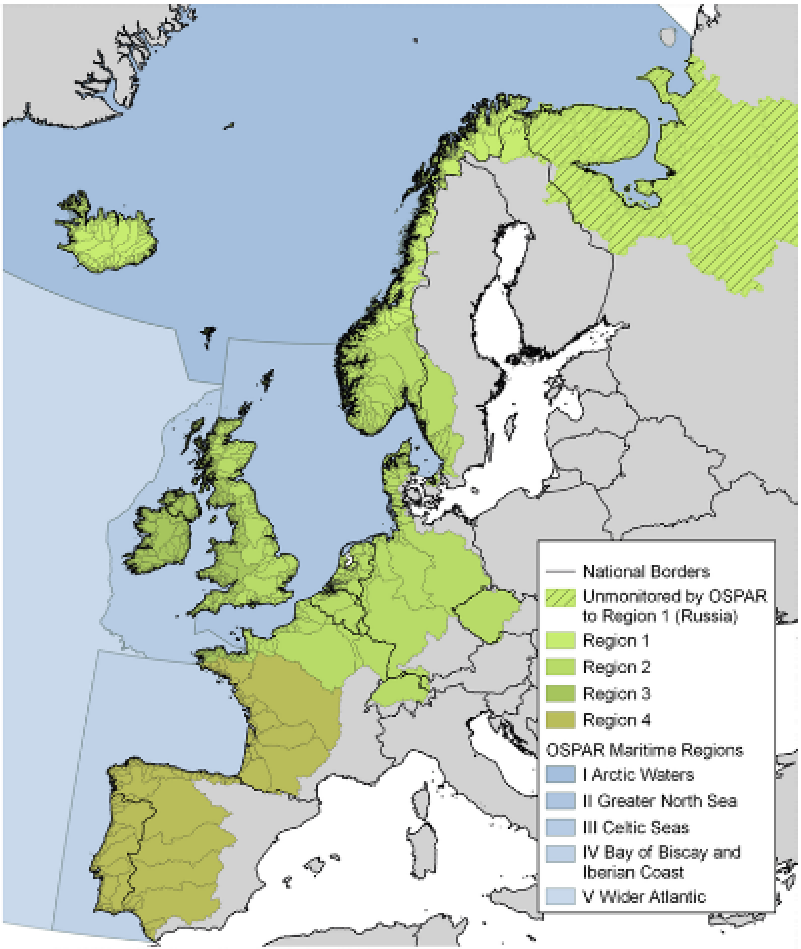
Confidence is set as "High" in the four Regions where RID data are available. Region V is not assessed owing to a lack of data on waterborne sources. There are data gaps in Regions I – IV but these are not considered to be sufficiently large to change the result of the assessment.

- Input of nutrients - diffuse sources, point sources, atmospheric deposition **[Substances, litter and energy]:**

The input of nutrients from diffuse sources, point sources and atmospheric deposition can lead to nutrient enrichment which in turn can result in deoxygenation and other signs of eutrophication. Even inputs of organic matter can intensify oxygen consumption because of bacterial respiration during decomposition.

Since the start of OSPAR riverine and direct discharge monitoring in 1990 **(Figure P.1),** the nutrient inputs to the Southern North Sea have been substantially reduced. Greater success in reducing phosphorus inputs may however lead to changes in phytoplankton community structure. Waterborne nutrient inputs to the Arctic have increased 3-5 times since 1990, owing to the increase in aquaculture production**.**

OSPAR's Joint Assessment and Monitoring Programme collates data on nutrient inputs from diffuse sources and direct discharges. Contracting Parties report annually the riverine and direct inputs from individual river mouths and discharge outfalls, from coastal sub-regions or basins (aggregated into direct and riverine sources) and at national level (also aggregated). Riverine sources are classified as river mouths – usually at the estuarine limit – or as unmonitored areas. Unmonitored areas are those between monitored river mouths where water and nutrients enter the marine environment via small streams only. Data from these areas are modelled. Direct discharges to the sea are reported. Discharges from upstream of the riverine measurement point are captured through the riverine measurements.



Sources: @GSHHS, @EuroGeographics, @OSPAR, @EPA.ie

Figure P.1: Catchments monitored by the OSPAR Riverine and Direct Discharges (RID) programme and the respective OSPAR Regions. There are no RID data from the Russian catchment to Region I, or from Region V

Atmospheric nitrogen deposition is measured through the OSPAR CAMP network of coastal monitoring sites. However, because of a lack of observations over the sea surface, the analysis of atmospheric nitrogen deposition comes from the EMEP modelling work, which makes use of the CAMP stations that are also included in the EMEP observation network and of emission data reported to the CEIP (Centre on Emission Inventories and Projections). Atmospheric phosphorus deposition is considered to be a natural process uncoupled from eutrophication and is not modelled or monitored.

Analysis of nutrient inputs is summarised in the Inputs of Nutrients Indicator Assessment and Waterborne and Atmospheric Inputs of Nutrients and Metals Other Assessment

Results presented in the factsheet indicate that for Regions I – IV of the OSPAR Maritime Area – those parts of the North-East Atlantic adjacent to the continental landmass including United Kingdom and Irish waters – pressure from nutrient inputs has decreased significantly, both since 1990 but also in the last 10 years (p values < 0,012 for both nitrogen and phosphorus). Closer analysis of the data reveals however that the greatest change in nitrogen inputs is due to reductions in atmospheric nitrogen deposition, which decreased from about 2 000 kt per year in 1990 to less than 1 500 kt in 2019. At the level of the four OSPAR Regions together, there is no significant decrease in waterborne nitrogen inputs.

Waterborne phosphorus inputs to Regions I – IV as a whole have more than halved since 1990 and continue to decrease with a statistically significant trend, albeit at a slower rate than over the 1990 – 2019 period. The marked changes in phosphorus inputs compared to nitrogen are apparent in the effective concentrations from individual rivers presented in **Figure P.2**.

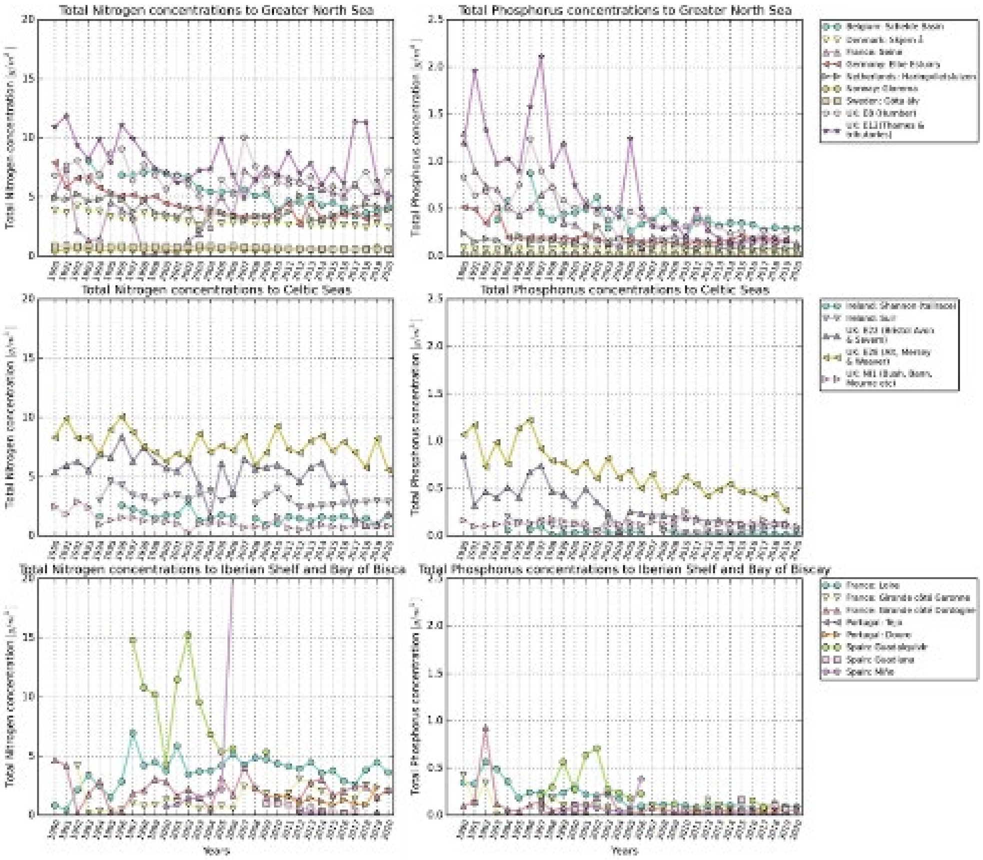


Figure P.2: Effective concentrations (load / flow) for nitrogen (left) and phosphorus (right) for selected rivers draining into OSPAR Regions II (top), III (middle) and IV (bottom)

A similar story emerges when looking at the flow-normalised inputs from selected major catchments and coastal regions (**Figure P.3**). Waterborne nitrogen inputs have decreased from the United Kingdom, the Rhine, the Elbe and Jutland compared to 1990 – 1999, but increases have occurred via the Loire and the Seine and also in northern Norway. Phosphorus inputs have been reduced substantially however, even from the

Loire and the Seine. The only major increases occur along the Norwegian coasts. These changes indicate a shift in the total eutrophication pressure northwards from Regions II and IV towards Region I (Arctic Waters). The greater success in reducing phosphorus compared to nitrogen however – particularly in the eastern Bay of Biscay where nitrogen loads increased while phosphorus loads decreased – can be expected to cause shifts in nitrogen to phosphorus ratios in coastal waters which have been associated with changes in species composition.

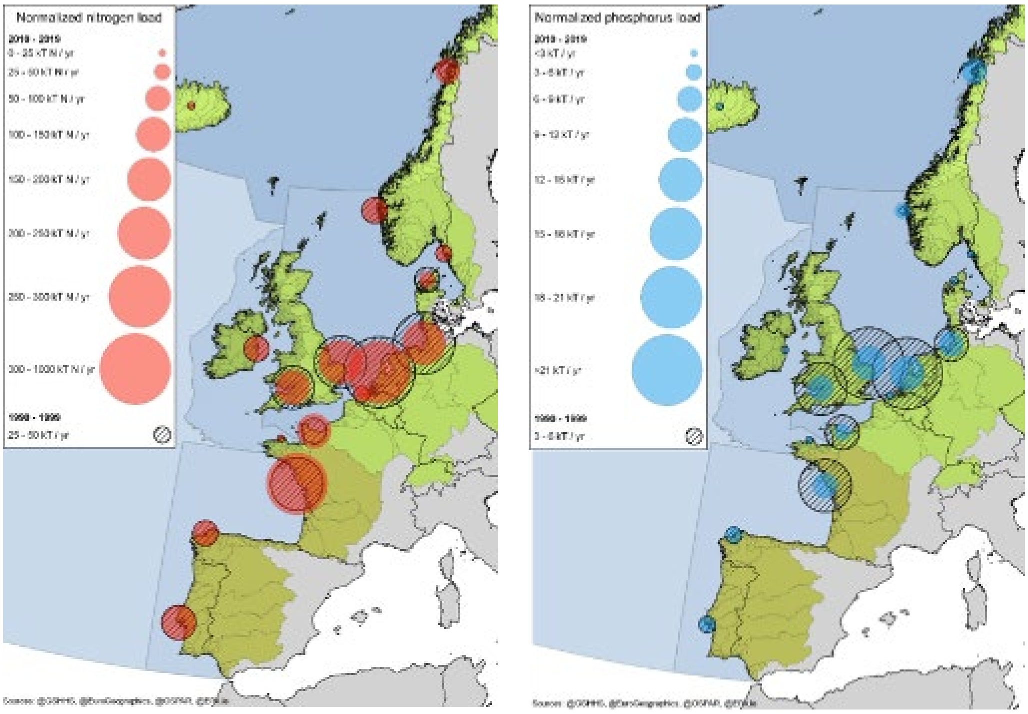


Figure P.3: Relative changes in nitrogen (left) and phosphorus (right) inputs from selected major catchments for the period 2010 - 2019 compared to 1990 – 1999. Catchments selected are those shown in the 3rd Common Procedure report (OSPAR, 2015)

N.B. The United Kingdom reports Total Inorganic Nitrogen and Total Inorganic Phosphorus, not Total Nitrogen and Total Phosphorus by persulphate oxidation. This results in a lower estimated input from the United Kingdom than would otherwise be expected.

The increase in nutrient inputs to the Arctic is of potential concern. While the total amount of nitrogen entering Region I because of reduced atmospheric emissions is decreasing, the waterborne amount has almost tripled since 1990 **(Figure P.4)**. The increase is likely to be an underestimate as no direct discharge data have been reported for Iceland or the Faroe Islands, which both have aquaculture industries. The aquaculture inputs occur on the coast, whereas the reduction in atmospheric inputs is spread across the whole region, so there is likely a process of oligotrophication occurring offshore with potential for eutrophication on the coast.

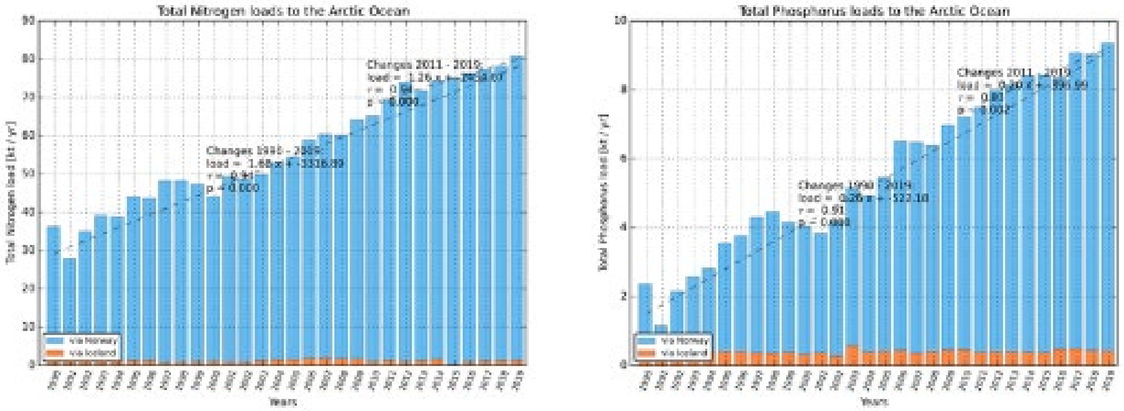


Figure P.4: Waterborne nitrogen and phosphorus inputs to the Arctic (Region I)

In addition, the effects of eutrophication are increased by pressures from:

- **Climate change** (Climate Change thematic assessment and Ocean Acidification Other Assessment):

Numerous drivers and activities (e.g., burning of fossil fuels, agriculture, deforestation) contribute to climate change, with a number of associated pressures potentially linked to eutrophication. Projections of climate change impacts on eutrophication are uncertain, however. They are linked to factors such as land use and crop choice, rainfall patterns and resulting freshwater input and run-off, and storminess affecting turbidity. Sea temperature, freshwater inputs and storminess affect the onset and breakdown of stratification.

These pressures change the biogeochemistry related to eutrophication directly and indirectly. Direct impacts, such as increased temperature, result in reduced oxygen concentrations by increasing phytoplankton growth rates and bacterial decomposition rates. Indirect impacts occur where, for example, increased stratification leads to reduced oxygen exchange in the water column, which in turn increases the risk of hypoxic events affecting both marine fauna and macrophytes.

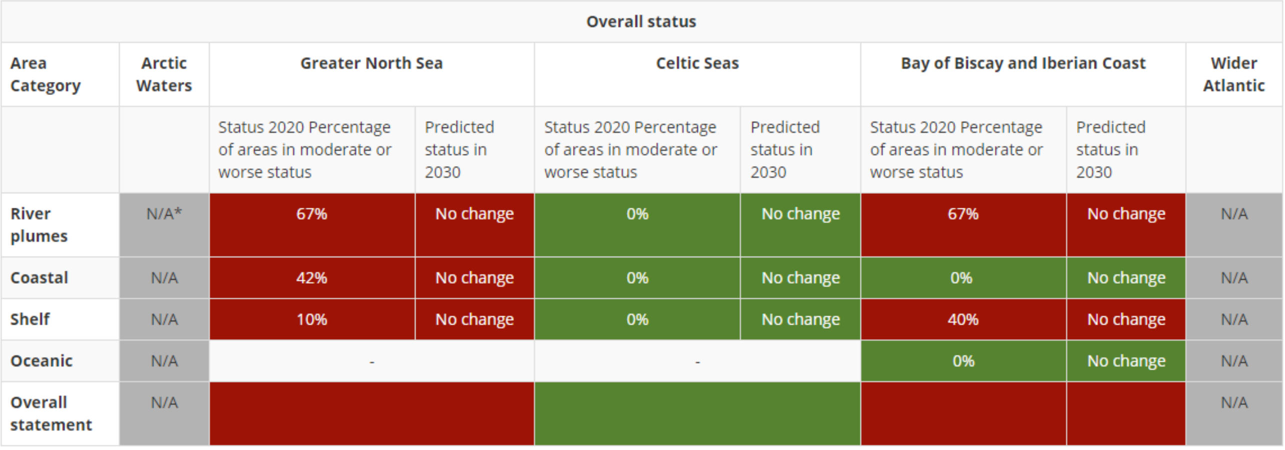
S – State

Eutrophication state of the OSPAR Maritime Area

Overall eutrophication assessment results are summarised per assessment area category (river plumes/variable salinity, coastal, shelf and oceanic areas) and OSPAR Region (**Table S.1**). These categories have also been used in the pelagic habitat and food web assessments to enable alignment of the indicator and thematic assessments, thereby supporting consistency across the assessments in accordance with QSR 2023 and MSFD requirements.

