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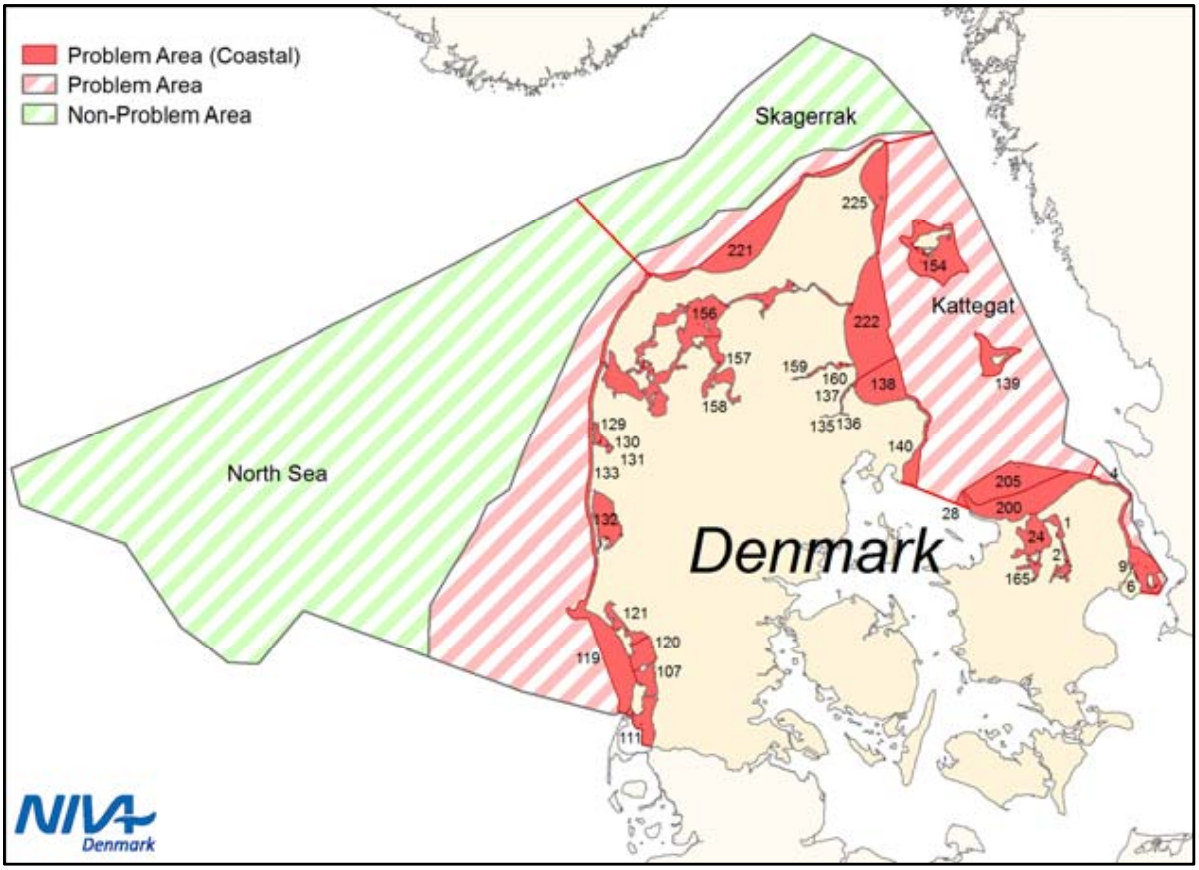
# Eutrophication in the Danish parts of the North Sea, Skagerrak and Kattegat 2006-2014. A literature-based status assessment



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# REPORT

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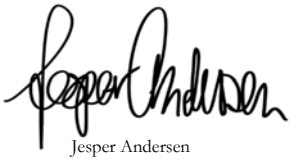
Abstract

We report eutrophication status 2006-2014 of the Danish parts of the North Sea, Skagerrak, Kattegat and northern and central parts of the Sound and have accordingly identified Eutrophication Problem Areas (EPAs) and Eutrophication Non-Problem areas (NPAs). All coastal waters, where the classification is based on the 2014 Danish Initial Assessment pursuant to the WFD, are classified as EPAs. For the open parts of the North Sea and Skagerrak, we have identified these as NPAs, which is in accordance with earlier indicator-based assessment of the eutrophication status. For the open part of the Kattegat and the Sound, the classifications are also in accordance with long-term monitoring and assessment of the eutrophication status, i.e. EPAs. Further, using long-term satellite-based monitoring of surface waters, we have focused on the separation of EPAs and NPAs in the North Sea and Skagerrak and have provided a more accurate delineation compared to previous Danish assessment of the eutrophication status in the areas.

| 4 keywords, Danish | 4 keywords, English |
|---|---|
| 1. Eutrofiering | 1. Eutrophication |
| 2. Næringsstoffer | 2. Nutrients |
| 3. OSPAR COMP3 | 3. OSPAR COMP3 |
| 4. Integreret tilstandsvurdering | 4. Integrated assessment |



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# Eutrophication in the Danish parts of the North Sea, Skagerrak and Kattegat 2006-2014

A literature-based status assessment

# Preface

This report, which is funded by the Danish Agency for Water and Nature Management (SVANA), follows up two previous national assessments of nutrient enrichment and 'eutrophication status' in the Danish parts of the North Sea, Skagerrak and Kattegat:

- Ærtebjerg, G., J.H. Andersen & O.S. Hansen (2003): Nutrients and Eutrophication in Danish Marine Waters. A Challenge to Science and Management. National Environmental Research Institute. 126 pp.
- Andersen, J.H. & H. Kaas (2008): Danish assessment of eutrophication status in the North Sea, Skagerrak and Kattegat: OSPAR Common Procedure 2001-2005. DHI Technical Report to the Danish Spatial and Environmental Planning Agency. 86 pp.

These two reports and this present report are all Danish contributions to a long-term effort reporting assessment of and trends in 'eutrophication status' in the Danish parts of the North Sea, Skagerrak and Kattegat.

The reporting is done under the umbrella of the OSPAR Common Procedure (OSPAR COMP), which is the OSPAR Commissions commonly agreed and harmonized procedure for assessment of 'eutrophication status', and is fully coordinated with Danish reporting of 'ecological status' in coastal waters under the EU Water Framework Directive and 'environmental status' in the open waters under the EU Marine Strategy Framework Directive.

We would like to thank Christina F. Nielsen, Danish Agency for Water and Nature Management for helping with access to background information as well as to the Danish WFD classifications of 'ecological status' in coastal waters. We would also like to thank Kai Sørensen for assisting us in analysing the satellite-based observations. Finally, we would like to thank Brockman Consult in Germany for highly appreciated help and allowing L3 processing on the CoastColour Calvalus portal for the dataset with almost 10 years of data.

Copenhagen, 1 July 2016

*Jesper H. Andersen*

# Contents

# Summary

The study area consists of the Danish parts of the North Sea, Skagerrak, Kattegat as well as the northern and central part of the Sound. The study area and its physical characteristics, including the salinity gradient from the highly saline waters of the North Sea to brackish in the Kattegat are in general very well understood and documented. It is also well documented that the environmental status of the larger parts of the study area is impaired due to excessive loads of nutrients (causing eutrophication), inputs and deposition of hazardous substances, overfishing, and physical modification

This Danish OSPAR COMP assessment has been based on the WFD Initial Assessment of ecological status in coastal waters, the MSFD Initial Assessment and a comprehensive analysis of satellite-based observation of chlorophyll *a* in order to separate coastal Problem Areas from offshore Non-Problem Areas.

In the Danish WFD Initial Assessment from 2015, ecological status in coastal waters has been assessed using the following intercalibrated indicators: chlorophyll *a*, depth limit of Eelgrass (*Zostera marina*), and DKI (Dansk KvalitetsIndeks). A multi-metric indicator-based assessment tool has not been applied due to the limited number of both indicators and biological quality elements.

In the Danish MSFD Initial Assessment from 2012, eutrophication status was assessed using multiple indicators in combination with the HEAT 2.0 tool.

The average chlorophyll *a* concentration was calculated for nearly 10 years of MERIS (MEdium Resolution Imaging Spectrometer) observations. The MERIS chlorophyll *a* concentration was corrected by comparison with in-situ observations of chlorophyll *a*. The results were used to determine the extent of the Problem Area, defined as the area where the 10-year average chlorophyll *a* concentration exceeds 3.5 $\mu g\ l^{-1}$.

The overall conclusions with regard to COMP3 are the same as found in both COMP2 and COMP1. All coastal waters as well as the open parts of the Kattegat are classified as Problem Areas, while most of the open parts of the North Sea and Skagerrak are classified as Non-Problem Areas.

A marked improvement compared to COMP2 and COMP1 is shown in the open parts of the North Sea. The extent of the Problem Area has decreased due to two factors. There have been reduced nutrient inputs to the south-eastern North Sea, especially to the German Bight but improvement in assessment methodology, i.e. the use of satellite-based observations has allowed a more reliable delineation of the boundary between the coastal Problem Area along the west coast of the Jutland peninsula and the Non-Problem Area in the offshore parts of the North Sea and Skagerrak.

# Sammenfatning

Farvandsområderne behandlet i denne OSPAR COMP3-assessment består af de danske dele af Nordsøen, Skagerrak, Kattegat samt de nordlige og centrale dele af Øresund.

Det undersøgte områdes miljømæssige status og dets fysiske karakteristika, heriblandt salinitetsgradienter, fra saltholdige farvandsområder i Nordsøen til brakvandsområder i Kattegat, er overordnet set veldokumenterede. Miljøklassifikationen for store dele af området er lav pga. den store næringsstofbelastning (der resulterer i eutrofiering), tilførsel og aflejring af miljøfarlige stoffer, fiskeri og fysiske modifikationer.

Denne OSPAR COMP3 er baseret på WFDs basisanalyse af økologisk status i kystvandene, MSFDs basisanalyse og omfattende analyse af satellitbaserede observationer af klorofyl a-koncentrationer. Herved er kystnære eutrofierede områder og ikke-kystnære eutrofierede områder blevet adskilt.