The Good and High classifications are merged into Good status (also termed non-problem areas in the Common Procedure Agreement), while moderate, poor and bad results are considered to be Not Good (also termed problem areas in the Common Procedure Agreement). The overall eutrophication status per area category and OSPAR Region was determined following the one-out-all-out principle. The assessment was carried out with the fully automated assessment tool COMPEAT. Information on the status classification of assessment areas, by category and Region, is included in **Table S.1** to support the interpretation of the overall result, with the different percentages indicating numbers of areas in moderate or worse status where improvements are still required in order to reach Good status.

Table S.1: Overall status of eutrophication per OSPAR Region. (*) N/A = not assessed. No or minimal changes are expected until 2030 assuming the current rate of load reduction continues. Ongoing efforts of reducing riverine and atmospheric nutrient inputs (e.g., WFD and MSFD programmes of measures, EU NEC Directive) can improve this trajectory



Overall status								
Area Category	**Arctic Waters**	**Greater North Sea**		**Celtic Seas**		**Bay of Biscay and Iberian Coast**		**Wider Atlantic**
		Status 2020 Percentage of areas in moderate or worse status	Predicted status in 2030	Status 2020 Percentage of areas in moderate or worse status	Predicted status in 2030	Status 2020 Percentage of areas in moderate or worse status	Predicted status in 2030	
River plumes	N/A*	67%	No change	0%	No change	67%	No change	N/A
Coastal	N/A	42%	No change	0%	No change	0%	No change	N/A
Shelf	N/A	10%	No change	0%	No change	40%	No change	N/A
Oceanic	N/A	-		-		0%	No change	N/A
Overall statement	N/A	🟥		🟩		🟥	🟥	N/A

In most assessment areas and categories, good status was achieved, indicating non-problem areas according to the Common Procedure. However, the overall not-good status of river plumes in Regions II and IV emphasises further need to reduce eutrophication effects. Whilst most coastal areas were assessed as good, the relatively high proportion of coastal areas in Region II that did not achieve good status clearly shows that these areas also require further improvement.

Along with the status assessment of eutrophication, a data-driven confidence assessment was conducted with the COMPEAT tool. The confidence assessment considers temporal, spatial and accuracy aspects per indicator (see Annex 13 in the Common Procedure) and is combined into an overall confidence result in the integration process of COMPEAT using three different levels of high, moderate and low confidence. The resulting overall confidence level was either moderate or even high in all OSPAR Regions, as shown in **Figure S.1** along with the status assessment.

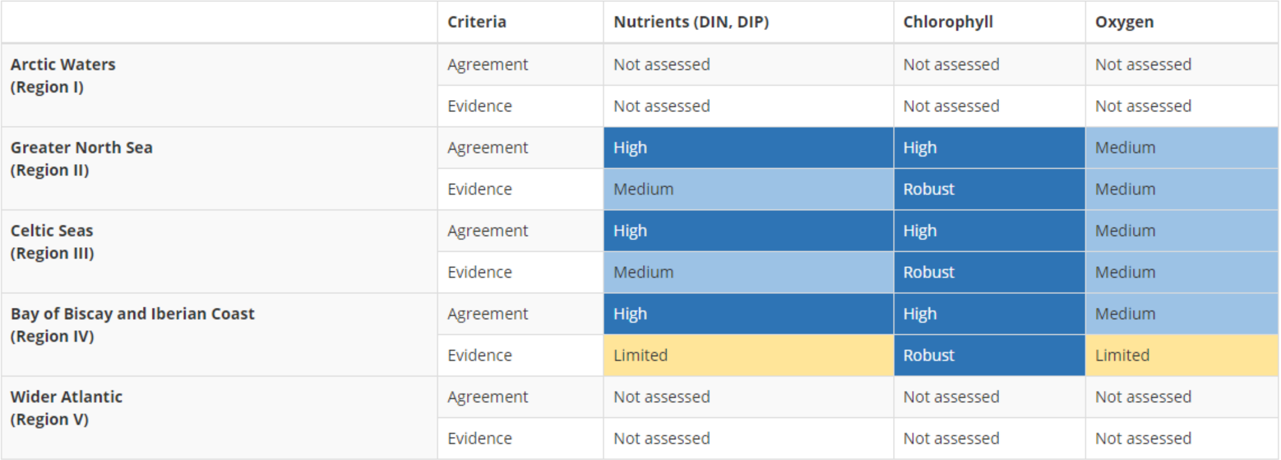
For this thematic assessment, the confidence assessment was conducted according to the recommendation in the QSR Guidance to be comparable with other thematic assessments (**Table S.2**). The overall confidence score for each OSPAR Region was assessed by considering the type, amount, quality, and consistency of evidence (using the classifications Robust, Medium, or Limited) and the degree of agreement (using the classifications High, Medium, or Low) in the results of the indicator assessments (see Annex 1 in the QSR 2023 Guidance Document).

Table S.2: Confidence assessment results for OSPAR Regions II, III and IV. Regions I and V were not assessed

OSPAR Region	**Arctic Waters (Region I)**	**Greater North Sea (Region II)**	**Celtic Seas (Region III)**	**Bay of Biscay and Iberian Coast (Region IV)**	**Wider Atlantic (Region V)**
Confidence	Not assessed	High	High	Medium	Not assessed

The overall confidence results per OSPAR Region were based on estimates of the agreement of and evidence for the different indicators, as shown in **Table S.3**. For the agreement, it was considered whether the indicator results were in line, i.e., showing similar trends and developments in concentrations over time among the different area categories. Other assessment outcomes were also reflected in the estimates where relevant, for example nutrient inputs and pelagic habitat assessment results. The evidence estimates were mainly based on underlying data coverage (temporal and spatial confidence) informed by the confidence assessment results from the different indicator assessments as calculated with the COMPEAT tool.

Table S.3: Confidence assessment of the type, amount, quality, and consistency of evidence (Robust, Medium or Limited), and the degree of agreement in the results (High, Medium or Low) for the common indicators used in the eutrophication assessment in OSPAR Regions II, III and IV. Regions I and V were not assessed



	Criteria	Nutrients (DIN, DIP)	Chlorophyll	Oxygen
Arctic Waters (Region I)	Agreement	Not assessed	Not assessed	Not assessed
	Evidence	Not assessed	Not assessed	Not assessed
Greater North Sea (Region II)	Agreement	High	High	Medium
	Evidence	Medium	Robust	Medium
Celtic Seas (Region III)	Agreement	High	High	Medium
	Evidence	Medium	Robust	Medium
Bay of Biscay and Iberian Coast (Region IV)	Agreement	High	High	Medium
	Evidence	Limited	Robust	Limited
Wider Atlantic (Region V)	Agreement	Not assessed	Not assessed	Not assessed
	Evidence	Not assessed	Not assessed	Not assessed

Assessment of eutrophication using COMPEAT.

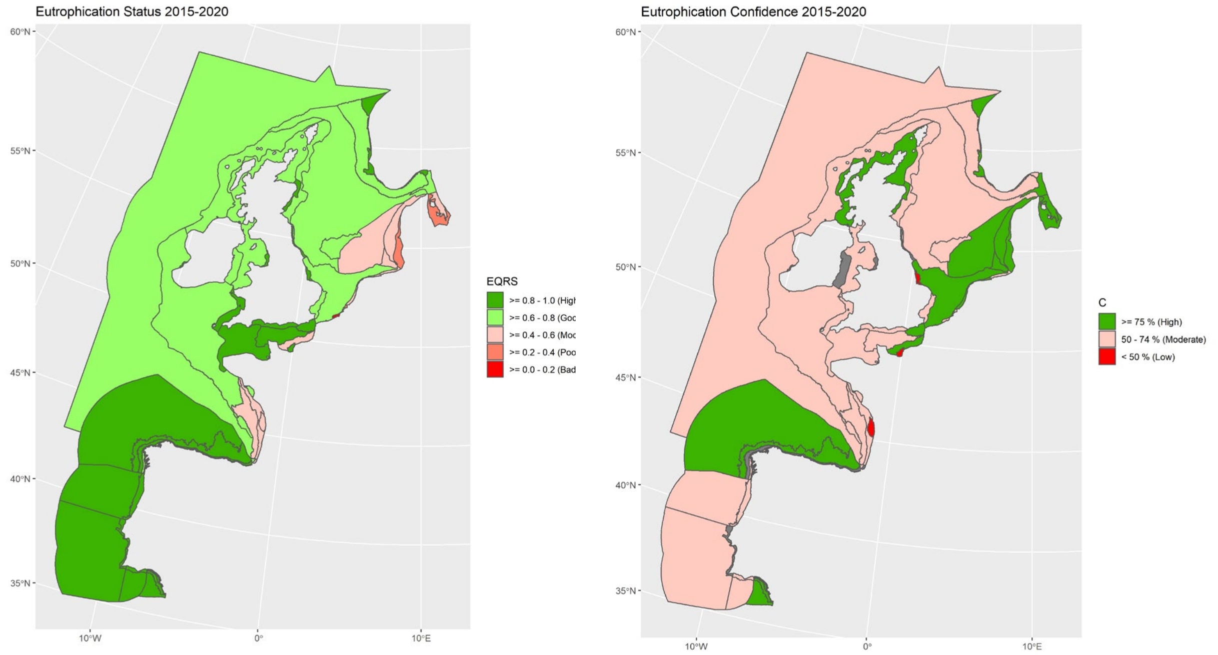
The assessment of eutrophication status is based on the degree of nutrient enrichment (Category I), the direct effects of nutrient enrichment (Category II) and the indirect effects of nutrient enrichment (Category III). For Category I, the Nutrients common indicator looks at winter mean concentrations of dissolved inorganic phosphorus (DIP) and dissolved inorganic nitrogen (DIN). For Category II, the Chlorophyll common indicator looks at growing season mean concentrations of chlorophyll. For Category III, the Dissolved Oxygen common indicator looks at oxygen concentrations near the seafloor. The overall result of the assessment depends on the outcome of the direct and indirect effects (Categories II, III), following the one-out-all-out principle. The degree of nutrient enrichment is not considered in the overall eutrophication result.

Here, we first provide an overview of the final results of the integrated assessment and a comparison of the assessment for the four different COMP periods, followed by an overview of more detailed results for each common indicator.

Integrated eutrophication assessment results

The three above-mentioned common indicators were integrated into the overall eutrophication assessment result following the assessment rules described above.

The final outcome for the COMP4 period is shown in **Figure S.1**, accompanied by the overall confidence assessment.



Available at:
https://odims.ospar.org/en/submissions/ospar_comp_eqrs_2020_06/

Available at:
https://odims.ospar.org/en/submissions/ospar_comp_confidence_2020_06/

Figure S.1: Eutrophication assessment result for the COMP4 period 2015-2020 (left) and overall confidence assessment based on spatial and temporal data coverage and accuracy as calculated in COMPEAT (right)

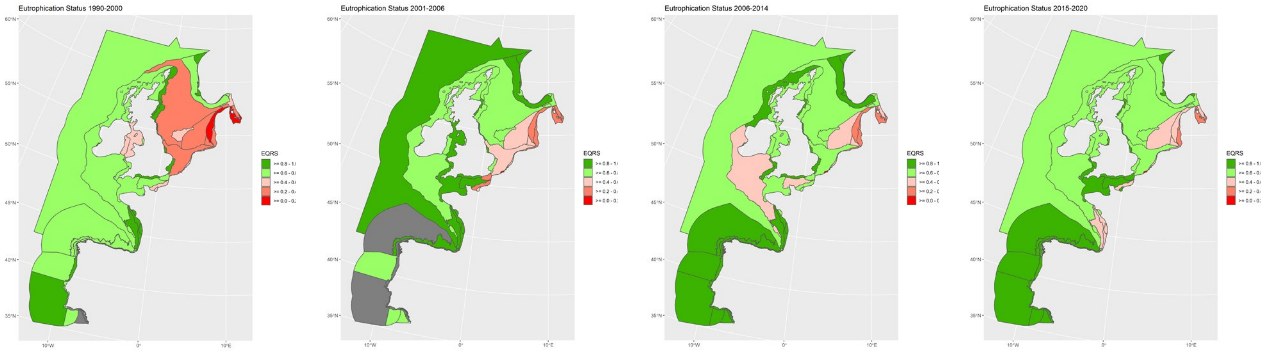
Assessment areas with moderate or worse status were mainly detected in the South-eastern North Sea and in river plumes along the continental coast from Belgium up to Denmark and the Kattegat (**Table S.4**).

Table S.4: Summary table of the eutrophication assessment for COMP4, showing only the assessment areas where at least one of the common indicators did not achieve good status

Category	Unit code	Description	DIN	DIP	Chlorophyll	Dissolved oxygen	Final assessment
Plume	ADPM	Adour plume			Good	Moderate	Moderate
Coastal	ELPM	Elbe plume	Poor	Moderate	Poor	Good	Poor
	EMPM	Ems plume	Poor	Good	Moderate	Good	Moderate
	GDPM	Gironde plume			High	Moderate	Moderate
	MPM	Meuse plume	Moderate	High	Poor	Good	Poor
	RHPM	Rhine plume	Poor	High	Moderate	Good	Moderate
	SCHPM1	Scheldt plume 1	Poor	High	Bad	Good	Bad
	SCHPM2	Scheldt plume 2	High	High	Moderate	Good	Moderate
	SHPM	Shannon plume	Poor	High	High	Good	Good
	CFR	Coastal FR channel	Good	Moderate	Moderate	High	Moderate
Shelf	CWAC	Coastal Waters AC (D5)	Moderate	High	High		High
	GBC	German Bight Central	Poor	Good	Moderate	Good	Moderate
	KC	Kattegat Coastal	Poor	Moderate	Poor	Poor	Poor
	KD	Kattegat Deep	Moderate	Moderate	Moderate	Moderate	Moderate
	OC DEDK	Outer coastal DEDK	Moderate	Good	Poor	Good	Poor
	ENS	Eastern North Sea	High	High	Good	Moderate	Moderate
	GBCW	Gulf of Biscay coastal waters			High	Moderate	Moderate
	GBSW	Gulf of Biscay shelf waters			High	Moderate	Moderate
	SK	Skagerrak	Moderate	High	Good	Good	Good

In a data-driven confidence assessment conducted with the COMPEAT tool, all indicators applied in the assessment are considered, using different aspects for temporal and spatial confidence, as well as accuracy, to estimate the probability of correct classification in relation to the respective thresholds. The confidence assessment is based on three classifications resulting from averaging of the different confidence aspects. In most areas, confidence scores were high or moderate and only in certain river plume areas was the confidence low. However, agreement is needed for a separate assessment of confidence in offshore areas, previously only assessed using a screening procedure, because the available data are not collected in the same way as in the more established eutrophication-sensitive areas, which are assessed according to the CEMP Guidelines for coordinated monitoring for eutrophication, CAMP and RID (OSPAR, 2021).

The eutrophication assessment was performed with COMPEAT for the first time for the most recent COMP4 period (2015-2020) and also retrospectively for the previous assessment periods COMP1 (1990-2000), COMP2 (2001-2006) and COMP3 (2006-2014). The agreed assessment areas and thresholds for applying COMP4 were also used to assess previous periods so as to identify developments over time, as illustrated in **Figure S.2**.



Available at: https://odims.ospar.org/en/submissions/ospar_comp_eqrs_2000_06/

Available at: https://odims.ospar.org/en/submissions/ospar_comp_eqrs_2006_06/

Available at: https://odims.ospar.org/en/submissions/ospar_comp_eqrs_2014_06/

Available at: https://odims.ospar.org/en/submissions/ospar_comp_eqrs_2020_06/

Figure S.2: Eutrophication assessment results for all four COMP periods covering a time span of 30 years. Assessment areas without data where no assessment was possible are indicated in grey

Comparison of the four different COMP periods shows a gradual decrease in the number and total surface area of assessment areas that do not achieve Good status. The areas that have been designated as moderate, poor or bad have decreased for DIN, DIP and Chl-a, but are increasing in overall area for DO (**Figure S.3**). Total surface area showed a more continuous decrease for DIN, but the development was different for DIP, which experienced an increase during the COMP2 and COMP3 periods, with a final surface area in not-good status in the most recent period of COMP4. Since the first COMP assessment, the total surface area of assessment areas where chlorophyll concentrations exceed thresholds has decreased, notably in coastal and shelf assessment areas. However, no change has been observed since the period 2006-2014. It should be noted that in the COMP1 period, the satellite data used for the Chlorophyll common indicator only became available from 1998 onwards. The chlorophyll assessment for the COMP1 period was therefore mainly determined by in situ data which increases the uncertainty of the assessment, notably because of low spatial confidence in offshore areas such as the Northern North Sea. Changes in the main data source for chlorophyll may, over time, have driven some of the changes observed in the overall eutrophication assessment, notably from COMP1 to COMP2. The surface area of assessment areas that do not achieve good status for DO has increased, from COMP1 (16 657 km^2) and COMP2 (98 318 km^2) to a maximum in COMP3 of 337 696 km^2, reducing to 110 261 km^2 in the current COMP4.

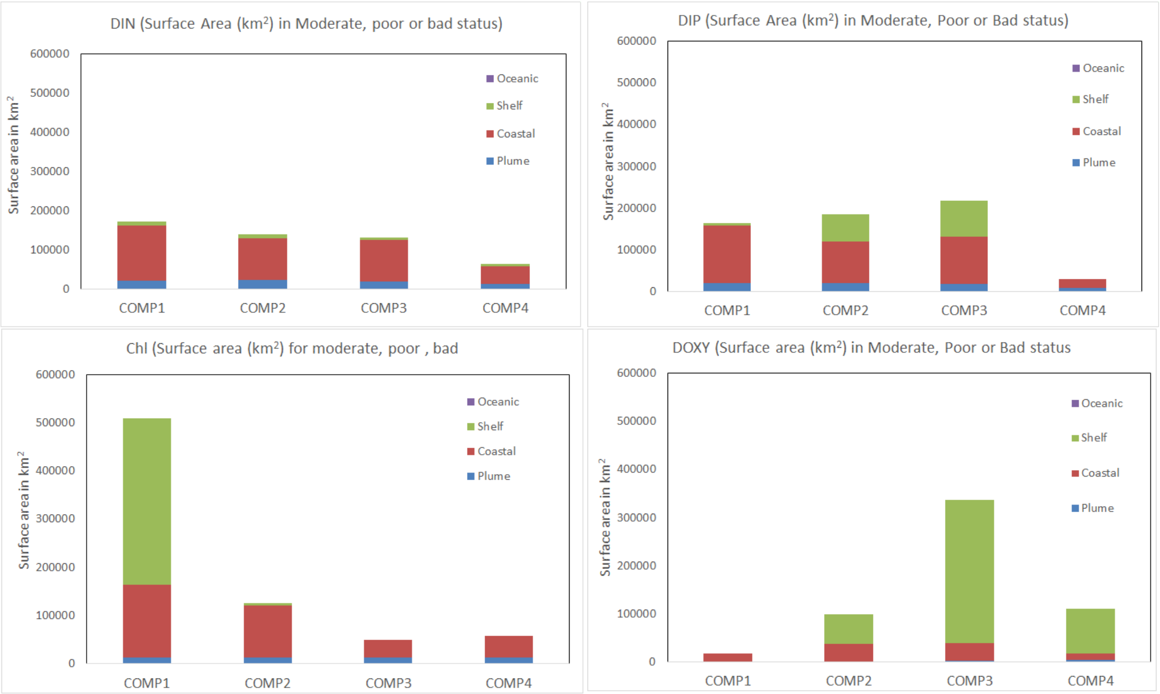


Figure S.3: Changes in the surface areas (km^2) for areas in moderate, poor or bad status presented for each indicator and separated into oceanic, shelf, coastal and plume areas

Category I – Degree of nutrient enrichment

Winter nutrient concentrations:

- The Winter Nutrient Concentrations common indicator assesses whether nutrient levels of dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) are elevated and may cause undesirable disturbances such as accelerated growth of algae, including shifts in the composition and extent of flora and fauna. Winter mean concentrations of DIN and DIP have continued to decrease since QSR 2010, mainly in river plumes and coastal areas. In the most recent assessment period 2015-2020, twelve assessment areas were assessed as moderate or poor for DIN, mostly in OSPAR Region II, while for DIP only four assessment areas were classified as being in Not-good status (**Figure S.4**). The total surface areas in not-good status for the period 2015-2020 are 63 537 km^2 for DIN and 29 603 km^2 for DIP. Broken down for the different area categories, this corresponds to 61% of the river plumes, 24% of the coastal waters and less than 1% of the shelf waters in the assessed OSPAR area (surface area km^2) not being in good status for DIN. For DIP, 38% of the river plumes and 11% of the coastal waters were in Not-good status. Most of the areas in moderate or worse status for DIN were found along the continental coast from France to Denmark/Sweden in several river plumes (e.g., Scheldt, Meuse, Rhine, Ems and Elbe) and coastal areas (e.g., German Bight central and Kattegat). Most of the areas with elevated DIN concentrations along the continental coast from Belgium to Denmark also showed chlorophyll concentrations above thresholds (cf. **Table S.3**).
- The development of areas in not-good status for DIN and DIP during the different COMP periods from 1990-2020 and the corresponding surface area in km^2 are illustrated in **Figure S.2**. While the number of these areas as well as their total surface area showed a more continuous decrease for DIN, the development was different for DIP, which experienced an increase during the COMP2 and COMP3 periods, with a final very low number of areas in not-good status in the most recent period COMP4. The increased DIP in the areas with moderate or worse status during the COMP2 and COMP3 periods was mainly due to increases in shelf areas, in particular in the Eastern North Sea and some Channel areas, leading to a significant increase in the surface area in not-good status. Between COMP3 and

COMP4, DIP concentrations decreased substantially both in coastal and shelf areas in the Southern and South-eastern North Sea.

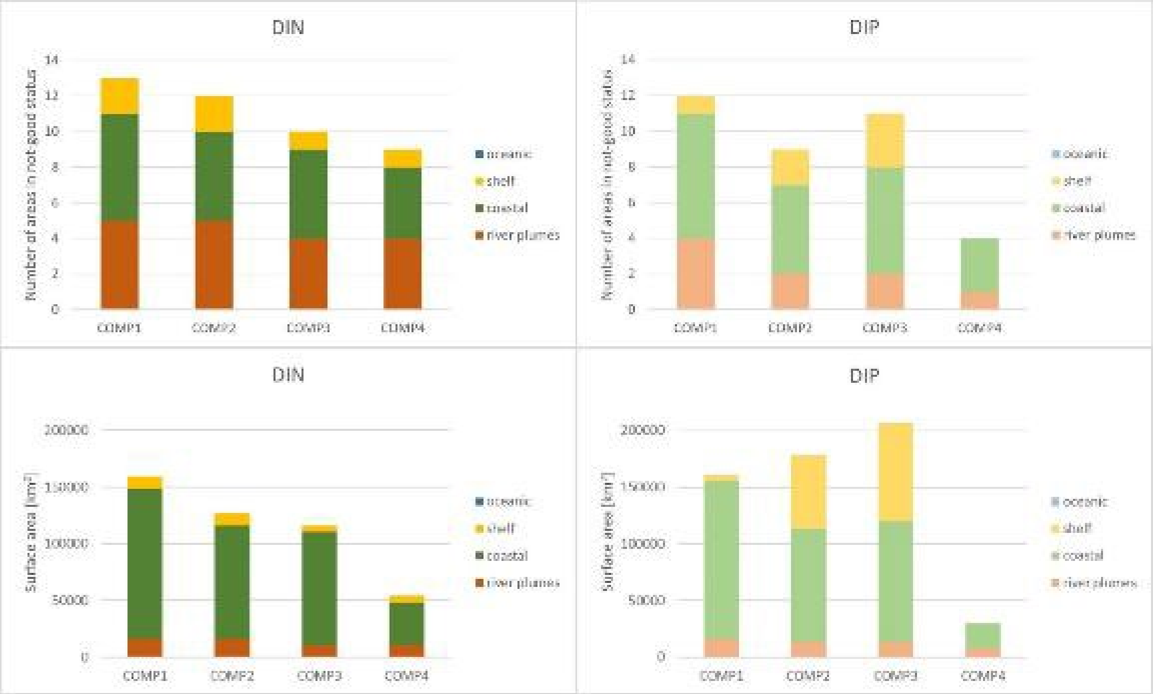


Figure S.4: Number of assessment areas and surface areas for DIN (left) and DIP (right) in moderate, poor or bad status in the four COMP periods, grouped into river plumes, coastal and shelf areas. Only assessment areas with results in all four COMP periods and moderate or high confidence were included

- Trend assessments for the period 1990-2020 showed significant decreases for DIN in the Meuse and Rhine plumes. Decreasing DIN concentrations were also observed in other river plumes, but these were not statistically significant. Assessment areas with DIP concentrations above the threshold, leading to a moderate status classification, were all located in OSPAR Region II (Kattegat, Elbe plume and French Coastal Channel). Only in the Elbe plume was a significant decreasing trend for DIP identified, while the decreasing developments observed in other areas were not statistically significant.

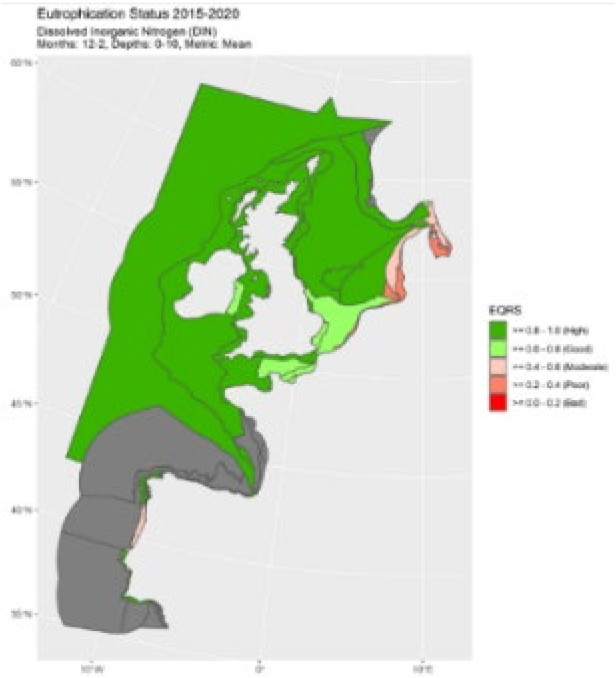


Figure S.5: Assessment results of winter DIN for the period 2015-2020 in OSPAR Regions II, III and IV. Assessment areas without data, where no DIN assessment was possible, are indicated in grey. Available at: https://odims.ospar.org/en/submissions/ospar_din_eqrs_2020_06/

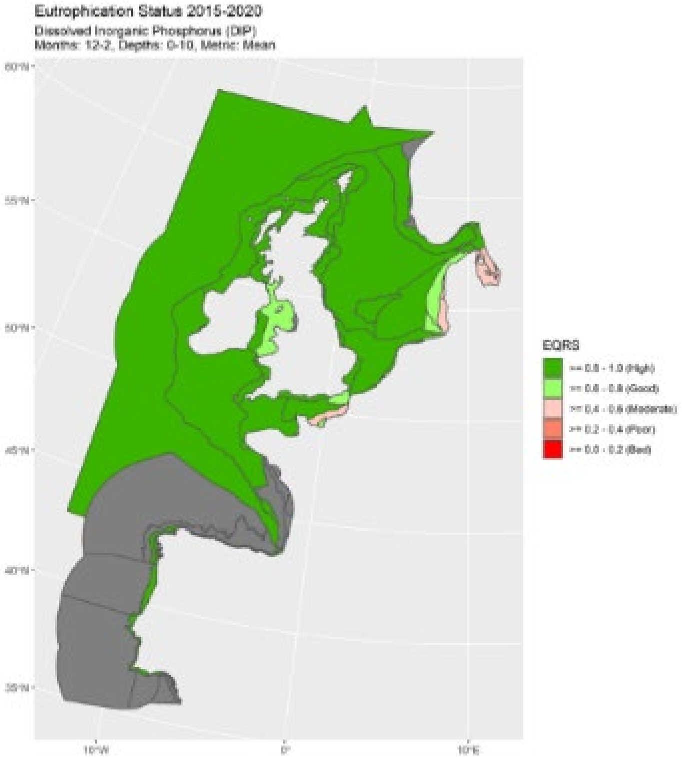
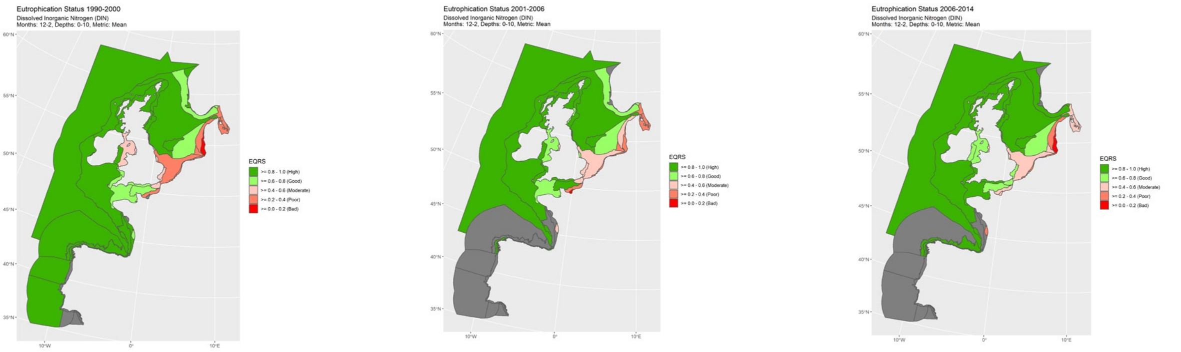


Figure S.6: Assessment results of winter DIP for the period 2015-2020 in OSPAR Regions II, III and IV. Assessment areas without data, where no DIP assessment was possible, are indicated in grey. Available at: https://odims.ospar.org/en/submissions/ospar_dip_eqrs_2020_06/

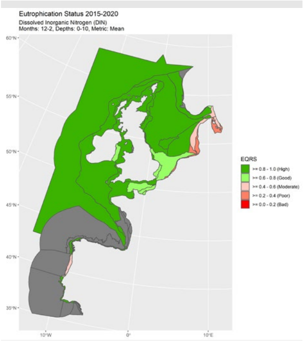
- The development of winter DIN (**Figure S.5**) and DIP (**Figure S.6**) concentrations during the different assessment periods of COMP1 (1990-2000), COMP2 (2001-2006), COMP3 (2006-2014) and COMP4 (2015-2020) is reflected in the changing status classifications over time in certain areas, as illustrated in **Figure S.7, Figure S.8, Figure S.9** and **Figure S.10**. In the automated assessment tool COMPEAT, retrospective assessment of previous COMP periods was applied by using the thresholds and assessment areas defined for the application of COMP4, in order to allow for a comparable assessment. These results are therefore not directly comparable with the previous OSPAR eutrophication assessment results summarised in the integrated reports, since they are based on different assessment areas and national thresholds. In general, the last 30 years have seen a decrease in nutrient input, as reflected in a decrease in DIN and DIP concentrations. Improved status classifications were thus observed in most of the assessment areas over the same period. This shows the effectiveness of the measures used to improve the status of marine ecosystems. However, there are exceptions showing interim increases, and in many areas the decreases in DIN and DIP concentrations have ceased over the last decade. As we know that there is a considerable time lag - probably decades – before ecosystems recover fully from eutrophication following a decrease in DIN and DIP concentrations, there is an urgent need for stronger measures if the OSPAR goal of good status by 2030 is to be achieved.