I den danske WFD basisanalyse fra 2015 er økologisk status for de kystnære farvandsområder blevet vurderet på baggrund af følgende interkalibrerede indikatorer: Chl a, dybdegrænse for ålegræs (*Zostera marina*), og DKI (Dansk KvalitetsIndeks). Et multimetrisk indikatorbaseret vurderingsværktøj er ikke blevet anvendt, pga. et begrænset antal af såvel indikatorer som biologiske kvalitetselementer.

I den danske MSFD basisanalyse fra 2012, er eutrofieringsstatus blevet vurderet på baggrund af en række forskellige indikatoer: næringsstofkoncentration, chl a-koncentration, DKI, undervandsvegetation (hvis relevant), iltkoncentration, etc.) i kombination med HEAT 2.0-værktøjet.

Den gennemsnitlige chl a-koncentration er beregnet ud fra omtrent 10 års MERIS (Medium Resolution Imaging Spectophotometer)-observationer. MERIS klorofyl a-koncentrationer er korrigeret vha. sammenligning med in situ observationer. Resultaterne er brugt til at bestemme udstrækningen af eutrofierede områder - defineret som et område, hvor det 10-årige genemsnit for klorofyl a-koncentrationen overstiger 3.5 $\mu g\ l^{-1}$.

De overordnede konklusioner fra COMP3 er de samme som dem fundet i både COMP2 og COMP1. Alle kystnære farvandsområder samt de åbne dele af Kattegat er klassificeret som eutrofierede områder, mens størstedelen af de åbne dele af Nordsøen og Skagerrak er klassificeret som ikke-eutrofierede områder.

En væsentlig forbedring af eutrofieringstilstanden, sammenlignet med COMP2 og COMP1 er dokumenteret i de åbne dele af Nordsøen. Udstrækningen af de eutrofierede områder er reduceret som følge af to faktorer: For det første har der været en reduktion i tilførslerne af næringsstoffer til den sydøstlige Nordsø (særligt til Den Tyske Bugt) og for det andet gør vurderingsmetodikken (brug af satellitbaserede observationer) det muligt at lave en mere præcis adskillelse af de kystnære eutrofierede områder langs Den Jyske Vestkyst og de ikke-eutrofierede områder i de ikke-kystnære dele af Nordsøen og Skagerrak.

# 1. Introduction

Walking along the shore of the Danish coasts along the North Sea, Skagerrak and Kattegat or sailing these areas is often a pleasant thing to do. The seascapes are nice to watch with plenty of leisure or commercial activities to catch the eye.

Looking at the water might however show a quite different picture with waters now and then looking like green paint because of algae blooms, sometimes we find foam on the shores, in some areas there are heaps of drifting macro-algae, and at rare occasion's even dead fishes or dead benthic animals washed ashore. Below the surface, deterioration can sometimes be even more severe than those observed at the sea surface with dying plants, impoverished bottom fauna and oxygen depletion.

The currently impaired conditions, which are generic for all Danish coastal waters, can be attributed to several, mostly human-generated, causes, e.g. resource exploitation (e.g. fisheries), pollution (nutrients and hazardous substances), physical modification of habitats, introduction of non-native species, and climate changes.

## 1.1 What are we talking about?

Pollution from excessive nutrients (nutrient enrichment; mainly compounds of nitrogen and phosphorus) is a major concern. This type of pollution is termed 'eutrophication'. The word 'eutrophication' has its root in two Greek words: 'eu' which means 'well' and 'trope' which means 'nourishment'. The modern use of the word eutrophication is related to the inputs and effects of nutrients in aquatic systems.

Many initiatives have been launched and much work has been put into mitigation of eutrophication, especially in relation to the reduction of inputs of nutrients from point sources (e.g. towns and industries). Focusing on nutrients and the reduction of nutrient inputs is sensible because eutrophication is a process being fuelled by excessive nutrient releases from various human-related sources. This increased supply of nutrients into a marine ecosystem may increase the concentrations of nutrients which, taken together with the availability of light and certain minerals, may cause an increase in primary production, for example, by microscopic planktonic algae.

Nutrient enrichment by nitrogen, phosphorus, and sometimes organic matter can result in a series of undesirable effects. The major effects of eutrophication include changes in the structure and functioning of the entire marine ecosystem and a reduction in stability.

The first response to increased nutrient inputs is a corresponding increase in nutrient concentrations. (e.g. nitrogen or phosphorus)Another effect is a change in the ratio between dissolved nitrogen and phosphorus in the water.

Primary production is most often limited by the availability of light and nutrients. Nutrient enrichment will therefore cause an increased phytoplankton primary production. Thus, there will be an increase in phytoplankton biomass and a decrease in light penetration through the water column. Decreased light penetration is often measured as a decrease in Secchi depth and can ultimately reduce the colonisation depth of macroalgae and seagrasses. The general responses of pelagic ecosystems to nutrient enrichment can, in principle, be a gradual change towards: (1) increased planktonic primary production compared to benthic production, (2) a dominance of microbial food webs over linear planktonic food chains, (3) a dominance of non-siliceous phytoplankton species over diatom species, and (4) a dominance of gelatinous zooplankton (jellyfish) over crustacean zooplankton.

Eutrophication issues are often divided into three groups: (1) causative factors, (2) direct effects, and (3) indirect effects (see **Figure 1**). The causative factors deal with inputs, elevated nutrient concentrations, and changes in the Redfield ratio. Direct effects are related to the primary producers, namely: (1) phyto-

plankton and (2) submerged aquatic vegetation. Secondary effects are related to: (1) zooplankton, (2) fish, and (3) invertebrate benthic fauna, that is, animals living on the seafloor. Some of the best-known and most easily understood primary and secondary effects of eutrophication are explained and discussed on the following pages.

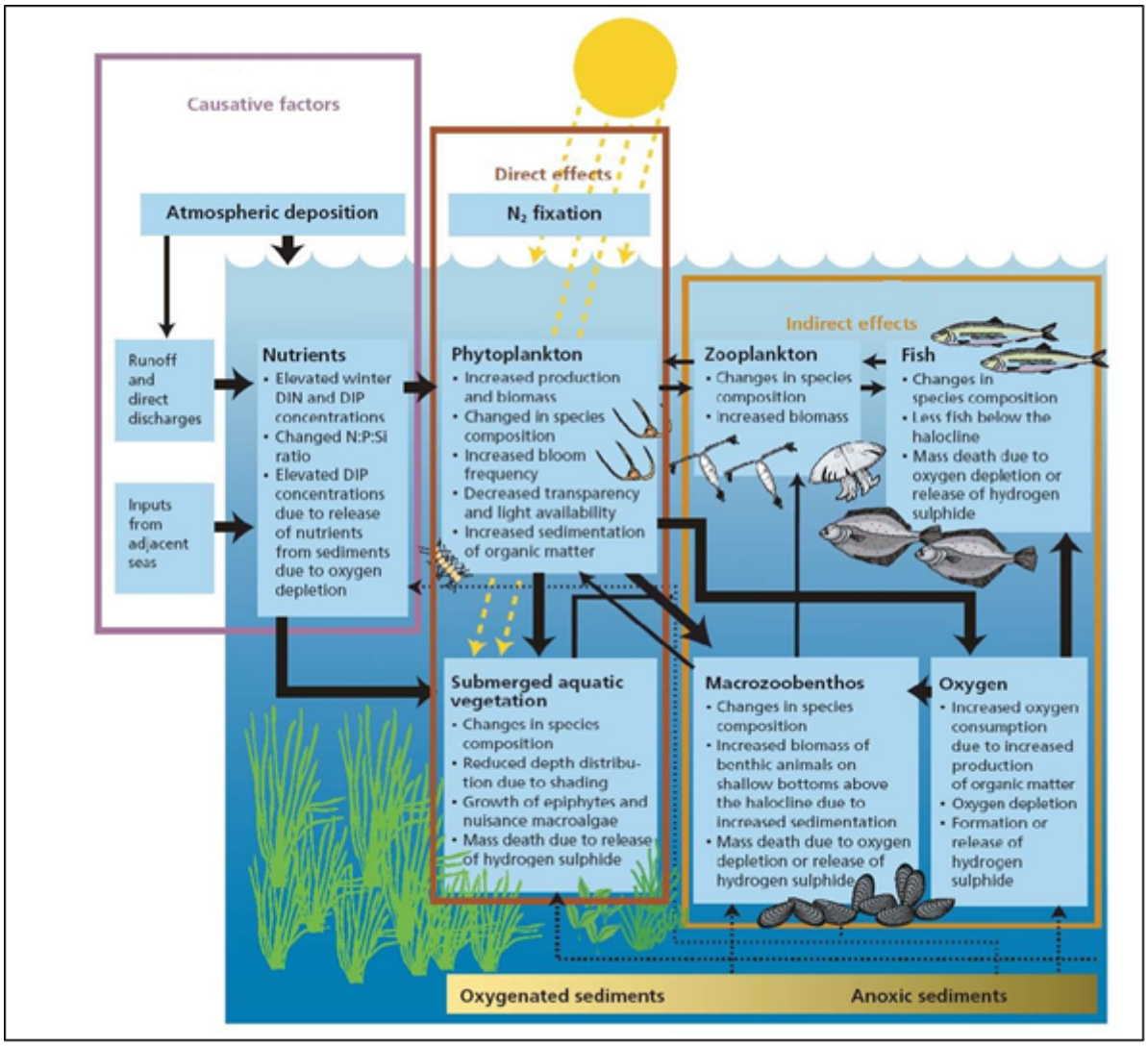


**Figure 1:** *Conceptual model of coastal eutrophication with compartments (1) causative factors, (2) direct effects and (3) indirect effect as well as connections within and between compartments. Based on the MSFD D5 Task Group Report (Ferriera et al. 2010).*

Nutrient enrichment does cf. **Figure 1** lead to a series of undesirable and very well documented eutrophication signals: Inputs of nutrients lead to increased nutrient concentrations (**Figure 2A**), which results in an augmented primary production (**Figure 2B**) and increased biomass of phytoplankton (measured as chlorophyll *a*, **Figure 2C**). This reduces water clarify and leads to a reduction in depth distribution of submerged aquatic vegetation (**Figure 2D**). These functional relations are generic and well documented for Danish marine waters as (e.g. Carstensen *et al.* 2006 and Riemann *et al.* 2016) well as for the Baltic Sea (HELCOM 2009, Andersen *et al.* 2015) and the North Sea (OSPAR 2009).

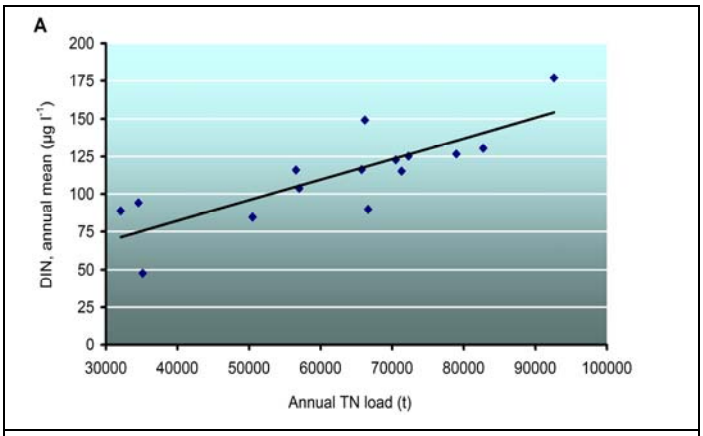


**Figure 2A:** *An example of the relationship between increased inputs (annual TN load in t) and nutrient concentrations (DIN, annual mean in µg l⁻¹). This example is from the Kattegat. From Andersen & Pawlak (2006).*

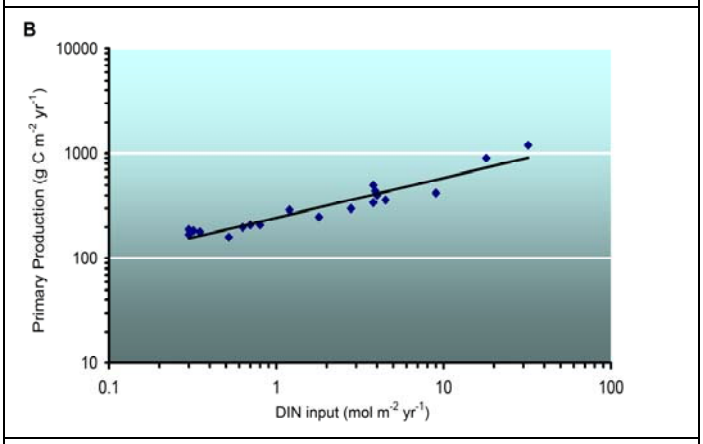


**Figure 2B:** *Relationship between nitrogen inputs (DIN in mol m⁻² yr⁻¹) and phytoplankton primary production (in g C m⁻² yr⁻¹). From Andersen & Pawlak (2006).*

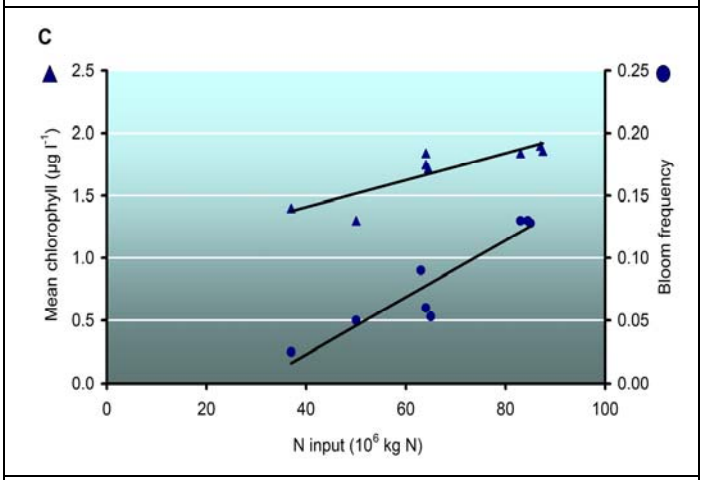


**Figure 2C:** *An example of relationships between nitrogen inputs (N in 10⁶ kg) and mean chlorophyll a concentrations (▲ in µg l⁻¹) and phytoplankton bloom frequency (●). From Andersen & Pawlak (2006).*

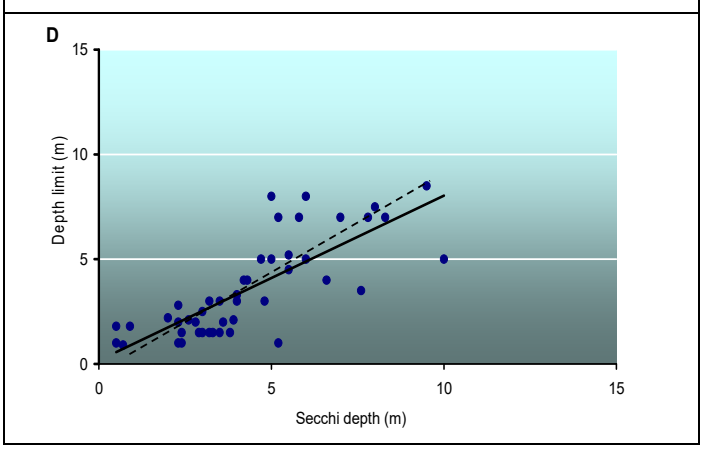


**Figure 2D:** *An example of a correlation between water clarity (here expressed as Secchi depth in m) and maximum depth limit of submerged aquatic vegetation (in m). From Andersen & Pawlak (2006).*

## 1.2 Where are we now?

The eutrophication problem in Danish waters is well-defined and well-understood and therefore monitored and assessed regularly.

This OSPAR COMP3 assessment follows up on two previous national assessments of nutrient enrichment and eutrophication status in the Danish parts of the North Sea, Skagerrak and Kattegat:

- Ærtebjerg, G., J.H. Andersen & O.S. Hansen (2003): Nutrients and Eutrophication in Danish Marine Waters. A Challenge to Science and Management. National Environmental Research Institute. 126 pp.
- Andersen, J.H. & H. Kaas (2008): Danish assessment of eutrophication status in the North Sea, Skagerrak and Kattegat: OSPAR Common Procedure 2001-2005. DHI Technical Report to the Danish Spatial and Environmental Planning Agency. 86 pp.

Both of these Danish eutrophication status assessments have reached the same conclusions: only offshore parts of the North Sea and Skagerrak have been classified as Eutrophication Non-Problem Areas. The offshore parts of the Kattegat and the northern and central Sound have been classified as Eutrophication Problem Areas. All Danish coastal waters have also been classified as Eutrophication Problem Areas.

## 1.3 Where are we going?

The Danish OSPAR COMP3 assessment of eutrophication status in the North Sea, Skagerrak, Kattegat as well as the northern and central parts of the Sound, i.e. the identification of Eutrophication Problem Areas and Non-Problem Areas, is partly literature based (see section 2.2).

Perhaps the most interesting question is not whether or not the offshore parts of the North Sea and Skagerrak can be classified as Non-Problem Areas or if the coastal waters can be classified as Eutrophication Problem Areas, but whether there might be changes in the extent of the areas. Hence, this question has been specifically addressed in this Danish OSPAR COMP3 assessment (see section 2.4).

# 2. Methods

## 2.1 Study area

The study area consists of the Danish parts of the North Sea, Skagerrak, Kattegat as well as the northern and central part of the Sound. The below description of the study area is based on Andersen & Kallenbach (2016).

The study area and its environmental status is in general very well understood and documented (see HELCOM 2010, OSPAR 2010 and Havsmiljöinstitutet 2014). The environmental status is impaired due to excessive loads of nutrients (causing eutrophication), inputs and deposition of hazardous substances, overfishing, and physical modification – see Ærtebjerg *et al.* (2003), HELCOM (2010), OSPAR (2010), Naturstyrelsen (2012), Andersen & Stock (2013) and Andersen *et al.* (2015) for details.

The North Sea is bounded by the Shetland Islands, Orkney Islands and east coast of Great Britain to the west and the northern and central European mainland to the east and south, including Norway, Denmark, Germany, the Netherlands, Belgium, and France. In the south-west, beyond the Straits of Dover, the North Sea becomes the English Channel connecting to the Atlantic Ocean. In the east, it connects to the Baltic Sea via the Skagerrak and Kattegat, narrow straits that separate Denmark from Norway and Sweden respectively. In the north it connects with the Norwegian Sea, which lies in the very north-eastern part of the Atlantic. Around the edges of the North Sea are sizeable islands and archipelagos, including Shetland, Orkney, and the Frisian Islands. The North Sea receives freshwater from a number of European continental watersheds, as well as the British Isles. A large part of the European drainage basin empties into the North Sea including water from the Baltic Sea. The largest and most important rivers flowing into the North Sea are the Elbe and the Rhine-Meuse watershed.

The Skagerrak is a strait between the south-east coast of Norway, the south-west coast of Sweden, and the Jutland peninsula of Denmark, connecting the North Sea and the Kattegat area, which leads to the Baltic Sea. The Skagerrak is 240 km (150 mi) long and between 80 and 140 km (50 and 87 mi) wide. It deepens toward the Norwegian coast, reaching over 700 m depth in the Norwegian Trench.

The Kattegat is a 30 000 km2 sea area bounded by the Jutlandic peninsula to the west, the Straits islands of Denmark to the south and the provinces of Bohuslän, Västergötland, Halland and Skåne (Scania) in Sweden to the east. The Baltic Sea drains into the Kattegat through the Danish Straits. The sea area is a continuation of the Skagerrak and may be seen as a bay of the North Sea, a bay of the Baltic Sea or - as in traditional Scandinavian usage - neither of these. Kattegat is a rather shallow sea and can be very difficult and dangerous to navigate, due to the many sandy and stone reefs and unpredictable, shifting currents. In modern times, artificial seabed canals have been dug, many reefs have been dredged, and a well-developed light signalling network has been installed, to safeguard the very heavy international traffic of this small sea.

The Sound is a narrow strait between Zealand and Scania with a mean depth of 11 m. Approximately 25 % of the discharge of water between Kattegat and the Baltic Sea flows through the Sound. The primary direction of flow is northerly, however near the bottom the flow is reversed, bringing saline water into the Baltic Sea.

A map of the study area can be found in **Figure 3**.

## 2.2 Data and information sources

This assessment is, as mentioned, partly literature-based and to a large extent anchored in the Danish WFD Initial Assessment for coastal water (MiljøGIS 2014) and the Danish MSFD Initial Assessment (Naturstyrelsen 2012, Andersen *et al.* 2012).