Available at: https://odims.ospar.org/en/submissions/ospar_din_eqrs_2000_06/

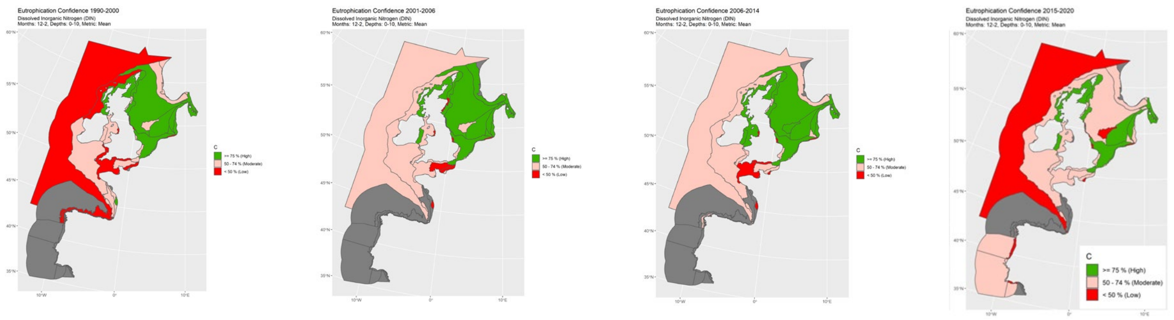
Available at: https://odims.ospar.org/en/submissions/ospar_din_eqrs_2006_06/

Available at: https://odims.ospar.org/en/submissions/ospar_din_eqrs_2014_06/



Available at: https://odims.ospar.org/en/submissions/ospar_din_eqrs_2020_06/

Figure S.7: Assessment results of winter DIN for all assessment periods of COMP1 (1990-2000), COMP2 (2001-2006), COMP3 (2006-2014) and COMP4 (2015-2020). Assessment areas without data, where no DIN assessment was possible, are indicated in grey



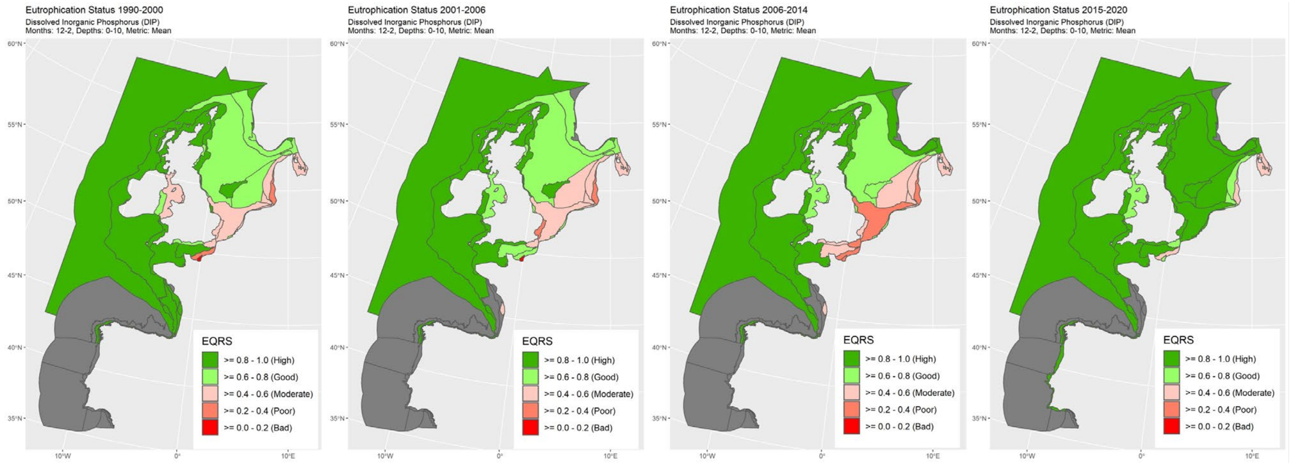
Available at: https://odims.ospar.org/en/submissions/ospar_din_confidence_2000_06/

Available at: https://odims.ospar.org/en/submissions/ospar_din_confidence_2006_06/

Available at: https://odims.ospar.org/en/submissions/ospar_din_confidence_2014_06/

Available at: https://odims.ospar.org/en/submissions/ospar_din_confidence_2020_06/

Figure S.8: Estimate of overall confidence for winter DIN for all assessment periods of COMP1 (1990-2000), COMP2 (2001-2006), COMP3 (2006-2014) and COMP4 (2015-2020). Assessment areas without data, where no assessment was possible, are indicated in grey



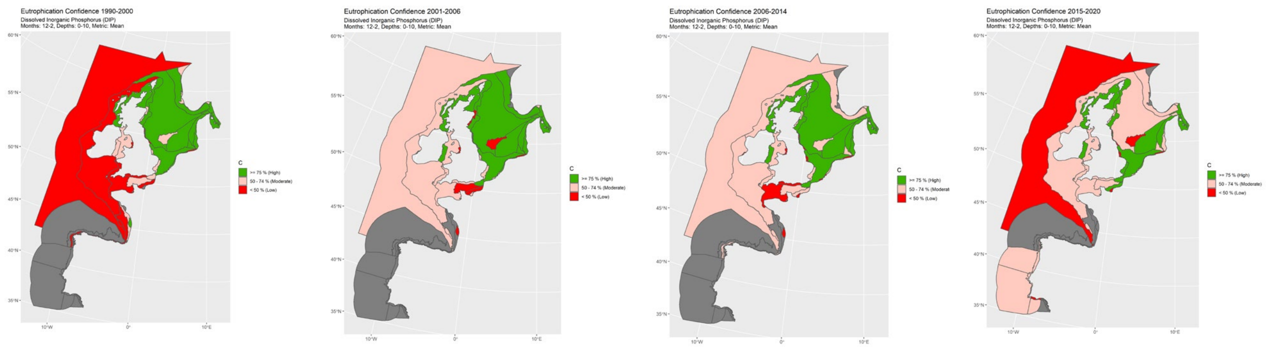
Available at: https://odims.ospar.org/en/submissions/ospar_dip_eqrs_2000_06/

Available at: https://odims.ospar.org/en/submissions/ospar_dip_eqrs_2006_06/

Available at: https://odims.ospar.org/en/submissions/ospar_dip_eqrs_2014_06/

Available at: https://odims.ospar.org/en/submissions/ospar_dip_eqrs_2020_06/

Figure S.9: Assessment results of winter DIP for all assessment periods of COMP1 (1990-2000), COMP2 (2001-2006), COMP3 (2006-2014) and COMP4 (2015-2020). Assessment areas without data, where no DIP assessment was possible, are indicated in grey



Available at: https://odims.ospar.org/en/submissions/ospar_dip_confidence_2000_06/

Available at: https://odims.ospar.org/en/submissions/ospar_dip_confidence_2006_06/

Available at: https://odims.ospar.org/en/submissions/ospar_dip_confidence_2014_06/

Available at: https://odims.ospar.org/en/submissions/ospar_dip_confidence_2020_06/

Figure S.10: Estimate of overall confidence for winter DIP for all assessment periods of COMP1 (1990-2000), COMP2 (2001-2006), COMP3 (2006-2014) and COMP4 (2015-2020). Assessment areas without data, where no assessment was possible, are indicated in grey

Category II – Direct effects of nutrient enrichment

Growing season concentrations of chlorophyll-a

- The Chlorophyll-a common indicator is a proxy for phytoplankton biomass. Chlorophyll is traditionally measured in situ but, given the variability in space and time of this indicator, the results of in situ sampling are often insufficient for detecting spatial patterns. Particularly in offshore areas, in situ sampling is very sparse. By using 'ocean colour', satellites can detect chlorophyll at a much higher temporal and spatial resolution and at relatively low costs per observation. Chlorophyll-a concentrations were thus assessed in all COMP4 assessment areas of OSPAR Regions II, III and IV (Greater North Sea, Celtic Seas, Bay of Biscay and Iberian Coast). For the first time, the assessment was based not only on in situ data but also on the Earth Observation (satellite) data available for 1998 onwards. The combination of in situ data and satellite data used in the assessment follows the methods described in the revision of the Common Procedure (OSPAR, 2022).
- For the most recent period 2015-2020, eleven assessment areas (**Figure S.11**), all in OSPAR Region II, are in moderate, poor or bad status (i.e. with concentrations above the threshold). Those areas along the continental coast from France to Denmark/Sweden are either river plumes (Scheldt, Meuse, Rhine, Ems, Elbe) or coastal waters (Coastal French Channel, German Bight, Coastal DEDK and Kattegat Coastal and Kattegat Deep).
- Five of the river plume assessment areas with chlorophyll concentrations above the threshold also have DIN concentrations exceeding the threshold. In one case, data are missing. In the Elbe plume, both DIN and DIP concentrations are above the threshold. The five coastal water assessment areas with chlorophyll concentrations above the threshold also have DIN and/or DIP concentrations above the threshold.

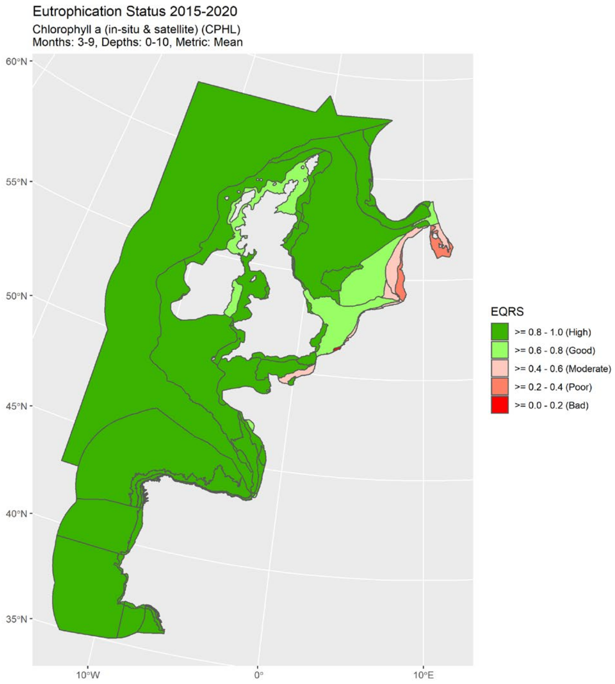


Figure S.11: Results of the COMP4 assessment of chlorophyll growing season mean, based on the combination of in situ and satellite data, for OSPAR Regions II, III and IV. Available at: https://odims.ospar.org/en/submissions/ospar_chlorophyll_eqrs_2020_01_001/

- Since the first COMP assessment, the number and total surface area of assessment areas with chlorophyll concentrations exceeding thresholds have decreased, notably in coastal and shelf assessment areas. However, no change has been observed since the period 2006-2014 (see **Figure S.12)**.

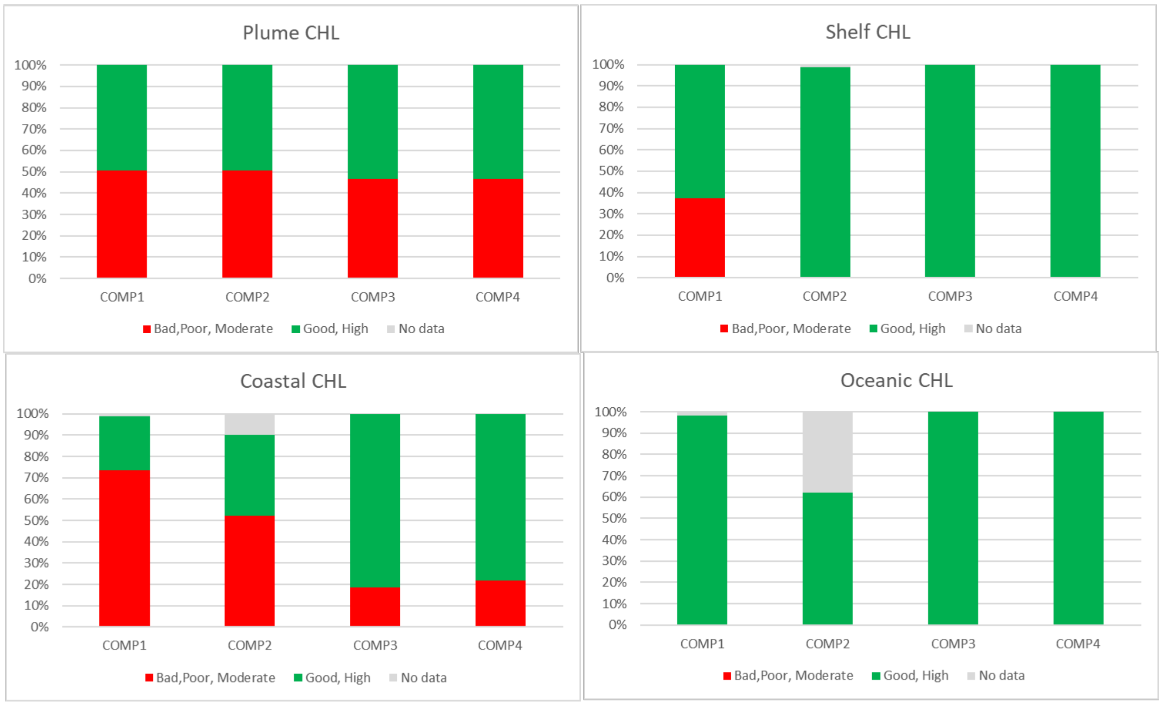
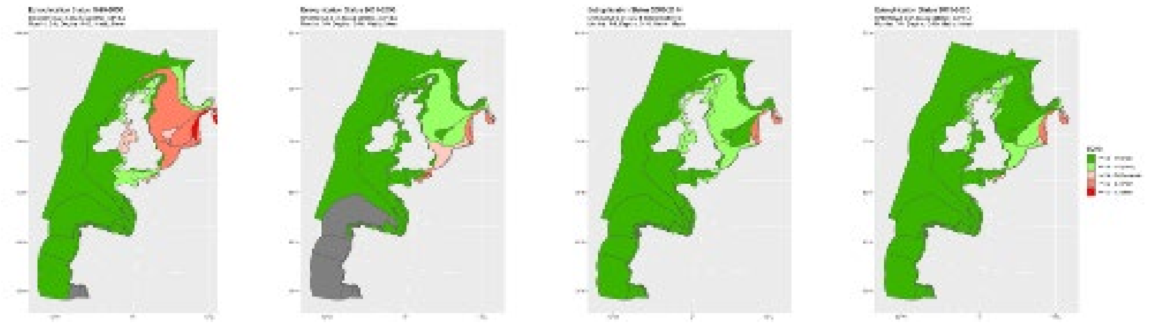


Figure S.12: Percentage of the surface area of river plumes, coastal waters, shelf areas and oceanic waters with bad, poor or moderate status (red) or good or high status (green) in the COMP1, COMP2, COMP3 and COMP4 assessment periods. Grey bars indicate assessment areas with missing data

For the period 2015-2020, the total surface area not in good/high status is 57 304 km^2 or 2,2% of the total assessed surface area. However, this low percentage reflects the vast areas of open ocean where eutrophication is absent. Split up over the different categories, 46% of the surface area of river plumes and 22% of the surface area of coastal areas is not in good/high status.

- A trend analysis of the growing season means in each assessment area was conducted and regression analyses done for the periods 1990-2020 (for in situ data) and 1998-2020 (for satellite data). The five coastal waters assessment areas that were classified as moderate, poor or bad in status (i.e. with concentrations above the threshold) for chlorophyll show significant decreasing trends in concentrations (whether Earth Observation or in situ data) over the last 25 to 30 years. These areas are all in coastal waters: Coastal French Channel, Outer Coastal DEDK, German Bight Central, Kattegat Coastal and Kattegat Deep. For some areas, for example Kattegat Coastal and Kattegat Deep, there is an increasing trend over approximately the last ten years. The nutrient concentrations in those areas (whether DIN or DIP) did not show a significant trend, possibly due to limited data availability in some of the areas (**Figure S.13** and **Figure S.14**).
- The river plume assessment areas classified as moderate, poor or bad in status did not show trends in chlorophyll concentrations despite decreasing trends in nutrients in some cases (DIN: Rhine, Meuse; DIP: Elbe). The lack of response by chlorophyll concentrations to decreasing nutrient concentrations may be partly due to high interannual variability in chlorophyll concentrations but may also point to nutrient concentrations which are still so high that phytoplankton growth is not limited by nutrient availability, and to ecological time lags between nutrient reduction and a measurable ecological response. The biomass of grazers can also control the biomass of phytoplankton, such that the chlorophyll concentration does not respond linearly to decreasing nutrient concentrations. Light availability also influences plankton community structure and the associated chlorophyll concentrations. In general, a time lag of decades is expected between a decrease in nutrient inputs and a full positive response from the biological system. Therefore, continuous, substantial reductions in nutrient inputs are needed in order to meet the OSPAR strategic objective with regard to eutrophication and achieve and maintain a healthy marine environment where anthropogenic eutrophication does not occur.



Available at: https://odims.ospar.org/en/submissions/ospar_chlorophyll_eqrs_2000_01/

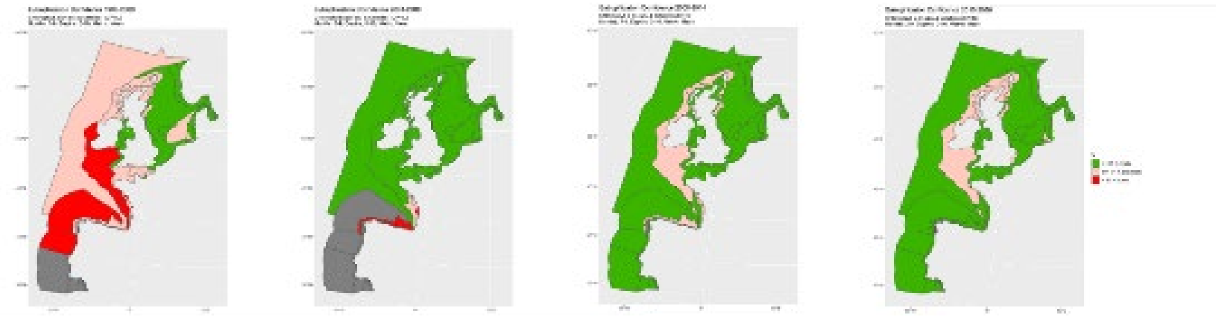
Available at: https://odims.ospar.org/en/submissions/ospar_chlorophyll_eqrs_2006_01/

Available at: https://odims.ospar.org/en/submissions/ospar_chlorophyll_eqrs_2014_01/

Available at: https://odims.ospar.org/en/submissions/ospar_chlorophyll_eqrs_2020_01/

Figure S.13: Assessment results of Chlorophyll for the assessment periods of COMP1 (1990-2000), COMP2 (2001-2006), COMP3 (2006-2014) and COMP4 (2015-2020). Assessment areas without data where no assessment was possible are indicated in grey

Note that in COMP1 the chlorophyll concentrations are mainly based on in situ sampling, which is less reliable in offshore waters (e.g., Northern North Sea), owing to low spatial confidence. This may partly explain the apparent changes seen between COMP1 and COMP2.