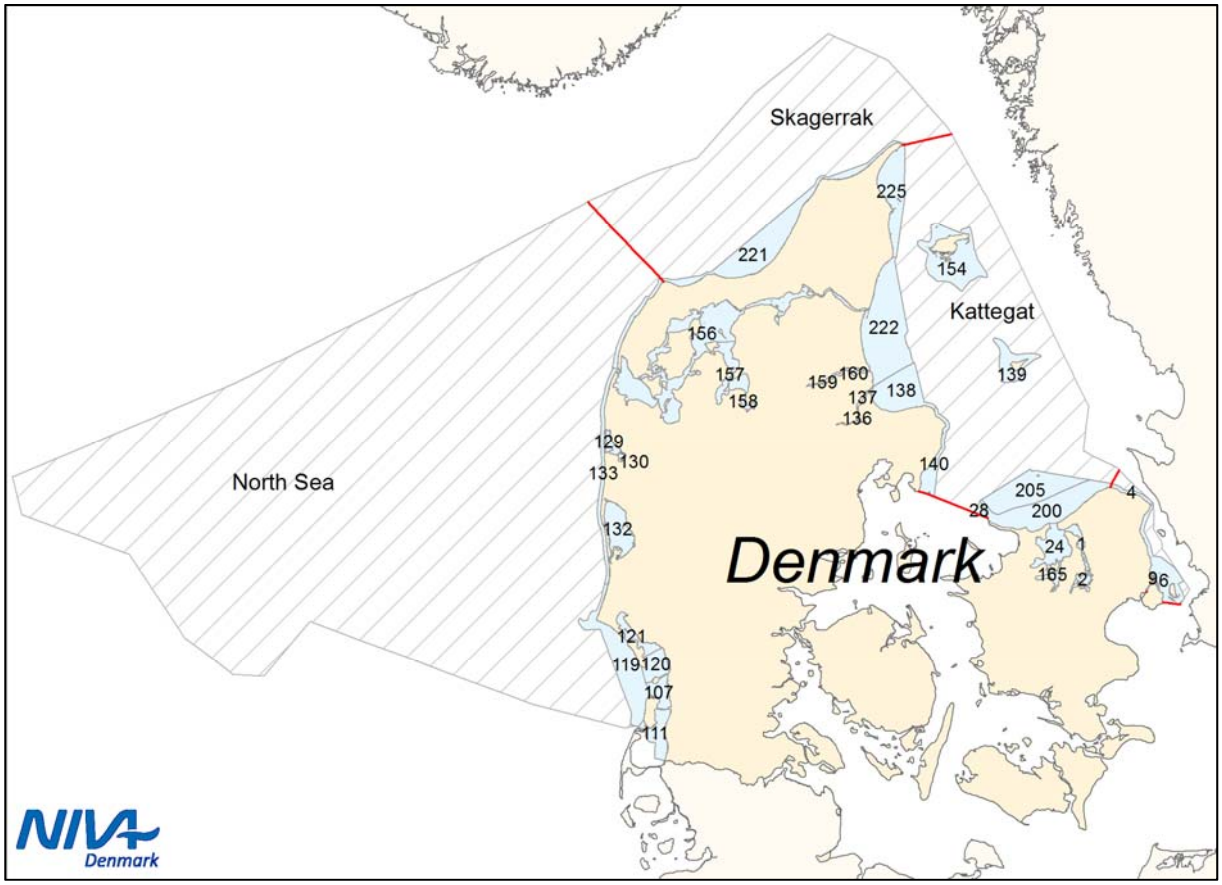


**Figure 3:** *Map of the Danish assessment units used in this study. A total of 40 assessment units, 4 offshore and 36 coastal, are included. See Appendix A for an overview.*

Both the WFD and MSFD Initial Assessments are based on data collected through the national NOVANA monitoring programme and the indicators used in the two assessments are largely the same. A key difference is the absence of numerical nutrient target values in the WFD Initial Assessment. An overview of the indicators can be found in **Table 1**.

**Table 1:** *Overview of parameters/indicators used for the Danish OSPAR COMP3 assessment.*

| Parametres/indicators | Coastal waters | Open waters |
|---|---|---|
| Inputs of nutrients (N and P)[1] | — | — |
| Nutrient concentrations (area-specific) | — | From MSFD |
| Chlorophyll a | chlorophyll *a*: from WFD | From MSFD |
| Phytoplankton indicator species | — | — |
| Submerged aquatic vegetation (SAV) | Eelgrass: from WFD | For the Kattegat: MSFD |
| Oxygen concentrations (hypoxia/anoxia) | —[2] | — |
| Benthin macroinvertebrates and fish | DKI: from WFD | DKI from HELCOM |
| Sediments (carbon/organic material) | — | — |
| Algae toxins | — | — |

*1) '—' indicates that no waterbody-specific target values, a prerequisite for making an assessment, have been agreed. 2) As all coastal waterbodies in the OSPAR area have been classified as having either a 'moderate', 'poor' or 'bad' ecological status, there is no added value in including oxygen concentrations in the assessment.*

Assessment of offshore parts of the North Sea and Skagerrak and the northern and central parts of the Sound are based on data, information and results from the following two key references:

- Naturstyrelsen (2012): Danmarks Havstrategi. Basisanalyse. Miljøministeriet, København, 100 pp. (In Danish).
- Andersen, J.H., J.W. Hansen, C. Murray, C. Göke & D.L.J. Petersen (2012): Klassifikation af eutrofieringstilstanden i de danske farvande – en indikator-baseret statusvurdering. Fagligt notat fra DCE - Nationalt Center for Miljø og Energi. 42 pp. (In Danish)

The assessment of eutrophication status in the offshore parts of the Kattegat is based on data from:

- Andersen, J.H., J. Carstensen, D.J. Conley, K. Dromph, V. Fleming, B. Gustafsson, A. Josefson, A. Norkko, A. Villnäs & C. Murray (2015): Long-term temporal and spatial trends in eutrophication status of the Baltic Sea. Biological Reviews. http://onlinelibrary.wiley.com/doi/10.1111/brv.12221/epdf

Coastal parts of the North Sea, Skagerrak and Kattegat as well as northern and central parts of the Sound are based on data, information and results from the Danish 2014 WFD Initial Assessment:

- http://miljoegis.mim.dk/cbkort?&profile=vandrammedirektiv2h2014

The aggregated data layers from MiljøGIS of specific relevance to OSPAR COMP 3 are: 1) chlorophyll *a*, 2) eelgrass (*Zostera marina*), and benthic invertebrates (DKI index). The underlying data has kindly been provided by the Danish Agency for Water and Nature Management (Christina F. Nielsen, *pers. comm.*).

## 2.3 Assessment principles and methodology

Despite the fact that this Danish OSPAR COMP3 assessment is literature based, it still applies the assessment principles and methodology in the OSPAR Common Procedure (OSPAR 2013). In principle the results are identical with those obtained by multi-metric indictor-based assessment of 'eutrophication status' (Clausen *et al.* 2009). Hence, indicators are grouped as follows: Category I: 'Nutrient levels', Category II 'Direct effects', Category III: 'Indirect effects' and Category IV 'Other effects'. These categories are assessed individually and subsequently integrated into a final assessment of 'eutrophication status'. Please observe that categories III and IV have been combined for practical reasons.

All Danish OSPAR COMP3 assessments are presented individually in Appendix B – an example showing the assessment for the offshore parts of the Kattegat is presented below (**Table 2**).

**Table 2:** *OSPAR COMP3 assessment for the offshore parts of the Kattegat. In the column 'assessment, + represents target values not met, while ÷ represents target values met. EPA = 'Eutrophication Problem Area'.*

| **Assessment criteria** | **COMP3** | | |
|---|---|---|---|
| CI: Nutrient levels | **Target value** | **Monitoring data** | **Assessment** |
| • Nitrogen concentrations | 5.00 | 5.48 | + |
| • Phosphorus concentrations | 0.49 | 0.53 | + |
| CII: Direct effects | | | |
| • Phytoplankton – chlorophyll *a* | 1.50 | 1.12 | ÷ |
| • Secchi depth (summer mean) | 7.65 | 6.45 | + |
| CIII+IV: Indirect/ other effects | | | |
| • Benthic invertebrates (DKI) | 0.68 | 0.70 | ÷ |
| **Final classification** | **EPA** | | |

## 2.4 EO-based separation of offshore Problem and Non-Problem Areas

MERIS (MEdium Resolution Imaging Spectrometer) data have been used to get high frequency and high spatial chlorophyll *a* data. MERIS have 15 spectral bands with the spectral range restricted to the visible near-infrared part of the spectrum between 390 and 1040 nm. The data have been processed using the CoastColour processor version 1.7. MERIS FRS L1B v2013, top of atmosphere (TOA) data, has been used as input to generate the L2, bottom of atmosphere (BOA), data. To get L2 data, atmospheric correction (AC) has to be performed. The atmospheric correction is correcting the influence the atmosphere have had on the signal going from the sun to the ocean and back to the five cameras of the MERIS instrument on the ENVISAT satellite. A more detailed description of these principles can be found in the CoastColour-PUG-v2.2.pdf document (Brockmann Consult 2014).

The CoastColour processor is available through the Calvalus on-demand service system developed through the ESA (European Space Agency) project CoastColour. The whole MERIS dataset from May 2002 to April 2012 has been processed for the west coast region of Denmark. The final L2 product contains several parameters, but for this purpose the chlorophyll *a* product has been used. Binning has been applied on the whole chlorophyll *a* dataset, also through the Calvalus on-demand service, with the resulting end product as an average product and a 90-percentile of nearly 10 years dataset.

Average annual values of MERIS chlorophyll *a* concentrations were compared with annual averages of concentrations measured in water samples at 4 Danish monitoring stations. This resulted in a correction which was applied to the 10-year average of the MERIS data product for the period 2002-2012. The corrected 10-year average chlorophyll *a* concentration was then used to determine the boundary between Problem and Non-Problem areas. The extent of the region where the 10-year average chlorophyll *a* concentration did not exceed 3.5 $\mu g\ l^{-1}$ was identified and this region was considered to be a Non-Problem Area.

Please see Appendix C for further details regarding the methodology.