Available at: https://odims.ospar.org/en/submissions/ospar_chl_confidence_2000_01/

Available at: https://odims.ospar.org/en/submissions/ospar_chl_confidence_2006_01/

Available at: https://odims.ospar.org/en/submissions/ospar_chl_confidence_2014_01/

Available at: https://odims.ospar.org/en/submissions/ospar_chl_confidence_2020_01/

Figure S.14: Estimate of overall confidence for Chlorophyll for all assessment periods of COMP1 (1990-2000), COMP2 (2001-2006), COMP3 (2006-2014) and COMP4 (2015-2020). Assessment areas without data where no assessment was possible are indicated in grey

Category III - Indirect effects of nutrient enrichment

Concentrations of dissolved oxygen near the seafloor

- The Dissolved Oxygen common indicator looks at the effects of nutrient enrichment and increased algal production on the concentrations of dissolved oxygen in the water column near the seafloor.
- All but seven assessment areas have been classified as having good or high status, based on the mean 5th percentile value of dissolved oxygen being greater or equal to a threshold value of 6,0 mg/L for

the period 2015-2020. The seven assessment areas in question are: Adour plume (4,4 mg/L), Kattegat Coastal (3,92 mg/L), Kattegat Deep (4,70 mg/L), Eastern North Sea (5,69 mg/L), Gironde plume (5.3 mg/L), Gulf of Biscay coastal (5,56 mg/L) and Gulf of Biscay shelf waters (5,86 mg/L) (**Figure S.15**).

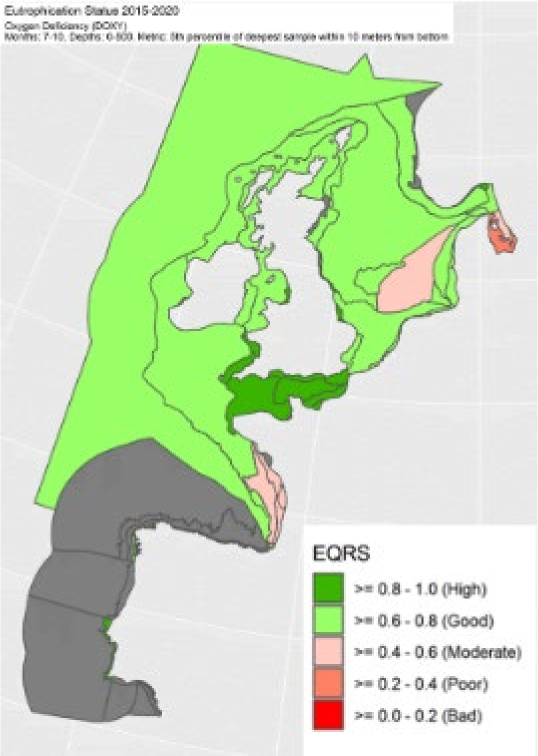
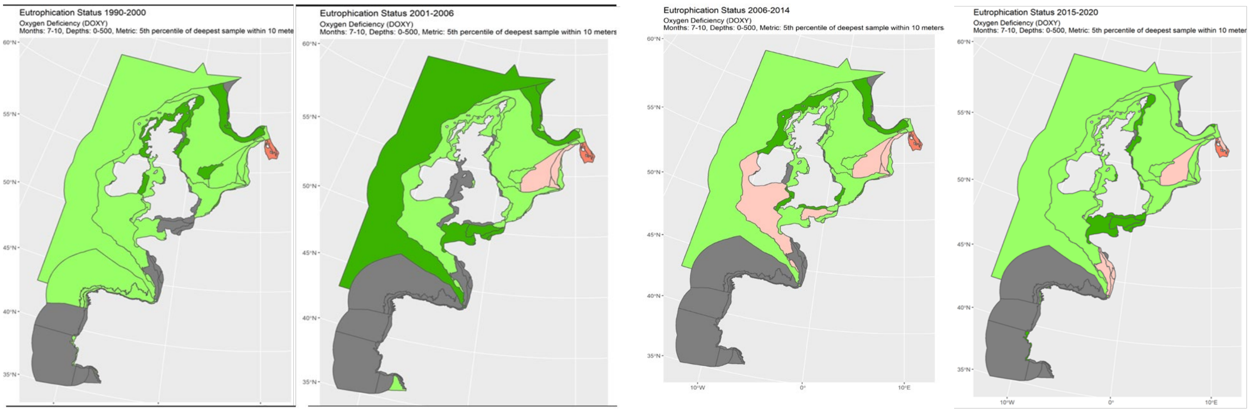


Figure S.15: Results of the COMP4 assessment for dissolved oxygen for OSPAR Regions II, III and IV. Available at: https://odims.ospar.org/en/submissions/ospar_dissolved_oxygen_eqrs_2020_06/

- The trend analysis was carried out on data for the period 1990 to 2020 (**Figure S.16**). Many of the assessment areas had sufficient long-term data (52 out of 64) to apply a trend assessment. Out of those 52 areas, one coastal area showed an increasing trend (Kattegat Coastal). The areas with decreasing trends for dissolved oxygen included two in river plumes (Meuse, Scheldt), two in shelf areas (Norwegian Trench, Atlantic Seasonally Stratified) and one in oceanic areas (Atlantic). The Thames plume also showed a decreasing trend, but it was not significant. Note that, in contrast to the other eutrophication common indicators, an increasing trend reflects an improving status, while a decreasing trend signifies that the status is deteriorating.
- The assessment results for the previous COMP periods, with application of the COMP4 thresholds, are shown in **Figure S.17.** In the COMP1 period (1990-2000), four assessment areas were classified as having moderate, poor or bad status, out of 36 areas. The assessment areas with eutrophication problems were mainly found in OSPAR Region II, namely Kattegat Coastal and Kattegat Deep, and also the Noratlantic Area NOR-NorC2 and Sudatlantic Area SUD-C1 in OSPAR Region IV. However, for the latter area the spatial and temporal confidence of the assessment is classified as low.
- In the COMP2 period (2001-2006) five out of 34 assessment areas were in moderate, poor or bad status, including Kattegat Coastal, Kattegat Deep, Eastern North Sea, German Bight and Coastal DEDK. In the COMP3 period (2006-2014) this was the case for eight out of 31 assessment areas. These comprise Kattegat Coastal, Kattegat Deep, Eastern North Sea, German Bight Central and

Coastal DEDK again, with the addition of Atlantic Seasonally Stratified, Channel Well-mixed Tidal Influenced, and Ems plume. In summary, the recurrent pattern over the entire period from 1990 to 2020 is that in OSPAR Region II a number of assessment areas are repeatedly classified as having moderate, poor or bad status. The oxygen concentrations show high spatial variability and are better assessed using a gridded approach, as was applied in the common indicator assessment**.**



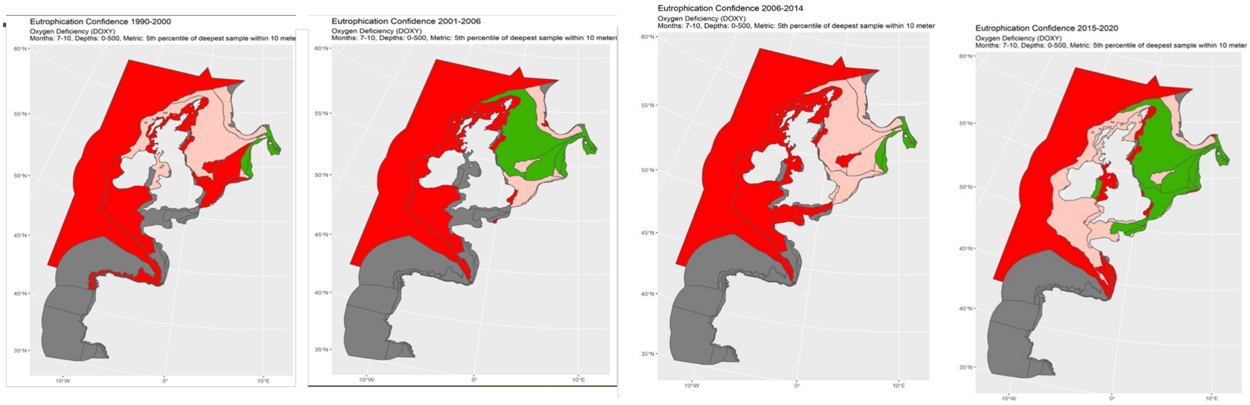
Available at: https://odims.ospar.org/en/submissions/ospar_dissolved_oxygen_eqrs_2000_06/

Available at: https://odims.ospar.org/en/submissions/ospar_dissolved_oxygen_eqrs_2006_06/

Available at: https://odims.ospar.org/en/submissions/ospar_dissolved_oxygen_eqrs_2014_06/

Available at: https://odims.ospar.org/en/submissions/ospar_dissolved_oxygen_eqrs_2020_06/

Figure S.16: Assessment results of Dissolved Oxygen (5th percentile) for all assessment periods of COMP1 (1990-2000), COMP2 (2001-2006), COMP3 (2006-2014) and COMP4 (2015-2020). Assessment areas without data, where no DO assessment was possible, are indicated in grey



Available at: https://odims.ospar.org/en/submissions/ospar_dissolved_oxygen_conf_2000_06/

Available at: https://odims.ospar.org/en/submissions/ospar_dissolved_oxygen_conf_2006_06/

Available at: https://odims.ospar.org/en/submissions/ospar_dissolved_oxygen_conf_2014_06/

Available at: https://odims.ospar.org/en/submissions/ospar_dissolved_oxygen_conf_2020_06/

Figure S.17: Estimate of overall confidence for Dissolved Oxygen for all assessment periods of COMP1 (1990-2000), COMP2 (2001-2006), COMP3 (2006-2014) and COMP4 (2015-2020). Assessment areas without data, where no DO assessment was possible, are indicated in grey

- These changes in assessment outcomes for dissolved oxygen are shown in terms of the number of assessment areas and amount of surface area identified as having moderate, poor or bad outcomes for each of the COMP periods (**Figure S.18**). The number of assessment areas identified as moderate, poor or bad increased between COMP1 (4 areas), COMP2 (5 areas), COMP3 (8 areas) and COMP4 (7 areas). The surface area covered has also increased, from COMP1 (16 657 km^2) and COMP2 (98 318km^2) to a maximum in COMP3 of 337 696 km^2, reducing to 110 261 km^2 in the current COMP4. The peak in COMP3 was influenced by the inclusion of the large Atlantic Seasonally Stratified area (5th percentile value = 5,79mg/L). However, confidence in the assessment for this area in COMP3 is low. Moreover, confidence in the dissolved oxygen assessments is low for the majority of the assessment areas, in all four COMP periods. This is particularly relevant for offshore areas with large data gaps and the plume areas with limited monitoring. Increased surveillance of these areas, coupled with the integration of modelling outcomes, will resolve these low-confidence issues for dissolved oxygen assessment.

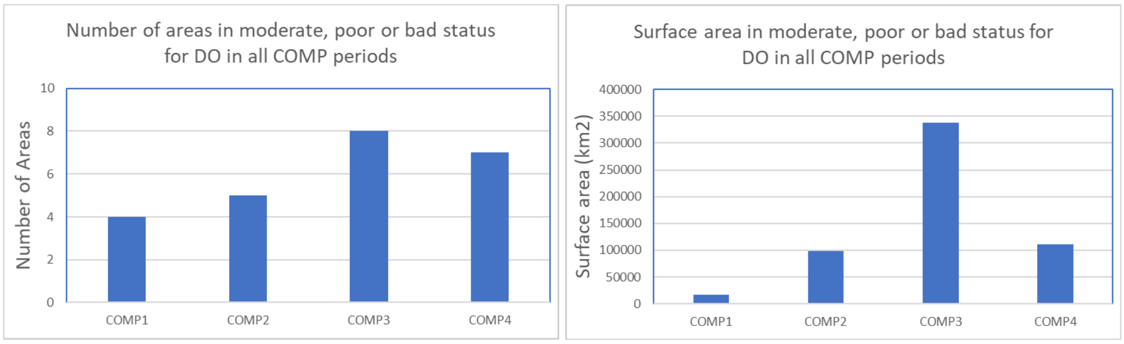


Figure S.18: Number and surface area of the assessment areas with Moderate, Poor or Bad status over the four COMP periods

- Across most of the assessment areas in the OSPAR COMP regions, there is no widespread oxygen deficiency. However, localised areas of oxygen deficiency are apparent, particularly in the eastern North Sea (shelf), Kattegat (coastal) and Gulf of Biscay (shelf). The Eastern North Sea, Kattegat Coastal and Kattegat Deep have long-term data available from 1990, demonstrating persistently low dissolved oxygen values. Although both Kattegat Coastal and Kattegat Deep show an increasing trend over the entire period from 1990 to 2020, positive development has been absent for the last decade, which corresponds with similar results for the other indicators. Concentrations in the Eastern North Sea show some improvement in recent years, but this is not significant and will require further observations to resolve the direction of trend. The persistent failures of the Eastern North Sea, alongside its increased susceptibility to dissolved oxygen sags, identify this as an area of concern.
- There are statistically significant trends of reducing oxygen concentration in five areas (Atlantic, Atlantic Seasonally Stratified, Meuse, Scheldt plume, Norwegian Trench) and of increasing oxygen concentration in one (Kattegat Coastal). Of these areas, it is only the Atlantic Seasonally Stratified area where the reduced solubility due to increased sea temperature is the dominant causative factor rather than eutrophication.

Additional eutrophication parameters in categories I and III

In some areas, additional parameters for total nutrients (total nitrogen and total phosphorus) and photic limit (Secchi depth) have been included to support assessment based on data availability and jointly agreed thresholds between the Contracting Parties sharing these areas. The assessment areas with additional parameters applied are mainly located in the eastern part of the North Sea, Kattegat and Skagerrak (**Figure S.19**), where some indicators still exceed the thresholds and thus point to potential eutrophication problems. Total nutrients are combined with dissolved inorganic nutrients (DIN and DIP) in the category I results for nitrogen and phosphorus, while Secchi depth is combined with oxygen in the category III results for indirect effects. The following figures show the areas where additional parameters have been included with the respective category results for causative factors/nutrient enrichment as well as direct and indirect effects, for the most recent assessment period of COMP4 from 2015 to2020 (**Figure S.20**).

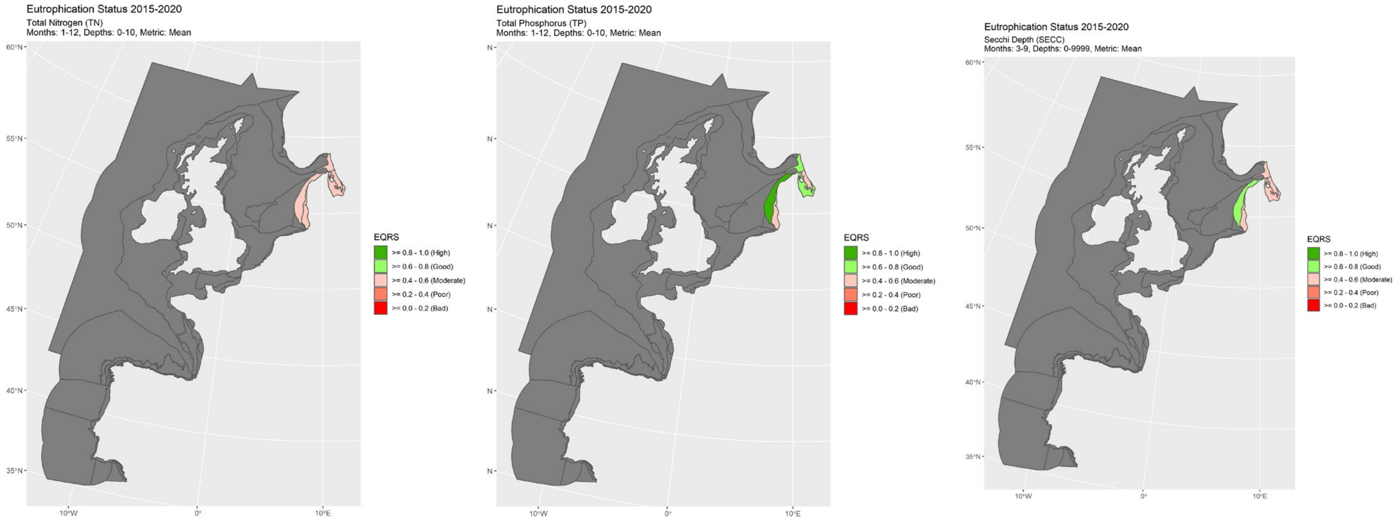
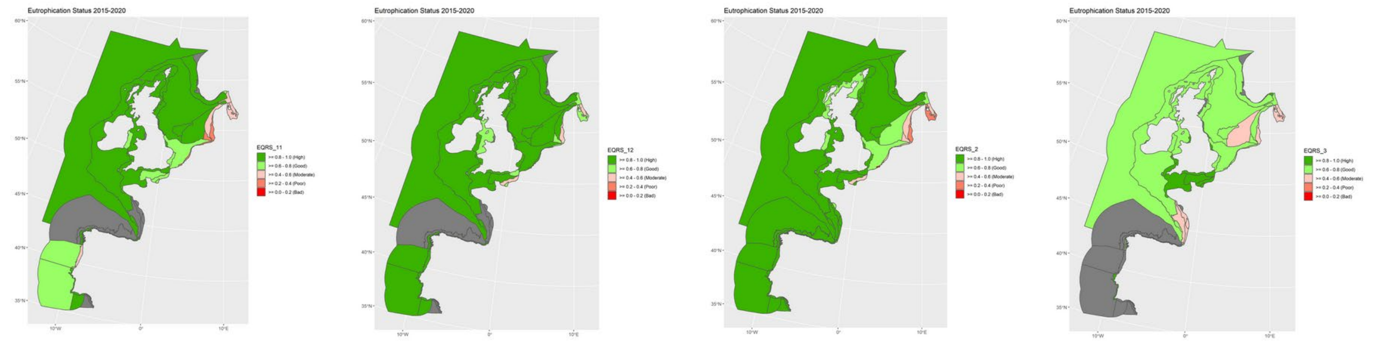


Figure S.19: Zoom to assessment results of additional parameters total nitrogen (TN), total phosphorus (TP) and photic limit (Secchi depth) for COMP4 (2015-2020)



Cat 1 Nitrogen (DIN, TN)

Cat 1 Phosphorus (DIP, TP)

Cat 2 Chlorophyll-a

Cat 3 Oxygen (Secchi)

Figure S.20: Assessment results per category for nutrient enrichment (separately for nitrogen and phosphorus), direct effects (chl-a) and indirect effects (oxygen, Secchi depth) in the COMP4 period 2015-2020 taking into account the additional assessment parameters

Relationships with pelagic habitats and food web assessments

The assessment areas developed for eutrophication and based on phytoplankton seasonal patterns and hydrological criteria have also been adopted for the assessments of pelagic habitat and food web indicators, thereby facilitating comparison between them. In addition to identifying areas where eutrophication is a problem, the information gathered also indicates spatial and temporal patterns for the primary producers (notably algae) that form an important basis of marine food webs.