## 2.5 Coordination with neighbouring countries

The draft maps of Problem Areas and Non-Problem Areas in the Danish parts of the North Sea, Skagerrak and Kattegat as well as the northern and central parts of the Sound have been forwarded to and discussed with Swedish Agency for Marine and Water Management (SwAM) in Sweden and the Federal Environment Agency (UBA) in Germany. This dialogue did not lead to any changes in the map as both SwAm and UBA were of the opinion that there seemed to be a fairly good match with their national results, as described in:

- Wesslander, K., L. Andersson, J. Johansson, J. Linders, N. Nixelius, A.-T. Skjevik (2016): Swedish National Report on Eutrophication Status in the Skagerrak, Kattegat and the Sound. OSPAR Assessment 2016. Report Oceanography No. 54, 2016.
- Brockmann, U., D. Topcu, M. Schütt (2016): 3rd Assessment of the eutrophication status of the German exclusive economic zone in the North Sea, according to the OSPAR Comprehensive Procedure. Hamburg University - Centre for Climate and Marine Research.

The Norwegian OSPAR COMP3 classifications of eutrophication status in the open parts of Skagerrak are identical to the Danish classifications. For further details regarding eutrophication in Norwegian marine water, please confer with:

- Norderhaug, K.M., H. Gundersen, T. Høgåsen, T.M. Johnsen, G. Severinsen, J. Vedal, K. Sørensen & M. Walday (*in prep.*): Eutrophication status for Norwegian waters. National report for the third application of OSPARs Common Procedure. Norwegian Environmental Agency

# 3. Results

Data and information from a total of 38 assessment units (4 offshore, 34 coastal) have been analysed in order to classify eutrophication status and to identify Eutrophication Problem Areas (EPAs) and Non-Problem Areas (NPAs) in the Danish parts on the North Sea, Skagerrak and Kattegat as well as northern and central parts of the Sound.

The assessment is largely literature-based and is not only anchored in but also completely coordinated with two comprehensive Danish Initial Assessments: (1) the WFD Initial Assessment from 2014 (MiljoeGIS 2014) and (2) the MSFD Initial Assessment form 2012 (Naturstyrelsen 2012).

The national monitoring of ecological/environmental/eutrophication status in Denmark is carried out under the umbrella of the nation-wide NOVANA programme. This programme has a long history and is targeting relevant theme such as eutrophication, contamination and biodiversity and encompassed monitoring activities originating from a wide array on national (law and policies) and international requirements (WFD, MSFD, Natura 2000, HELCOM and OSPAR). Therefore, monitoring data (e.g. indicators) and assessment results from activities such as the two mentioned Initial Assessments are fit for purpose with regard to OSPAR COMP3.

The Danish literature-based OSPAR COMP3 assessment is based on the assumption that the findings in the WFD and MSFD Initial Assessments are still valid and that there currently is no development or trends taking place in the assessed areas. Based on temporal trend analyses of the monthly mean DIN concentrations of two stations, 'Blåvand' in the south-eastern part of the North Sea and 'Hirtshals' in the Skagerrak, the approach pursued by Denmark seem justified cf. **Figure 4**.

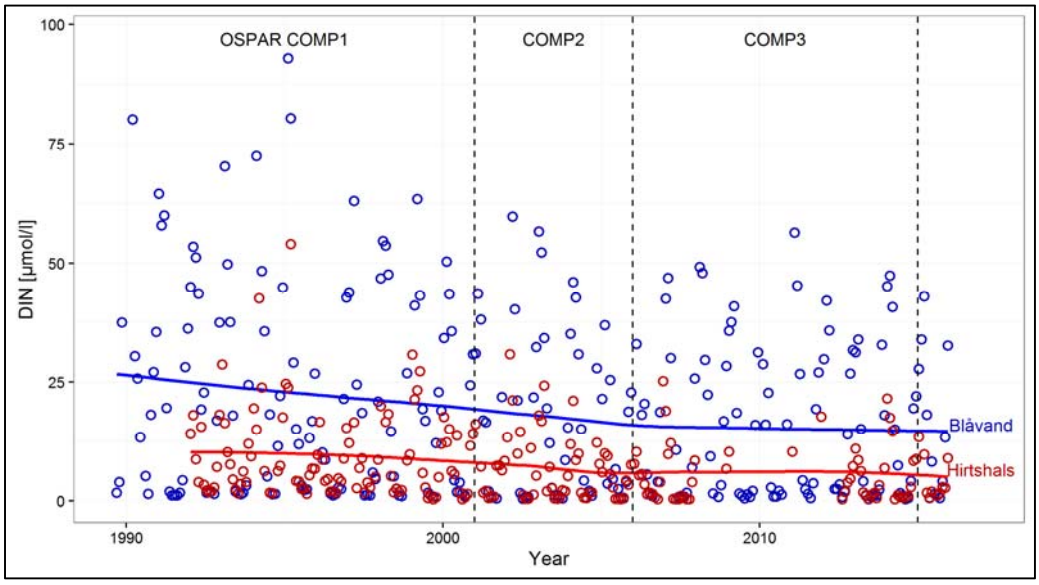


**Figure 4:** *Long term temporal trends in monthly mean DIN concentrations (µmol l$^{-1}$) at Blåvand (1990-2015) and Hirtshals (1992-2015). Data is downloaded from ODA on 5 April 2016.*

## 3.1 Offshore waters

The assessment of Danish offshore water is done for: The North Sea, Skagerrak, Kattegat and the northern and central parts of the Sound and is based on Naturstyrelsen (2012) and Andersen *et al.* (2015).

The offshore Danish parts of the North Sea were assessed based on Naturstyrelsen (2012) and classified as Non-Problem Areas with respect to nutrient enrichment and direct effects. Similarly, offshore parts of the Skagerrak are assessed on the basis of Naturstyrelsen (2012) and classified as a Non-Problem Area with respect to nutrient enrichment and direct effects.

The assessment of the eutrophication status in the offshore parts of the Kattegat is based on Andersen *et al.* (2015) and results in a classification as an Eutrophication Problem Area. The root causes for this classification are elevated nutrient concentration and a reduced Secchi depth, where the target values are not met. For chlorophyll *a* and benthic invertebrates, the target values are met (see **Table 2** for details).

A recently published study on long-term temporal and spatial trends of eutrophication status in the Baltic Sea region has revealed that the open parts of the Kattegat is not only recovering from the effects of nutrient inputs can in some years (2006, 2010 and 2011) be classified as an NPA (Andersen *et al.* 2015; **Figure 5**).

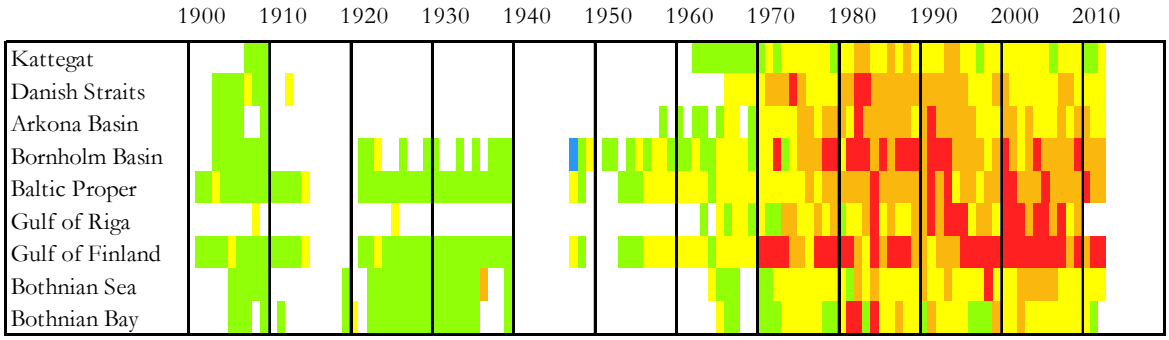


**Figure 5:** *Integrated annual classification of eutrophication status in the Kattegat 1960–2012 based on five-year running averages. For details, please confer with Andersen et al. (2015) on which this modified illustration is based.*

The recovery trajectory documented for the open parts of the Kattegat is more apparent when looking at the long-term trend in the status for benthic macroinvertebrates (**Figure 6**).

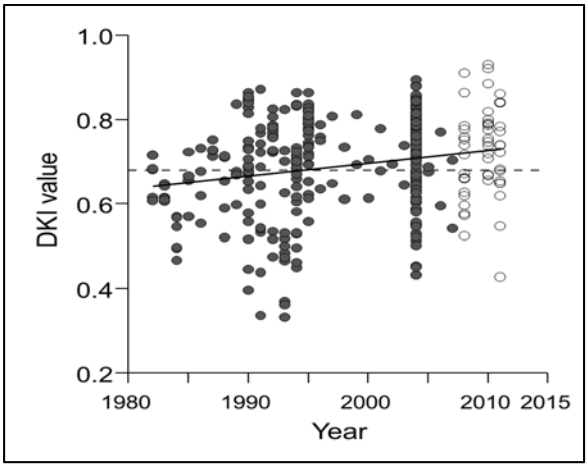


**Figure 6:** *Trends in environmental status of macrozoobenthos communities (based on DKI, the Danish benthic quality index) in the Kattegat, 1982–2011. From Andersen et al. (2015).*

The offshore parts of the Sound are assessed based on Naturstyrelsen (2012) and classified as an Eutrophication Problem Area based on the categories 1 and 2, 'Nutrient levels' and 'Direct effects'.

The initial classifications as well as final classification of the offshore Danish waters in the North Sea, Skagerrak and Kattegat as well as northern and central parts of the Sound are summarized in **Table 3**.

**Table 3:** *Initial and final classification of eutrophication status, i.e. identification of Non-Problem areas (NPA) and Eutrophication Problem Areas (EPA) in the offshore Danish parts of the North Sea, Skagerrak and Kattegat as well as the northern and central parts of the Sound. See Appendix B for details.*

| Assessment unit | Number | Initial classification | | | Final classification |
|---|---|---|---|---|---|
| | | Nutrients | Direct | Indirect | |
| North Sea, offshore parts | 1 | ÷ | ÷ | n.i. | **NPA** |
| Skagerrak, offshore parts | 2 | ÷ | ÷ | n.i. | **NPA** |
| Kattegat, offshore parts | 3 | + | + | + | **EPA** |
| The Sound, offshore parts | 4 | + | + | n.i. | **EPA** |

The above conclusion is in line with earlier Danish OSPAR COMP assessments (Ærtebjerg *et al.* 2003, Andersen & Kaas 2008).