In the Changes in Phytoplankton Biomass and Zooplankton Abundance (PH2) Indicator Assessment, chlorophyll-a is also used as a proxy for algal biomass, but the focus is on mean chlorophyll concentrations over the entire year and on change in the amplitude of monthly deviation from mean conditions in the 2015-2019 assessment period compared to previous years (1998-2014). Predominantly decreasing trends were observed in the Greater North Sea and the Celtic Seas (river plumes, coastal and shelf areas) and in the Bay of Biscay and Iberian Coast (coastal and oceanic areas), which generally does not reflect the findings in the eutrophication chlorophyll assessment, where most of assessment areas displayed no trend. This may be due to differences in the data sources and methods used to calculate the annual means for each assessment area, which should be further investigated. Surprisingly, mean chlorophyll concentrations based on satellite data gathered over the entire year are in many cases higher than those for the growing season. This indicates that the selected period for the growing season in the eutrophication assessment does not capture the highest chlorophyll concentrations in all cases, but that in a number of areas plankton blooms are missed in February and well into November.

Another important comparison is with the Pilot Assessment of Primary Productivity (FW2), which is strongly related to phytoplankton biomass and therefore chlorophyll-a. The data were retrieved from local in situ measurements and broad-scale satellite observation. This assessment concluded that over the long term (1997-2019) primary productivity was stable in Regions II, III and IV. Significant decreases occurred in the majority of the assessment areas, except for the Kattegat area, in 2015-2019, likely driven by de-eutrophication and climate change, which may disturb higher trophic levels. Since only long-term trend analyses were performed for the eutrophication indicator, chlorophyll-a comparison is not straightforward. Significant long-term decreases in chlorophyll-a concentrations were only observed in a limited number of coastal and shelf areas, mostly located in the eastern part of the North Sea, thereby only partly supporting the findings of the primary productivity assessment.

The Indicator Assessment on Changes in Phytoplankton and Zooplankton Communities (PH1/FW5) looked into changes in functional groups in the current assessment period (2015 and 2019) compared with previous years. Changes in the abundance of diatoms and/or dinoflagellates were estimated to be driven by changes in nutrients in several coastal waters in the eastern part of the North Sea, the Channel, around the United Kingdom and Ireland and also in the area named Atlantic Seasonally Stratified.

The Changes in Plankton Diversity (PH3) Indicator Assessment also compared the current assessment period against previous years, focusing on diversity indices for phytoplankton and zooplankton. Significant changes in phytoplankton diversity were observed in only a small number of areas in the Celtic Seas and the North Sea. Nutrients were considered drivers of change mainly in coastal areas around the United Kingdom and Ireland, including the Atlantic Seasonally Stratified area and along the Spanish and Portuguese coasts, and to a lesser extent in the eastern part of the North Sea.

It should be noted that further harmonisation of data sources and assessment methods between eutrophication and pelagic and food web assessments is expected to increase comparability. Moreover, further analyses of the relationships between these assessments will help improve understanding of how nutrient loads affect ecosystem functioning and at which nutrient concentrations the ecosystem can be considered healthy.

I – Impact (on ecosystem services)

Eutrophication impact on ecosystem services

Eutrophication has a substantial impact, limiting access to ecosystem services by acting as a pressure on biodiversity and the ecosystem. Even at a low level, increased nutrient loads and changing proportions of nutrients result in biomass and phytoplankton species shifts which affect higher species. Species shifts are frequently characterised by bloom events which have significant economic impacts, as they reduce the attractiveness and amenity value of coastal waters. Increased phytoplankton biomass reduces light penetration, which in turn causes habitat loss by limiting areas where seaweeds and seagrasses can grow. These habitats are important for maintaining nursery populations. Healthy seaweeds and seagrasses themselves perform important water quality regulation functions, sequestering nutrients and binding sediment. More serious eutrophication involves hypoxic events which harm many organisms but are particularly damaging to sessile benthic fauna, whose loss again affects the food web and biotic water quality regulation. Extreme hypoxia and anoxia lead to a loss of both biotic and abiotic water quality regulation, as previously sequestered nutrients are lost from sediment surfaces and bacterial denitrification processes change.

This application of the Common Procedure identifies eutrophication problems in river plumes and coastal waters. These waters are under the most pressure, but also have the highest value to society in terms of recreation, visual amenity and artistic uses. These are the shallower areas where seagrasses and seaweeds would be expected to maintain nursery populations and habitat structure. They are also the recipients of land-based pollution, and the restoration of biotic and abiotic water quality regulation will be essential if eutrophication is to be addressed.

Qualification of impacts on ecosystem services

On the basis of the Eutrophication thematic assessment and expert judgement on how this relates to the ecosystem services associated with pelagic and benthic habitats, an estimate of the magnitude and direction of state change impacts on the relevant ecosystem services was made.

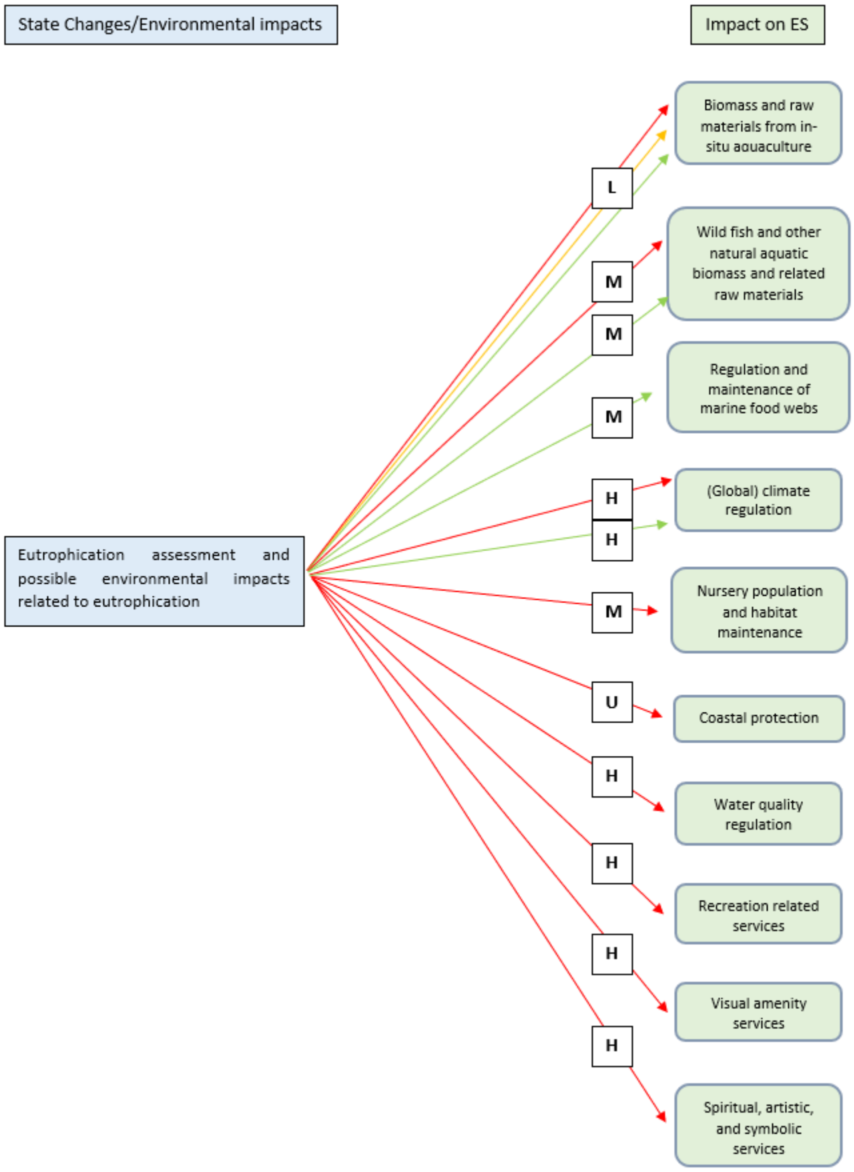


Figure I.1: Eutrophication assessment and possible impacts on ecosystem services related to eutrophication. H = high impact, M = medium impact, L = low impact, U = unknown impact. Arrow colours: green = positive, red = negative and yellow = neutral impact

Detailed rationale behind identified impacts on ecosystem services

Eutrophication is the result of excessive enrichment of water by nutrients. Eutrophication leads to increased growth of algae (phytoplankton) and plants, changes in the balance of organisms and degradation of water quality. The decomposition of algal and plant material by microbes promotes increased oxygen consumption in bottom waters, leading to hypoxia (a reduction of oxygen in the water) and subsequent deterioration of marine ecosystems and loss of biodiversity (EEA, 2015; Limburg *et al*., 2020; OSPAR, 2017k). Increasing levels of nutrients in the water, increased chlorophyll, reduced dissolved oxygen and increased occurrence of nuisance species associated with eutrophication lead to changes in the state of the environment through increased mortality, behavioural changes and health problems in marine organisms (e.g., suffocation due to lack of oxygen), reduced water quality, changes in the supply and quality of food for marine organisms, reduction in resources, and species shifts (OSPAR HASEC, 2021a). These environmental impacts are also associated with effects on benthos, increase in low-oxygen tolerant species, reduction in species diversity, changes in grazing capacity of species and changes in food web structure (OSPAR HASEC, 2021a). The environmental problems created by eutrophication are known to reduce the quality of ecosystem services (EEA, 2015).

Nuisance species can negatively impact those ecosystem services based on recreation and visual attraction and the associated psychological and mental well-being, through beach fouling and water- quality degradation. For example, increases in the local presence of microalgae and related chlorophyll concentrations reduce water transparency (O'Higgins and Gilbert, 2014). In the North Sea, eutrophication induces algal blooms along the coasts. Disruption to the plankton community is a phenomenon thought to be related to eutrophication affecting marine food webs and is known to have knock-on effects on aquatic biomass and consequently on fisheries. Foam deposits on beaches related to these bloom events also contribute to impacts on cultural ecosystem services associated with coastal environments (EEA, 2015). These events impact the provision of ecosystem services through loss of biodiversity, damage to the biomass produced in aquaculture settings (biomass and raw materials from in situ aquaculture), human harm (sea foam leading to the deaths of five surfers in 2020) and reduced attractiveness, thus affecting recreation and other cultural ecosystem services (EEA, 2015).

According to O'Higgins and Gilbert (2014), the main ecosystem services involved when considering eutrophication are the maintenance of balanced food webs (‘regulation and maintenance of marine food webs’), the service of habitat maintenance (nursery population and habitat maintenance), provision of aquatic biomass (wild fish and other natural aquatic biomass and related raw materials), climate regulation ((global) climate regulation), and services related to amenity and recreation values (visual amenity services and recreation-related services).

Algae, seagrasses and dissolved oxygen all play a role in habitat maintenance. In turn, the nursery population and habitat maintenance services represent an intermediate service which underpins several final ecosystem services including aquatic biomass production and recreation related services. In addition, chlorophyll concentrations, transparency and marine macroflora are correlated by feedback interactions. Chlorophyll concentration is a proxy for marine primary production. In turn, marine primary production plays an important role in ocean-atmosphere gas exchange processes, including carbon capture and oxygen production ((global) climate regulation). Regarding carbon storage and burial, the situation is mixed. While carbon burial increases as primary production increases, a reduction in carbon storage follows declines in ecosystem components such as seagrass beds and reefs that are often associated with advanced stages of eutrophication (Kermagoret *et al*., 2019; O'Higgins and Gilbert, 2014).

Furthermore, primary production is essential for the production and maintenance of the very biomass that supports marine food webs, and thus the ecosystem service here identified as ‘regulation and maintenance of marine food webs’ (O'Higgins and Gilbert, 2014). At more advanced stages of eutrophication, hypoxic conditions cause mass mortality of fish and invertebrates either directly, or indirectly through reduced prey abundance. This in turn results in a significant reduction in biomass supply (Crowe and Frid, 2015). The reduction of dissolved oxygen in bottom waters, while leading to a decline in the abundance of macrobenthic animals and an increase in the flow of energy through the microbial food web, leads to a reduction in the flow of energy through metazoan food webs that support mobile consumers belonging to higher trophic levels, a change that may reduce the ability to produce and supply biomass of interest to fisheries (Malone and Newton, 2020). In addition, changes in habitat conditions alter the composition of fish communities towards less valued species and cause the loss of nursery and feeding grounds for commercially important fish species (Crowe and Frid, 2015).

It should be mentioned that the water quality regulation service is also impacted following eutrophication. Some of the marine ecosystem components that contribute most to this service are the photosynthetic ones: phytoplankton, macrophytes, macroalgae and microphytobenthos. Of these, phytoplankton is the component that contributes most to primary productivity and hence nutrient uptake. However, in the presence of excess nutrients (eutrophication), this service can be compromised. Phytoplankton can grow in a detrimental way by impacting the surrounding marine environment, for example leading to hypoxia and/or anoxia in the benthic environment. As the presence of nutrients increases, the nutrient-limited phytoplankton grow exponentially. However, a threshold is reached where excessive increases in nutrient concentration begin to have a negative impact on the surrounding environment (Kermagoret *et al*., 2019). The service is considered to be negatively impacted when the negative effects of excessive nutrient input extend beyond the ability of ecological components (such as phytoplankton) to process them, and lead to other associated impacts (such as a decrease in dissolved oxygen) on other ecosystem components such as benthos (Culhane *et al*., 2020).

The study conducted by Kermagoret *et al*., (2019), in which impacts on bundles of ecosystem services along eutrophication gradients were observed, also showed that cultural ecosystem services are negatively affected, as events such as *Ulva sp* blooms affect recreational activities, spatial identity and emblematic biodiversity (thus also impacting the service here identified as spiritual, artistic, and symbolic services). Furthermore, it was observed how the degradation of marine ecosystem components such as seagrass beds and reefs can impact the provision of the ecosystem service of coastal protection (Kermagoret *et al*., 2019; Malone and Newton, 2020). Seagrass beds have the capacity to attenuate waves and slow currents, while reefs can dissipate a significant proportion of wave energy. Indeed, eutrophication is known to induce deterioration and gradual disappearance of elements such as seagrass beds and reefs (Kermagoret *et al*., 2019).

R – Response

The response to eutrophication

Starting as early as 1988, the OSPAR Contracting Parties agreed to reduce nutrient emissions to the Greater North Sea by 50%. Since then, several OSPAR Recommendations as well as other management actions have been taken to combat eutrophication. These include measures targeting diffuse run-off from land, atmospheric nitrogen emissions, wastewater, and other point sources.

These responses have led to significant improvements in nutrient loadings to the OSPAR Maritime Area since the start of monitoring in 1990. During the last decade, improvements have slowed down, however, and waterborne nutrient inputs to Region I (Arctic Waters), have shown a significant increase caused mainly by nutrient inputs from the growing marine aquaculture industry.