## 3.2 Coastal waters

9 coastal waterbodies in the Danish parts of the North Sea have been assessed and are all classified as Eutrophication Problem Areas (**Table 4**). The conclusions are in line with both national assessments (MiljoeGIS 2014) and earlier Danish OSPAR COMP assessments (Ærtebjerg *et al.* 2003, Andersen & Kaas 2008).

**Table 4:** *Initial and final classification of eutrophication status, i.e. identification of Non-Problem Areas (NPA) and Eutrophication Problem Areas (EPA) in Danish coastal waters in the Skagerrak. See Appendix B for details.*

| Assessment unit | Number | Initial classification | | | Final classification |
|---|---|---|---|---|---|
| | | Nutrients | Direct | Indirect | |
| Juvre Dyb (107) | 1.1 | n.i. | n.i. | n.i. | **EPA**[1] |
| Listerdyb (111) | 1.2 | n.i. | + | + | **EPA** |
| Vesterhavet syd 1 sømil (119) | 1.3 | n.i. | + | n.i. | **EPA** |
| Knude Dyb (120) | 1.4 | n.i. | + | n.i. | **EPA** |
| Grådyb (121) | 1.5 | n.i. | + | + | **EPA** |
| Nissum yderfjord (129) | 1.6 | n.i. | ÷ | + | **EPA** |
| Nissum mellemfjord ((130) | 1.7 | n.i. | + | + | **EPA** |
| Ringkøbing Fjord (132) | 1.8 | n.i. | + | + | **EPA** |
| Vesterhavet nord 1 sømil (133) | 1.9 | n.i. | + | n.i. | **EPA** |

*1 Based on supporting information cf. Naturstyrelsen (2014).*

The Danish coastal waters in the Skagerrak have, based on MiljoeGIS (2014), been assessed and are classified as Eutrophication Problem Areas (**Table 5**). The conclusion is in line with earlier Danish OSPAR COMP assessments (Ærtebjerg *et al.* 2003, Andersen & Kaas 2008).

**Table 5:** *Initial and final classification of eutrophication status, i.e. identification of Non-Problem Areas (NPA) and Eutrophication Problem Areas (EPA) in Danish Skagerrak coastal waters. See Appendix B for details.*

| Assessment unit | Number | Initial classification | | | Final classification |
|---|---|---|---|---|---|
| | | Nutrients | Direct | Indirect | |
| The Skagerrak, coastal (221) | 2.1 | n.i. | + | ÷ | **EPA** |

21 coastal waterbodies in the Danish parts of the North Sea have been assessed and are all classified as Eutrophication Problem Areas (**Table 6**) and the conclusions are in line with earlier Danish OSPAR COMP assessments (Ærtebjerg *et al.* 2003, Andersen & Kaas 2008).

**Table 6:** *Initial and final classification of eutrophication status, i.e. identification of Non-Problem Areas (NPA) and Eutrophication Problem Areas (EPA) in Danish coastal waters in the Kattegat. See Appendix B for details.*

| Assessment unit | Number | Initial classification | | | Final classification |
|---|---|---|---|---|---|
| | | Nutrients | Direct | Indirect | |
| Roskilde Fjord, ydre (1) | 3.1 | n.i. | + | ÷ | **EPA** |
| Roskilde Fjord, indre (2) | 3.2 | n.i. | + | + | **EPA** |
| Kattegat > 20 m (205) | 3.3 | n.i. | + | + | **EPA** |
| Kattegat < 20 m (200) | 3.4 | n.i. | ÷ | ÷ | **EPA** |
| Isefjord ydre (24) | 3.5 | n.i. | + | + | **EPA** |
| Sejerø Bugt (28) | 3.6 | n.i. | n.i. | + | **EPA** |
| Randers Fjord, Grund Fjord (135) | 3.7 | + | + | + | **EPA** |
| Randers Fjord, mellem del (136) | 3.8 | n.i. | + | + | **EPA** |
| Randers Fjord, ydre del (137) | 3.9 | n.i. | + | + | **EPA** |
| Hevring Bugt (137) | 3.10 | n.i. | ÷ | + | **EPA** |
| Farvandet ved Anholt (139) | 3.11 | n.i. | + | ÷ | **EPA** |
| Farvandet Djursland Øst (140) | 3.12 | n.i. | + | n.i. | **EPA** |
| Farvandet ved Læsø (154) | 3.13 | n.i. | ÷ | + | **EPA** |
| Kattegat, Aalborg Bugt (222) | 3.14 | n.i. | ÷ | + | **EPA** |
| Kattegat, Ålbæk Bugt (225) | 3.15 | n.i. | ÷ | + | **EPA** |
| Vestlige Limfjord (156) | 3.16 | n.i. | + | + | **EPA** |
| Centrale og sydlige Limfjord (157) | 3.17 | n.i. | + | + | **EPA** |
| Hjarbæk Fjord (158) | 3.18 | n.i. | + | + | **EPA** |
| Mariager Indrefjord (159) | 3.19 | n.i. | + | n.i. | **EPA** |
| Mariager Yderfjord (160) | 3.20 | n.i. | n.i. | + | **EPA** |
| Isefjorden, indre dele (165) | 3.21 | n.i. | + | + | **EPA** |

3 coastal waterbodies in the Danish parts of the Sound have been assessed and are all classified as Eutrophication Problem Areas (**Table 7**). The conclusions are in line with earlier Danish OSPAR COMP assessments (Ærtebjerg *et al.* 2003, Andersen & Kaas 2008).

**Table 7:** *Initial and final classification of eutrophication status, i.e. identification of Non-Problem Areas (NPA) and Eutrophication Problem Areas (EPA) in Danish coastal waters in the Sound. See Appendix B for details.*

| Assessment unit | Number | Initial classification | | | Final classification |
|---|---|---|---|---|---|
| | | Nutrients | Direct | Indirect | |
| Øresundstragten (4) | 4.1 | n.i. | ÷ | ÷ | **EPA**[1] |
| Nordlige Øresund (6) | 4.2 | n.i. | ÷ | + | **EPA** |
| Københavns Havn (9) | 4.3 | n.i. | n.i. | n.i. | **EPA**[1] |

*1 Based on supporting information cf. Naturstyrelsen (2014).*

## 3.3 Nation-wide mapping of Problem and Non-Problem Areas

Perhaps the most important product of the OSPAR COMP3 assessment process is a nation-wide map identifying Eutrophication Problem Areas and Eutrophication Non-problem Areas.

Classifying offshore waters as well as coastal waters is straight forward as can be seen in the previous sections and especially in Tables 3, 4, 5 and 6. The challenge is to accurately identify where the boundary between the two types of areas is located. This has been done by analysing satellite observations (see section 2.4 and Appendix C) and the results are presented in **Figure 7** on the following page.

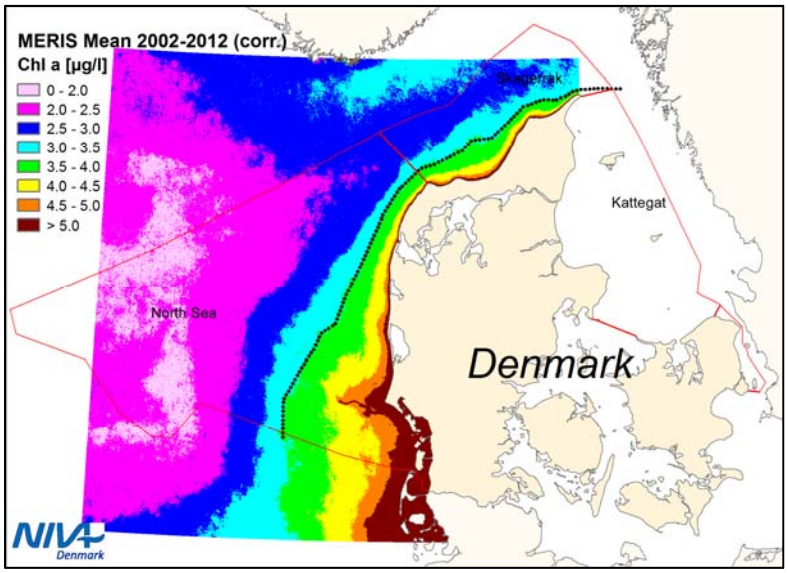


**Figure 7:** *EO-based segregation of Eutrophication Problem Areas (EPAs) and Non-Problem Areas (NPAs) for the period 2002-2012. Please confer with Appendix C for details.*

When combining the final classifications for offshore waters (Table 2) and coastal waters (tables 3, 4 and 5) and separating the coastal Eutrophication Problem Areas and offshore Non-Problem Areas as described above, we arrive at a nation-wide mapping of NPAs and EPAs (**Figure 8**).