The commitment to further reduce nutrient inputs is reinforced in the new OSPAR Strategy for the Protection of the Marine Environment of the North-East Atlantic (NEAES) 2030. The Contracting Parties have committed to determining maximum nutrient inputs and agreeing nutrient reduction needs for each Contracting Party. Under the MSFD, Contracting Parties take measures directed towards atmospheric emissions and shipping, emissions from ports and harbours, aquaculture and habitat restoration. Within the EU, the Urban Wastewater Treatment Directive is under revision. So is the Gothenburg Protocol. These will make important contributions to combating eutrophication in the North-East Atlantic. However, despite the ongoing and future responses, there are still many activities that will continue to discharge anthropogenic nutrients into coastal and marine waters.

The automated COMPEAT tool was successfully applied for the first time and the methodology should be further developed towards COMP5. It is also important to improve understanding of the interactions between eutrophication and biodiversity and between eutrophication and climate change. An improved understanding is needed in order to permit the follow-up of implemented measures and to further understand the ecosystem's response to eutrophication pressures.

Measures implemented

The OSPAR Contracting Parties have made significant efforts in the past to reduce nutrient losses to the marine environment. Widespread eutrophication in the OSPAR Convention area and particularly the North Sea, led to the agreement of PARCOM Recommendation 88/2, wherein the Contracting Parties agreed to reduce nutrient emissions by 50% relative to 1985 values. PARCOM Recommendation 89/4 introduced a coordinated programme for the reduction of nutrients while PARCOM Recommendation 92/7 committed the Contracting Parties to better management of agricultural nutrient releases – both nitrogen and phosphorus - to both atmosphere (for ammonia) and water.

In addition to the OSPAR Recommendations, many OSPAR Contracting Parties that are EU Member States, and even some that are not, have adopted EU directives into national law. Although the EU and its predecessor, the European Community, introduced water quality directives in the 1970s, conditions continued to deteriorate throughout the 1980s. In 1991, the EC introduced Nitrates Directive 91/676/EEC to prevent water pollution from agriculture, which requires the definition of Nitrate Vulnerable Zones and the implementation of additional measures (restrictions) on agriculture in those regions. Many measures under the Nitrates Directive mirror those in PARCOM Recommendation 92/7. While measures required under the Nitrates Directive are binding and therefore not eligible for financial support, the EU's Common Agricultural Policy includes an increasing amount of support for agri-environmental measures beyond the minimum requirements laid down in the Nitrates Directive.

In addition to tackling diffuse nutrient losses from agriculture, the EU has addressed pollution from point sources through the Urban Wastewater Treatment Directive (91/271/EEC) and several generations of industrial directives such as the Integrated Pollution Prevention and Control Directive (2008/1/EC) and the subsequent Industrial Emissions Directive (2010/75/EU). The Urban Wastewater Treatment Directive improved water treatment standards in many OSPAR Member States while the Industrial Emissions Directive developed the concept of agreed Best Available Techniques and Best Environmental Practice to drive down emissions to both air and water, with standards described in a series of sector-specific reference documents. Connected to the Industrial Emissions Directive, the National Emissions Ceiling Directives (2001/81/EC and 2016/2284) set binding reduction targets for atmospheric emissions.

In 2000, the EU agreed the Water Framework Directive (2000/60/EC) (WFD). This requires harmonised methodologies for regional status assessments in fresh and coastal waters and the implementation of programmes of measures aimed at raising the quality of water bodies to 'Good Ecological Status' – similar, but not identical to non-problem eutrophication status – over a six-year management cycle. Through this directive, water management in the catchment was connected administratively to coastal water status. Like the Water Framework Directive, the Marine Strategy Framework Directive (2008/56/EC) uses a six-year management cycle, albeit with separate deliverables for status assessments, monitoring programmes and programmes of measures. The aim of the MSFD is to achieve Good Environmental Status, and it includes an explicit focus on eutrophication as one of the descriptors, while acknowledging that the WFD water bodies (coastal waters up to 1 nm from the baseline) are to be assessed according to WFD threshold values.

As awareness of marine and aquatic pollution has grown, so has knowledge of the impacts of atmospheric pollution. In 1979, thirty-two countries signed the UNECE Convention on Long-range Transboundary Air Pollution. The Convention was a response to acid rain on forests and lakes, among other pressures. In 1988, the Convention adopted the Sofia Protocol concerning emissions of Nitrogen Oxides, and in 1999 the Gothenburg Protocol was adopted to abate acidification, eutrophication and ground-level ozone. The Convention also agreed in 1984 to create a monitoring and modelling organisation, the EMEP, for the monitoring and evaluation of the long-range transmission of air pollutants in Europe. The emission reduction goals agreed and revised under the Gothenburg Protocol form the basis of the National Emissions Ceilings (NEC) Directive targets, and thus have legal force among EU Member States.

Effectiveness of measures

By 2005, six out of nine reporting Contracting Parties had met the 50% reduction target for phosphorus. Only Denmark had achieved the reduction target for nitrogen although several Contracting Parties came close. Rapid input reductions occurred, particularly with the introduction of secondary, and in some areas tertiary, wastewater treatment, which in most countries occurred at the end of the 1980s and the start of the 1990s. The effects of these nutrient reductions are visible in declining trends for nitrogen and phosphorus inputs in most OSPAR Regions and in improvements in eutrophication status. Inputs of nutrients to OSPAR Regions I – IV have decreased significantly since the start of monitoring in 1990. Nitrogen inputs have decreased by 1 350 kt since 1990, while phosphorus inputs have decreased by 70 kt (Common Indicator on Nutrient Inputs). Waterborne nutrient inputs to Region I (Arctic Waters), however, have shown a significant increase, which is mainly caused by nutrient inputs from the growing marine aquaculture industry. Since the last QSR, significant but smaller annual decreases in nutrient loads of approximately 28 kt for nitrogen and 1,6 kt for phosphorus have continued in OSPAR Regions I-V as a whole (Common Indicator on Nutrient Inputs). For nitrogen, these reductions are due to reductions in atmospheric deposition, since no statistically significant trend has been observed in waterborne inputs during the last decade. Since the first application of the Common Procedure (1990–2001), the extent of the OSPAR Maritime Area classified as either a problem or a potential problem area has decreased steadily to 38 764 km^2 (≈1,5% of the assessed area) in COMP4.

Reporting on PARCOM Recommendation 88/2 was suspended in 2006 in expectation of better, ecosystem-based nutrient reduction targets. While, therefore, no reporting on nutrient sources currently takes place in OSPAR, examples from selected catchments (INPUT report) continue to demonstrate that agriculture is the main source of nutrient inputs, with sewage treatment plants, stormwater overflows, scattered dwellings, aquaculture and shipping constituting other important sources.

Ongoing and future actions

The commitment to further reduce nutrient inputs is reinforced in the new OSPAR strategy. More specifically, the Contracting Parties have committed to “determine the maximum inputs of nutrients for relevant assessment areas which prevent deterioration and enable the achievement of non-problem area status throughout the North-East Atlantic” by 2022 (objective S1.O2) and to “identify and quantify relevant sources, including transboundary transport, and agree nutrient reduction needs for each Contracting Party to stay at or below the maximum input levels” by 2023 (S1.O3). Fulfilling these objectives of the OSPAR NEAES will pave the way for scientifically founded, ecosystem-based nutrient reduction targets in OSPAR and possibly a revision of PARCOM Recommendation 88/2 to include regular reporting on sources and pathways.

Actions on land in the catchments are the principal tool to tackle eutrophication in coastal and marine waters. Most Contracting Parties take action under the Water Framework Directive or equivalent national legislation. In addition, the Nitrates Directive, the Waste Framework Directive, the Urban Wastewater Treatment Directive, the Industrial Emissions Directive or the National Emission Ceiling Directive have been identified as appropriate for defining measures associated with land-based sources of nutrient pollution. Despite the long history of the Urban Wastewater Treatment Directive, Contracting Parties have identified a need for intensified work, both in terms of higher levels of treatment where possible, but also in managing stormwater flows and reducing losses from the sewage pipe network. Within the EU, the Urban Wastewater Treatment Directive is under revision. The revised directive may address the concerns identified by Contracting Parties. Otherwise, joint action through OSPAR could be appropriate.

The Nitrates Directive is also long-established and builds on the work of PARCOM Recommendation 89/4. The measures under this directive aim, for example, to better manage fertilizers and prevent emissions. Landscape restoration and nature recovery on land are also used as a tool to improve freshwater quality and reduce coastal eutrophication.

Under the MSFD, Contracting Parties take measures to address atmospheric and shipping emissions, emissions from ports and harbours, aquaculture, habitat restoration and what may be described as ‘knowledge’, including target setting and monitoring. Proposed actions connected to atmospheric emissions involve implementing and strengthening the Gothenburg Protocol under the UNECE CLRTAP. Some Contracting Parties have identified the need to reduce NOx discharges from shipping. Joint OSPAR work to reduce scrubber discharges is ongoing. Spain and Germany identify issues relating to the management of ports and harbours. Germany proposes the development of Best Available Techniques for bulk fertilizer handling, which has been identified as a potential pathway for large quantities of nutrients entering the Baltic Sea. Given the larger amounts of fertilizer handled by ports in OSPAR Contracting Parties, this could be a significant source. In addition to this source, Spain has identified a general need to better manage stormwater, sewage and greywater discharges in ports. Some Contracting Parties also recognise aquaculture as a source of nutrient inputs and are committing to setting conditions for sustainable mariculture, promotion of no-net-input and extractive aquaculture. The restoration of seagrass meadows, lagoons and estuaries is also foreseen to mitigate eutrophication effects.

About 35 - 40% of nitrogen input stems from atmospheric deposition (2015 - 2019) (Input thematic assessment). Atmospheric nitrogen emissions are addressed by UNECE CLRTAP and the EU NEC Directive, both aiming at limiting a number of air pollutants, among them nitrogen oxide (NOx) and ammonia (NH3), by setting emission reduction targets to be achieved in 2020 and 2030, respectively. Therefore, full implementation of the Gothenburg Protocol and the EU NEC Directive (2016/2284/EU) will make an important contribution to combating eutrophication in the North-East Atlantic. A prognosis by EMEP conducted in 2017 on the reduction of atmospheric nitrogen deposition achievable by implementing the Gothenburg Protocol until 2020 and the EU NEC Directive until 2030 indicated that an overall reduction of approximately 30% of the nitrogen deposition of 2005 was possible for OSPAR Region II (EMEP 2017). The prognosticated reduction in deposition for oxidised nitrogen was larger than for reduced nitrogen, reflecting the higher reduction commitments for the respective emissions. Recent EMEP modelling data has shown that the reduced emissions of nitrogen to air have led to a reduction of almost 600 kt in annual atmospheric nitrogen deposition to Regions I – IV, with the greatest reductions in the Arctic and Greater North Sea (OSPAR

Common Indicator on Nutrient Inputs). This reduction constitutes 86% of the overall reduction achieved for total nitrogen inputs, highlighting the substantial contribution made by clean air policies to reducing eutrophication effects in coastal and marine waters. The Gothenburg Protocol reduction commitments consider, inter alia, human health aspects and the susceptibility of terrestrial and freshwater ecosystems, but not yet marine eutrophication. The Protocol is currently undergoing a review process with the aim of agreeing new emission reduction targets up to 2030. OSPAR has committed to cooperate with the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) to promote consideration of marine pollution and eutrophication when setting emission targets. A prerequisite to achieving this is the setting of nutrient reduction needs in OSPAR. As soon as such targets are agreed in OSPAR, as foreseen in the NEAES, they can be considered in future revisions of the Gothenburg Protocol.

The Contracting Parties have committed under the NEAES to “ensure that sufficient measures are taken to achieve the necessary input reductions to prevent coastal and offshore eutrophication in the North-East Atlantic, working where appropriate with national and international organisations and authorities concerned” by 2028 (S1.O4). This commitment necessitates establishing an analysis of the sufficiency of measures, building on the portfolio of measures under MSFD and WFD. Based on this analysis, and building on the identified nutrient reduction needs, OSPAR could undertake to develop recommendations addressing nutrient inputs from selected sources of concern, such as aquaculture and agriculture. The newly established Intersessional Correspondence Group on Measures and Recommendations (ICG-MaRE) under HASEC will work on dedicated measures to further reduce nutrient inputs to the OSPAR Maritime Area so as to provide guidance over the next few years.

There are still many activities that will continue to discharge anthropogenic nutrients into coastal and marine waters. The marine aquaculture sector is projected to further expand, especially in Norway, where the FAO anticipates an increase of 20% between 2018 and 2030 (Aquaculture Feeder Report). The consequences of such an increase are evident from the well documented significant increases to nutrient inputs in Region I (Common indicator on nutrient inputs). There are growth strategies for the aquaculture sector in a number of other OSPAR Contracting Parties, highlighting the urgent need to work on guidelines for a sustainable aquaculture that minimises nutrient pollution. So far, OSPAR has taken few specific measures on aquaculture, but they include the guidelines on reporting nutrient discharges/losses from marine and freshwater aquaculture plants issued in 2004 and revised in 2018 (OSPAR, 2018). PARCOM Recommendation 94/6 covers the reduction of inputs from potentially toxic chemicals used in aquaculture. In 2006, OSPAR agreed that, for the time being, implementation reporting on PARCOM Recommendation 94/6 could cease. Since there are now significant developments in the aquaculture industry giving rise to concern about pollution, OSPAR decided in 2020 to initiate a new reporting round under Recommendation 94/6 and compile the results in 2022.

Concerning the agricultural sector, across the OSPAR Regions there was a decrease in the agricultural nitrogen balance between 2000 and 2015, indicating an improving trend (Feeder report on agriculture). However, the main decrease occurred between 2000 and 2010, with the trend remaining relatively constant or decreasing only marginally from 2010 (Eurostat, 2019). The phosphorus surplus in 2015 was less than half of its value in 2000 in most OSPAR countries (Eurostat 2019); however, phosphorus fertilizer use has also been increasing since 2010 (Feeder report on agriculture). Since 2010, ammonia emissions from OSPAR countries, stemming mainly from animal husbandry, have been rising again after a 20% decrease before 2010 (Feeder report on agriculture). Overall, these increasing trends point to the need for a common approach in OSPAR to curb nutrient inputs from agriculture. Under the EU Green Deal published in 2020, the European

Union committed itself to a series of agri-environmental goals, including reducing nutrient losses by 50% by 2030. To complement this commitment there is a growing interest in recycling nutrients from livestock manure and other organic sources. Furthermore, volatility in the natural gas market is encouraging the development of mineral fertilizer substitutes that use other sources of nitrogen, such as recycled manure products.

Lessons learned and future developments

The automated COMPEAT tool has been successfully applied for the first time and should be further developed for COMP5, adding additional properties and revising the status and confidence assessment methodology if needed. Currently, eutrophication effects are primarily diagnosed by means of elevated dissolved nutrient concentrations, elevated levels of chlorophyll-a and oxygen depletion, and to fully substantiate the evidence it is important to spatially widen the application of additional indicators such as total nutrient concentration and Secchi depth in COMP5.

Furthermore, it is important to improve understanding of how eutrophication affects biodiversity, in particular the quality of pelagic habitats and food webs. The linkage between the eutrophication assessment and the OSPAR pelagic indicators PH1 , PH2 and PH3 needs to be better understood and strengthened in order to allow for ecosystem-based management. Confidence in the eutrophication assessment could be further strengthened by improving monitoring, particularly in those areas where the temporal and/or spatial coverage is currently inadequate. The application of satellite data for eutrophication assessment should be further developed. Future assessments could be conducted based on a gridded approach, in order to obtain better spatially resolved information on eutrophication problems that could guide management decisions. Concerning oxygen concentrations near the seafloor, in situ data alone will not adequately capture the high spatial and temporal variability of depletion events. The use of automated monitoring devices and modelling of the spatial extent of depletion events should be developed for application in COMP5.

Lastly, climate change is leading to more frequent and intense floods and droughts which result in stronger variations in nutrient inputs. Understanding the ecological effects of this larger variability and how to adequately monitor and assess such extreme events for future eutrophication assessments needs to be solved in order to permit the follow-up of implemented measures and to further understand the response of the ecosystem to eutrophication pressures.

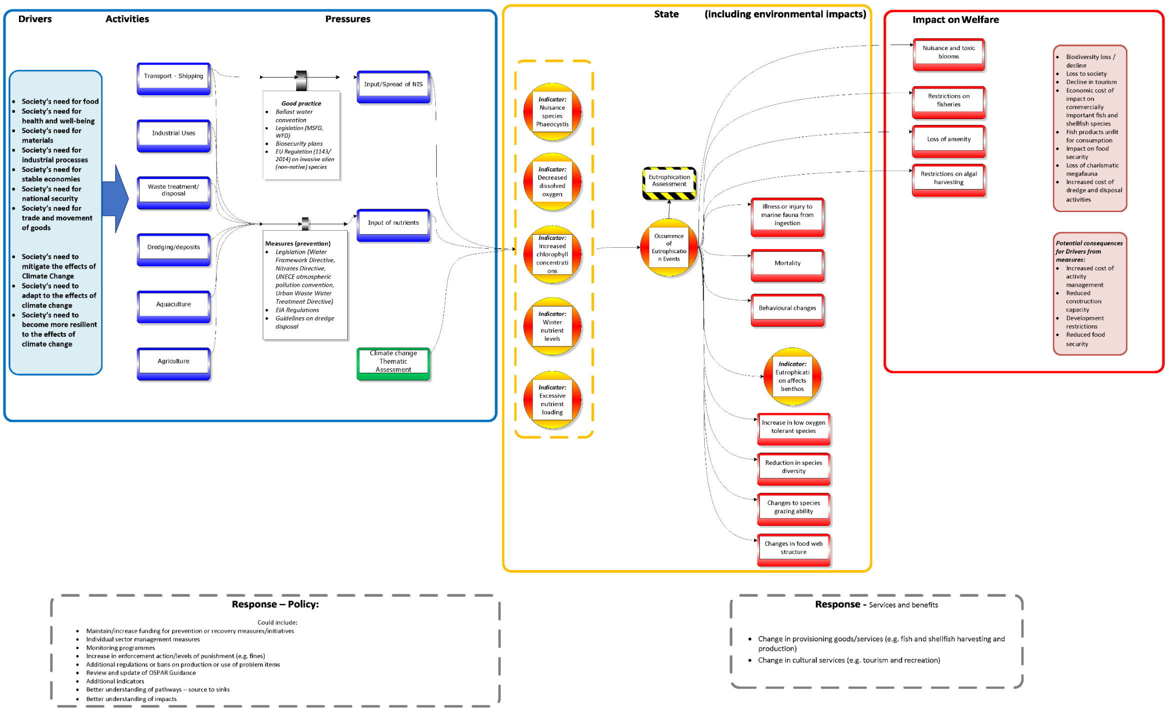
Cumulative Effects

Bow-tie analysis

The bow-tie analysis for eutrophication shows the relationships between the DAPSIR components which need to be considered in a cumulative effects assessment. Human activities have been identified which contribute to eutrophication pressures and have the potential to both individually and cumulatively contribute to biodiversity state changes: transport – shipping; industrial uses; wastewater treatment and disposal; aquaculture and agriculture. The main pressure associated with eutrophication is the input of nutrients from these human activities and climate change. These can lead to eutrophication changes in state through effects that increase biomass (algal blooms) and increase turbidity and anoxia, leading to decreases in species diversity and trophic cascade in food webs.

The State section describes the potential ecological impacts associated with eutrophication in the marine environment. The input levels, frequency of occurrence, spatial extent and exposure to different human activities all collectively contribute to the extent to which eutrophication pressures are exerted on pelagic habitats, fish, benthic habitats and food webs. To undertake a full quantitative analysis of cumulative effects requires consideration of the exposure pathways and ecological impacts. Further analyses and evidence of ecological impacts are required in order to progress the assessment of cumulative effects.

Eutrophication can also combine with other pressures to collectively affect marine species and habitats. The assessment of cumulative effects is considered within the biodiversity thematic assessments on Pelagic Habitats, Fish, Benthic Habitats and Food Webs .



Climate Change

Climate change can have an effect on many physical processes that influence physics, biogeochemistry and the lower food web, resulting in changes that are not straightforward to predict (Holt *et al.*, 2016).

Climate change may also have an impact on the level of nutrient enrichment itself. Climate change could lead to changes in circulation patterns and occurrence and in duration of stratification, which could impact nutrient levels and primary production. Expectations about the direction of the effects are uncertain, however (Holt *et al.*, 2016, Schrum *et al.*, 2016).

In general, a freshening of the Greater North Sea is expected owing to increased river discharges, changes in ocean- shelf exchange and increased outflow from the Baltic Sea, but again the uncertainty is large (Schrum *et al*., 2016; Holt *et al*., 2016). Conversely, increases in drought conditions are also expected. A short drought in the Kattegat catchment in summer 2018 resulted in reduced crop yield. This left a nutrient excess in farmland that in turn resulted in a higher winter nutrient load. Changes in seasonal rainfall patterns in either direction can change both the intensity and frequency of nutrient inputs where sudden, large events can cause excessive flooding and increased inputs into the marine environment. It is expected that climate change will result in more hydrological extremes and higher river discharges, particularly in the northern parts of the North Sea (Willems and Lloyd-Hughes, 2016). Under future climate change scenarios, generally lower annual mean river flow in Region IV and higher annual mean river flow in Regions I, II and III is expected (see Climate Change Thematic Assessment). Increased nutrient loading could be expected if river discharges increase, but this also depends to a large extent on future land use and socio-economic developments (Arheimer *et al.,* 2012; Bartosova *et al*., 2019).

Climate change may also have an impact on the direct and indirect effects of nutrient enrichment. Increased water temperatures have been shown to lead to phenological shifts, biogeographical changes and changes in abundance of plankton (see Brander *et al.*, 2016 for an overview). With changes in phytoplankton composition, changes in chlorophyll concentrations and primary production can be expected.

The indirect effects of eutrophication on oxygen concentrations in the near-bottom layer now show only localised but persistent areas of oxygen deficiency in OSPAR Regions II and IV. Climate change can impact upon dissolved oxygen concentration in many ways, most evidently via the direct effect on solubility, but it can also increase metabolic rates and oxygen demand and increase stratification, which inhibits the supply of oxygenated waters to lower levels. The duration of stratification is expected to increase and regions that show oxygen depletion are expected to become larger (Wakelin *et al.,* 2020).

It is also important to consider Ocean Acidification and its interaction with eutrophication effects. There are likely to be changes in our activities to reduce GHG emissions which could affect the scale of the eutrophication impacts. There is also the need to consider the role of eutrophication in oxygen sags and how we will separate out this response from climate change impacts. Ultimately, managing non-climate-related pressures through programmes of measures to reduce eutrophication will result in a more resilient ecosystem, benefiting both humans and the environment they depend on.

Annex

To be included in, or associated with the thematic assessment:

- Table showing all detailed results, so all assessment areas and the average concentrations of nutrients, chlorophyll and oxygen for COMP 4 period in support of MSFD reporting.

References

Arheimer, B., J. Dahné and C. Donnelly (2012). Climate Change Impact on Riverine Nutrient Load and Land-Based Remedial Measures of the Baltic Sea Action Plan. AMBIO 41: pp. 600-612.

Bartosova, A., R. Capell, J.E. Olesen, M. Jabloun, J.C. Refsgaard, C. Donnelly, K. Hyytiäinen, S. Pihlainen, M. Zandersen & B. Arheimer (2019). Future socioeconomic conditions may have a larger impact than climate change on nutrient loads to the Baltic Sea. AMBIO 48: pp. 1325-1336.

Brander, K.M., G. Ottersen, J.P. Bakker, G. Beaugrand, H. Herr, S. Garthe, A. Gilles, A. Kenny, U. Siebert, H.R. Skjoldal & I. Tulp (2016). Environmental Impacts—Marine Ecosystems.In: North Sea Region Climate Change Assessment; Quante, M. en Colijn, F. (eds.). Springer International Publishing, Cham. pp. 241-274. 10.1007/978-3-319-39745-0_8

Copernicus (2018) https://land.copernicus.eu/pan-european/corine-land-cover/clc2018

Crowe, T.P., Frid, & C. L. J. (Eds.) (2015), Marine Ecosystems: Human Impacts on Biodiversity, Functioning and Services *Cambridge University Press*

Culhane, F. E., Frida, C. L. J., Gelabert, E. R., Piet, G., White, L., and Robinson, L. A. (2020). Assessing the capacity of European regional seas to supply ecosystem services using marine status assessments. *Ocean Coast. Manag.* 190:105154.

EC, 2018, CAP Specific objectives… explained – Ensuring viable farm income, Brief No 1, (https://agriculture.ec.europa.eu/system/files/2021-01/cap_specific_objectives_-_brief_1_-_ensuring_viable_farm_income_0.pdf accessed 10 November 2022.

EU Nitrogen Expert Panel (2015) Nitrogen Use Efficiency (NUE) - an indicator for the utilization of nitrogen in agriculture and food systems. Wageningen University, Alterra, PO Box 47, NL-6700 Wageningen, Netherlands.

EEA (2015) The European environment — state and outlook 2015: synthesis report, European Environment Agency, Copenhagen

EEA (2017) Landscapes in transition. EEA Report EEA Report No 10/2017, European Environment Agency (Landscapes in transition — An account of 25 years of land cover change in Europe — European Environment Agency (europa.eu)) accessed 10 November 2022.

EEA (2018) The circular economy and the bioeconomy — partners in sustainability, EEA Report No 8/2018, European Environment Agency (https://www.eea.europa.eu/publications/circular-economy-and-bioeconomy) accessed 10 November 2022.

EEA (2022) Rethinking agriculture, EEA briefing, European Environment Agency (Rethinking agriculture — European Environment Agency (europa.eu)) accessed 10 November 2022.

EFMA, 2009, Forecast of food, farming and fertilizer use in the European Union 2009 – 2019, available online at https://issuu.com/efma2/docs/lo-res-final-forecast2009 accessed 20220916

European Union (2008) The EU Nitrates Directive. EUR-Lex - 01991L0676-20081211 - EN - EUR-Lex (europa.eu) accessed 11 November 2022,

Eurostat (2019) Gross nutrient balance on agricultural land by nutrient. Gross nutrient balance on agricultural land by nutrient - Products Datasets - Eurostat (europa.eu) accessed 10 November 2022.

Fertilizers Europe, 2019, Forecast of food, farming and fertilizer use in the European Union 2019 – 2029, available online at https://www.fertilizerseurope.com/wp-content/uploads/2019/12/Forecast-of-food-farming-and-fertilizer-use-in-the-European-Union.pdf, accessed 20220916

Klein, H., Gauss, M; Tsyro, S; Nyíri, A; Heinesen, D and Fagerli, H 2022, Transboundary air pollution by sulphur, nitrogen, ozone and particulate matter in 2020: The European Union, https://www.emep.int/publ/reports/2022/Country_Reports/report_EU.pdf

Gauss, M. and Klein H., 2022, Nitrogen depositions to the OSPAR Maritime Area in the period 1995 – 2019, EMEP MSC-W Report for OSPAR, 89 pp

Holt, J; Shrum, C; Cannaby, H; Daewel, U; Allen, I; Artioli, Y; Bopp, L; Butenschon, M; Fach, B.A; Harle, J; Pushpadas, D; Salihoglu, B and Wakelin, S. (2016) Potential impacts of climate change on the primary production of regional seas: A comparative analysis of five European seas, Progress in Oceanography, Volume 140, 2016, Pages 91-115, ISSN 0079-6611, https://doi.org/10.1016/j.pocean.2015.11.004.

Jalkanen, J-P., Grönholm, T., Hassellöv, I-M., 2022, Discharges from Exhaust Gas Cleaning Systems in the OSPAR Marine area, FMI & Chalmers University of Technology report to OSPAR EIHA, 57 pp

Kermagoret, C., Claudet, J., Derolez, V., Nugues, M., Ouisse, V., Quillien, N., Baulaz, Y., Le Mao, P., Scemama, P., Vaschalde, D., Denis, B., and Mongruel, R. (2019). How does eutrophication impact bundles of ecosystem services in multiple coastal habitats using state-and-transition models. Ocean & Coastal Management. 174, pp. 144-153. 10.1016/j.ocecoaman.2019.03.028.

J. Bartnicki; J. Eiof Jonson; M. Gauss; A. Nyiri; H. Klein, 2017, Reduction of Atmospheric Nitrogen Deposition to OSPAR Convention Waters Achievable by Implementing Gothenburg Protocol/EU-NEC Directive. EMEP MSC-W Report for OSPAR; Meteorological Synthesizing Centre-West (MSC-W) of EMEP, Norwegian Meteorological Institute

M. Gauss, Nyiri A, and Klein H., 2020, Atmospheric Deposition of Nitrogen to the OSPAR Maritime Area in the period 1995-2018. EMEP MSC-W Report for OSPAR; Meteorological Synthesizing Centre-West (MSC-W) of EMEP, Norwegian Meteorological Institute

H. Fagerli, A. Benedictow, B. Rolstad Denby, M. Gauss, D. Heinesen, J-E Jonson, K. S. Karlsen, H. Klein, A. Mortier, Á. Nyíri, A. Segers, D. Simpson, S Tsyro, Á. Valdebenito, P. Wind, W Aas, A., Hjellbrekke, S. Solberg, S Platt, K. Tørseth, K. Espen Yttri, B. Matthews, S. Schindlbacher, B. Ullrich, R. Wankmüller,: Z. Klimont,T. Scheuschner, I.A. Gonzalez Fernandez, J..J.P. Kuenen, 2022, Transboundary particulate matter, photo-oxidants, acidifying and eutrophying components, EMEP Status Report 2022; August 25, 2022, ISSN 1504-6192, https://emep.int/publ/reports/2022/EMEP_Status_Report_1_2022.pdf

Holt, J., C. Schrum, H. Cannaby, U. Daewel, I. Allen, Y. Artioli, L. Bopp, M. Butenschon, B.A. Fach, J. Harle, D. Pushpadas, B. Salihoglu and S. Wakelin (2016). Potential impacts of climate change on the primary production of regional seas: A comparative analysis of five European seas. Progress in Oceanography 140, pp. 91-115.

Jickells, T. D., and K. Weston (2011), 5.08—Nitrogen cycle—External cycling: Losses and gains, in Treatise on Estuarine and Coastal Science, edited, pp. 261– 278, Academic Press, Waltham.

Limburg, K., Breitburg, D., Swaney, D., and Jacinto, G. (2020). Ocean Deoxygenation: A Primer. One Earth. 2. 24-29. 10.1016/j.oneear.2020.01.001.

Lu, Chaoqun and Tian, Hanqin. (2017). Global nitrogen and phosphorus fertilizer use for agriculture production in the past half century: Shifted hot spots and nutrient imbalance. Earth System Science Data. 9. pp. 181-192. 10.5194/essd-9-181-2017.

Malone, T., and Newton, A. (2020). The Globalization of Coastal Eutrophication: Causes and Consequences. Frontiers in Marine Science, 7, 670, https://doi.org/10.3389/fmars.2020.00670

O'Higgins T.G., Gilbert A.J. (2014) Embedding ecosystem services into the Marine Strategy Framework Directive: Illustrated by eutrophication in the North Sea, Estuarine, Coastal and Shelf Science, Vol. 140,2014, pp. 146-152,ISSN 0272-7714,https://doi.org/10.1016/j.ecss.2013.10.005

OSPAR (2021). CEMP guidelines for coordinated monitoring for eutrophication, CAMP and RID Agreement 2016-05, revised 2021: https://www.ospar.org/documents?v=35414. Accessed 23 December 2022.

Schrum, C., J. Lowe, H.E.M. Meier, I. Grabemann, J. Holt, M. Mathis, T. Pohlmann, M.D. Skogen, A. Sterl and S. Wakelin (2016). Projected Change—North Sea. In: North Sea Region Climate Change Assessment; Quante, M. en Colijn, F. (eds.). Springer International Publishing, Cham. pp 175-217. 10.1007/978-3-319-39745-0_6

Wakelin, S.L., Y. Artioli, J.T. Holt, M. Butenschön and J. Blackford (2020). Controls on near-bed oxygen concentration on the Northwest European Continental Shelf under a potential future climate scenario. Progress in Oceanography 187: 102400.

Willems, P., and B. Lloyd-Hughes (2016). Projected Change—River Flow and Urban Drainage.In: North Sea Region Climate Change Assessment; Quante, M. en Colijn, F. (eds.). Springer International Publishing, Cham. pp 219-237. 10.1007/978-3-319-39745-0_7

Thematic Metadata

Field	Data Type	Explanation
Relevant OSPAR documentation	Text	OSPAR Agreement 2016-05 CEMP guidelines for coordinated monitoring for eutrophication, CAMP and RID OSPAR Agreement 2022-07 on The Common Procedure for the Identification of the Eutrophication Status of the OSPAR Maritime Area PARCOM Recommendation 88/2 of 17 on the reduction in inputs of nutrients to the paris convention area PARCOM Recommendation 89/4 on a coordinated programme for the reduction of nutrients PARCOM Recommendation 92/7 on the reduction of nutrient inputs from agriculture into areas where these inputs are likely, directly or indirectly, to cause pollution. PARCOM Recommendation 94/6 on Best Environmental Practice (BEP) for the Reduction of Inputs of Potentially Toxic Chemicals from Aquaculture Use

OSPAR Secretariat
The Aspect
12 Finsbury Square
London
EC2A 1AS
United Kingdom

t: +44 (0)20 7430 5200
f: +44 (0)20 7242 3737
e: secretariat@ospar.org
www.ospar.org

Our vision is a clean, healthy and biologically diverse North-East Atlantic Ocean, which is productive, used sustainably and resilient to climate change and ocean acidification.

Publication Number: 843/2022