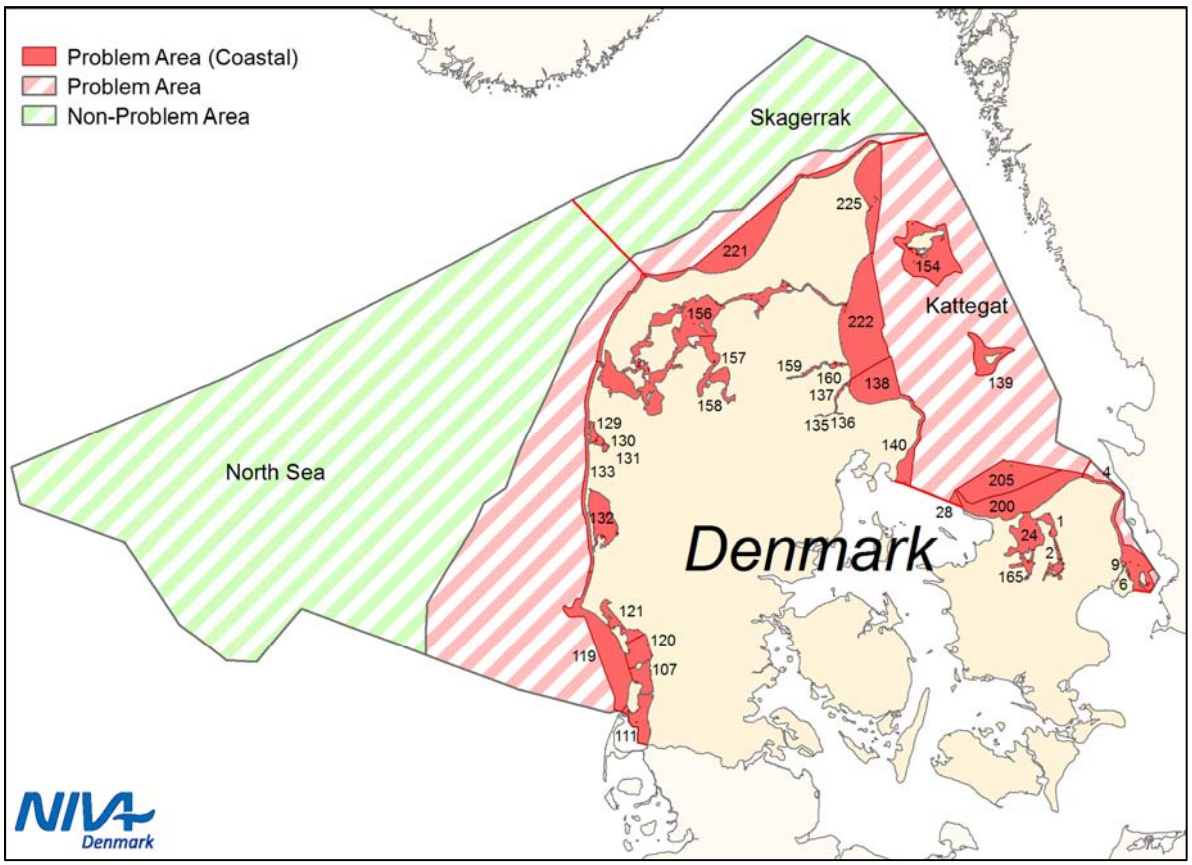


**Figure 8:** *Eutrophication status in the Danish parts of the North Sea, Skagerrak and Kattegat as well as the northern and central parts of the Sound.*

# 4. Discussion and conclusions

This Danish OSPAR COMP3 assessment of eutrophication status in the Danish parts of the North Sea, Skagerrak and Kattegat as well as the northern and central parts of the Sound is based on the following:

1. the Danish MSFD Initial Assessment from 2012,
2. the Danish WFD Initial Assessment from 2014, and
3. a specific endeavour to separate Eutrophication Problem Areas and Non-Problem Areas in the offshore parts of the North Sea and Skagerrak based on EO measurements of chlorophyll *a* (i.e. satellite data).

The data and assessment tools on which the Danish MSFD Initial Assessment is based (Naturstyrelsen 2012, Andersen *et al.* 2012) are of high quality and scientifically credible. There may be specific parts which can be discussed or perhaps improved, especially with regard to the design of the monitoring networks and the GES target values applied, but the conclusions are in general considered both valid and robust.

The Danish WFD Initial Assessment (MiljøGIS 2014) and its classifications of ecological status in the coastal waters are based on comprehensive monitoring and intercalibrated indicators and are, as the WFD Initial Assessment mentioned above, considered both valid and robust. It is not based on quantitative nutrient criteria, only quantitative biological criteria for chlorophyll *a*, submerged aquatic vegetation (depth limit of Eelgrass) and/or benthic macroinvertebrates (DKI index) but nevertheless very useful in the context of the OSPAR COMP. This is directly linked to the assessment principles applied, i.e. the 'one out, all out' principle. Hence, water bodies classified as having a 'moderate', 'poor' or 'bad' ecological status will always be classified as an Eutrophication Problem Area in the context of the OSPAR COMP.

The delineation of assessment units can potentially affect the outcome of both the initial classification and the final, integrated classification of eutrophication status. This has been the case in the Danish parts of the North Sea and Skagerrak, where the picture is very clear: Coastal waters are Eutrophication Problem Areas and offshore waters are Non-Problem Areas. A specific challenge has been to accurately separate the two areas. This has in the context of the Danish OSPAR COMP3 assessment been done via analyses of satellite-based observations of chlorophyll *a* concentrations in the surface water for the period 2002-2012. This represents an important step forward and for the first time, the Danish separation of EPAs and NPAs is evidence-based and not a result of how the assessment units have been delineated.

Further, the Danish OSPAR COMP3 assessment has been based on an assumption that the assessment period (2006-2012) can be regarded as relatively stable with regard to eutrophication signals, e.g. inputs of nutrient and the resulting nutrient concentrations. Based on the long-term temporal trends of mean monthly DIN concentrations at marine monitoring stations at Blåvand and Hirtshals, we conclude that the assumption is valid and hence that the Danish assessment approach is justified.

Based on the above, data and information have been reanalysed and 5 conclusions have been drawn with respect to classification of eutrophication status and identification of Eutrophication Problem Areas and Non-Problem Areas.

**Conclusion 1:** All Danish coastal water bodies in the North Sea, Skagerrak, Kattegat as well as the northern and central parts of the Sound are classified as Eutrophication Problem Areas.

This conclusion is in line with the Danish reporting of 'ecological status' in coastal waters under the EU Water Framework Directive (MiljøGIS 2014), the Danish MSFD Initial Assessment (Naturstyrelsen 2012) as well as earlier Danish OPSAR COMP assessments (Ærtebjerg *et al.* 2003, Andersen & Kaas 2008).

**Conclusion 2:** The offshore parts of the Kattegat are classified as Eutrophication Problem Areas.

This conclusion is evidence-based but partly a consequence of how the assessment unit 'Kattegat' is defined. The offshore parts of the Kattegat are defined as single water body, but spatial variations between the northern parts and especially the southern parts are large. The findings by Andersen *et al.* (2015) indicate that the open parts of the Kattegat are relatively close to being classified as a Non-Problem Area. Hence, future assessment should re-examine the sub-division of the Kattegat and perhaps carry out separate assessment for the northern, central and southern parts.

**Conclusion 3:** The offshore part of the Skagerrak is classified as an Eutrophication Non-Problem Area.

This conclusion is in line with earlier Danish assessments, e.g. Ærtebjerg *et al.* (2003), Andersen & Kaas (2008) and Naturstyrelsen (2012).

**Conclusion 4:** A large proportion of the offshore parts of the North Sea are classified as Eutrophication Non-Problem Areas.

Again, this conclusion is in line with earlier Danish assessments, e.g. Ærtebjerg *et al.* (2003), Andersen & Kaas (2008) and Naturstyrelsen (2012).

**Conclusion 5:** The geographical boundary between the coastal Eutrophication Problem Areas and the offshore Non-Problem Areas is dynamic and controlled by hydraulic features. This study has improved the identification and location of the boundary and also revealed that the geographical coverage of the Eutrophication Problem Areas in the Danish parts of the North Sea probably have been reduced over the past decades.

We have overcome the influence of the definition of the assessment unit by using EO-data to identify and locate the boundary between coastal Eutrophication Problem Areas and offshore Non-Problem Areas. Compared to earlier OSPAR COMP assessment, the extent of the Eutrophication Problem Areas has been reduced from approximately 40000 km$^2$ in 2008 to approximately 32300 km$^2$ in 2012. The total reduction is tentatively estimated to be in the order of 7700 km$^2$. Despite the dynamical nature of the EPA/NPA boundary and to uncertainties in the methodology applied, we document large scale improvements in eutrophication status of the Danish parts of the North Sea.

The spatial extent of the Danish Eutrophication Problem Areas appears to be reduced, as indicated above Hence, it is important to monitor relevant eutrophication related signals in order to be able to carry out future assessments with an adequate spatial resolution.

Further, we recommend a much closer coordination and harmonisation between all eutrophication related assessments, i.e. the WFD Initial Assessment, MSFD Initial Assessment, UWWTD reporting, and ND reporting as well HELCOM's and OSPAR's regular eutrophication assessment. Not only do we see room for improvements, we anticipate that a convergence process with respect to these eutrophication related assessments could potentially result in more cost-effective reporting.

Finally, and as a word of caution: The road to alleviating eutrophication problems is straight forward – we need to reduce inputs of nutrient to acceptable levels and to restore resilience of coastal ecosystems. However, we also need to consider the potential effects of global warming, especially a temperature increase in coastal and continental marine waters. The effect of increasing temperature counteracts reductions in nutrient inputs. If nutrient inputs are not reduced in due time, we may risk irreversible and undesirable changes in our coastal marine ecosystems.

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# Appendix A. List of assessment units

| Number | Area/name |
|---|---|
| | **The North Sea** |
| 1 | The North Sea, offshore parts |
| 1.1 | Juvre Dyb, tidevandsområde (107) |
| 1.2 | Listerdyb (111) |
| 1.3 | Vesterhavet syd, 1 sømil (119) |
| 1.4 | Knude Dyb, tidevandsområde (120) |
| 1.5 | Grådyb, tidevvandsområde (121) |
| 1.6 | Nissum Yderfjord (129) |
| 1.7 | Nissum Mellem Fjord (130) |
| 1.8 | Ringkøbing Fjord (132) |
| 1.9 | Vesterhavet nord 1 sømil (133) |
| | **The Skagerrak** |
| 2 | The Skagerrak, offshore parts |
| 2.1 | The Skagerrak, kystvande (221) |
| | **The Kattegat** |
| 3 | The Kattegat offshore parts |
| 3.1 | Roskilde Fjord, ydre (1) |
| 3.2 | Roskilde Fjord, indre (2) |
| 3.3 | Kattegat >20 m (205) |
| 3.4 | Kattegat <20 m (200) |
| 3.5 | Isefjord ydre (24) |
| 3.6 | Sejrø Bugt (28) |
| 3.7 | Randers Fjord, Grund Fjord (135) |
| 3.8 | Randers Fjord, mellem del (136) |
| 3.9 | Randers ydre del (137) |
| 3.10 | Hevring Bugt (138) |
| 3.11 | Farvandet ved Anholt (139) |
| 3.12 | Farvandet Djursland Øst (140) |
| 3.13 | Farvandet ved Læsø(154) |
| 3.14 | Kattegat, Aalborg Bugt (222) |
| 3.15 | Kattegat, Ålbæk Bugt (225) |
| 3.16 | Vestlige Limfjord (156) |
| 3.17 | Centrale og sydlige Limfjord (157) |
| 3.18 | Hjarbæk Fjord (158) |
| 3.19 | Mariager Inderfjord (159) |
| 3.20 | Mariager Yderfjord (160) |
| 3.21 | Isefjord, indre (165) |
| | **The Sound** |
| 4 | The Sound, offshore parts |
| 4.1 | Øresundstragten (4) |
| 4.2 | Nordlige Øresund (6) |
| 4.3 | Københavns Havn (9) |

# Appendix B. Individual OSPAR COMP3 assessments sheets

The following tables are based on data from OSPAR common procedure 1 (COMP 1), 2 (COMP 2) and 3 (COMP3) (Ærtebjerg *et al.* 2003; Andersen & Kaas 2008). A "+" is indicating an Eutrophication Problem Area and a "÷" represents a Non-Problem Area. The Final classification is based on the one out – all out principle, meaning that a single "+" in an assessment unit result in a classification as Eutrophication Problem Area.
For COMP2, the "+" and "÷" is based on the COMP2, however the final classification is based on the HEAT-classification. The COMP3 assessment is separated into three columns. The first contains the reference value, the second contains the status and the third contains the assessment as either "+" or "÷" n.a. indicates that the assessment unit is not assessed, n.i. indicates that there are no information on the assessment criteria, n.r. indicates that the assessment criteria is not relevant.

All assessment units included in COMP3 are included in this appendix. Since total compliance between the boundaries of each assessment units for the different common procedures does not exist, it is written which COMP1 and COMP2 assessment unit is applied in the concerned matrix.

**1. The North Sea, offshore parts**
The OSPAR COMP3 assessment is based on Andersen *et al.* (2012).

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | ÷ | | 8.25 | 8.00 | ÷ |
| • Phosphorus concentrations | | ÷ | 0.98 | 0.60 | ÷ |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | n.i. | ÷ | 3.45 | 3.00 | ÷ |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | n.i. | n.i. | | | n.i. |
| • Benthic invertebrates (DKI) | n.i. | n.i. | | | n.i. |
| • Oxygen concentrations | ÷ | n.i. | | | n.i. |
| **Final classification** | **NPA** | **EPA** | **NPA** | | |

**1.1 Juvre Dyb, tidevandsområde (107)**
The COMP1 and COMP2 data originates from the assessment unit "Wadden Sea". In COMP3 the area Juvre Dyb has not been assessed, but the areas final classification is "EPA", due to the status of the biological parameters in the adjacent assessment unit (Naturstyrelsen, 2014).

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | + | + | | | n.i. |
| • Phosphorus concentrations | | ÷ | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | + | + | 7.5 | | n.i. |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | + | n.i. | | | n.i. |
| • Benthic invertebrates (DKI) | n.i. | n.i. | 0.53 | | n.i. |
| • Oxygen concentrations | ÷ | n.i. | | | n.i. |
| **Final classification** | **EPA** | **EPA** | **EPA** | | |

### 1.2 Listerdyb (111)

The data from COMP1 and COMP2 originates from the assessment unit "Wadden Sea". In COMP 3 the specific area has been assessed.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | + | + | | | n.i. |
| • Phosphorus concentrations | | ÷ | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | + | + | 7.5 | 17 | + |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | + | n.i. | | | n.i. |
| • Benthic invertebrates (DKI) | n.i. | n.i. | 0.53 | 0.42 | + |
| • Oxygen concentrations | ÷ | n.i. | | | n.i. |
| **Final classification** | **EPA** | **EPA** | **EPA** | | |

### 1.3 Vesterhavet syd, 1 sømil (119)

The area has not been assessed in COMP1. The data from COMP2 originates from the assessment unit "North Sea – southern coastal waters" no. 2. Just a single indicator "chlorophyll a" has been assessed for this area in COMP3.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | n.a. | + | | | n.i. |
| • Phosphorus concentrations | | ÷ | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | n.a. | ÷ | 6.9 | 15 | + |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | n.a. | n.r. | | | n.r. |
| • Benthic invertebrates (DKI) | n.a. | n.i. | 0.53 | | n.i. |
| • Oxygen concentrations | n.a. | n.i. | | | n.i. |
| **Final classification** | **N.A.** | **EPA** | **EPA** | | |

### 1.4 Knude Dyb, tidevandsområde (120)

The data from COMP1 and COMP2 originates from the assessment unit "Wadden Sea". In COMP3 the area has been assessed in regard to chlorophyll *a* concentration.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | + | + | | | n.i. |
| • Phosphorus concentrations | | ÷ | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | + | + | 7.5 | 23.0 | + |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | + | n.i. | | | n.i. |
| • Benthic invertebrates (DKI) | n.i. | n.i. | 0.53 | | n.i. |
| • Oxygen concentrations | ÷ | n.i. | | | n.i. |
| **Final classification** | **EPA** | **EPA** | **EPA** | | |

**1.5 Grådyb, tidevandsområde (121)**

The data from COMP1 and COMP2 originates from the assessment unit "Wadden Sea". In COMP3 the area has been assessed in regard to chlorophyll a concentration and DKI.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| Nitrogen concentrations | + | + | | | n.i. |
| Phosphorus concentrations | | ÷ | | | n.i. |
| C2: Direct effects | | | | | |
| Phytoplankton – chlorophyll *a* | + | + | 7.5 | 17.0 | + |
| C3+C4: Indirect/ other effects | | | | | |
| Eelgrass (*Zostera marina*) depth limit | + | n.i. | | | n.i. |
| Benthic invertebrates (DKI) | n.i. | n.i. | 0.53 | 0.42 | + |
| • Oxygen concentrations | ÷ | n.i. | | | n.i. |
| **Final classification** | **EPA** | **EPA** | **EPA** | | |

**1.6 Nissum Yderfjord (129)**

The area has not been assessed in COMP1. The data for COMP2 originates from assessment unit 6 "Nissum Fjord". The COMP2 assessment in regard to nutrients is based on input of nitrogen and phosphorus and not the concentration.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| Nitrogen concentrations | n.a. | + | | | n.i. |
| Phosphorus concentrations | | ÷ | | | n.i. |
| C2: Direct effects | | | | | |
| Phytoplankton – chlorophyll *a* | n.a. | n.i. | 8 | 5.3 | ÷ |
| C3+4: Indirect/other effects | | | | | |
| Eelgrass (*Zostera marina*) depth limit | n.a. | + | 2 | 0.8 | + |
| Benthic invertebrates (DKI) | n.a. | n.i. | 0.68 | 0.67 | + |
| Oxygen concentrations | n.a. | n.i. | | | n.i. |
| **Final classification** | **N.A.** | **EPA** | **EPA** | | |

**1.7 Nissum Mellemfjord (130)**

The area has not been assessed in COMP1. The data for COMP2 originates from assessment unit 6 "Nissum Fjord". The COMP2 assessment in regard to nutrients is based on input of nitrogen and phosphorus and not the concentration.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| Nitrogen concentrations | n.a. | + | | | n.i. |
| Phosphorus concentrations | | ÷ | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | n.a. | n.i. | 8 | 13.9 | + |
| C3+4: Indirect/other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | n.a. | + | | | n.i. |
| • Benthic invertebrates (DKI) | n.a. | n.i. | 0.68 | 0.67 | + |
| • Oxygen concentrations | n.a. | n.i. | | | n.i. |
| **Final classification** | **N.A.** | **EPA** | **EPA** | | |

### 1.8 Ringkøbing Fjord (132)

COMP1 did not include an assessment of Ringkøbing Fjord. COMP2 and COMP3 both assess Ringkøbing Fjord.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| **C 1: Nutrient levels** | | | **T** | **M** | **A** |
| Nitrogen concentrations/Nitrogen inputs | n.a. | + | | | n.i. |
| Phosphorus concentrations | | n.i. | | | n.i. |
| C2: Direct effects | | | | | |
| Phytoplankton – chlorophyll *a* | n.a. | n.i. | 8 | 9.3 | + |
| Secchi depth limit | n.a. | + | | | n.i. |
| Ruppia sp., depth limit | n.a. | + | | | n.i. |
| C3+C4: Indirect/ other effects | | | | | |
| Eelgrass (*Zostera marina*) depth limit | n.a. | + | 2.2 | 0.9 | + |
| Benthic invertebrates (DKI) | n.a. | + | 0.68 | 0.85 | + |
| Oxygen concentrations | n.a. | n.i. | | | n.i. |
| **Final classification** | **N.A.** | **EPA** | **EPA** | | |

### 1.9 Vesterhavet nord 1 sømil (133)

For COMP1 and COMP2 the data originates from the assessment unit "North Sea, coastal area".

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | **T** | **M** | **A** |
| Nitrogen concentrations / Nitrogen inputs | + | + | | | n.i. |
| Phosphorus concentrations | n.i. | ÷ | | | n.i. |
| C2: Direct effects | | | | | |
| Phytoplankton – chlorophyll *a* | + | + | 6.8 | 9.2 | + |
| Secchi depth limit | n.i. | n.i. | | | n.i. |
| Ruppia sp., depth limit | n.i. | n.i. | | | n.i. |
| C3+C4: Indirect/ other effects | | | | | |
| Eelgrass (*Zostera marina*) depth limit | + | n.i. | | | n.i. |
| Benthic invertebrates (DKI) | n.i. | n.i. | 0.53 | | n.i. |
| Oxygen concentrations | ÷ | n.i. | | | n.i. |
| **Final classification** | **EPA** | **EPA** | **EPA** | | |

### 2. Skagerrak, offshore parts

The OSPAR COMP3 assessment is based on Andersen *et al.* (2012).

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | **T** | **M** | **A** |
| • Nitrogen concentrations | ÷ | ÷ | 8.25 | 7.5 | ÷ |
| • Phosphorus concentrations | | ÷ | 0.98 | 0.7 | ÷ |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | + | ÷ | 3.6 | 2.9 | ÷ |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | n.i. | n.i. | | | n.i. |
| • Benthic invertebrates (DKI) | n.i. | n.i. | | | n.i. |
| • .Oxygen concentrations | ÷ | n.i. | | | n.i. |
| **Final classification** | **EPA** | **NPA** | **NPA** | | |

**2.1 Skagerrak, kystvande (221)**

The COMP1 and COMP2 assessment is based on the assessment unit "Skagerrak coastal areas". The values for COMP3 are based on the assessment unit "Skagerrak" no. 221.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | + | + | | | |
| • Phosphorus concentrations | | ÷ | | | |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | + | ÷ | 4.0 | 7.8 | + |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | + | n.i. | | | n.i. |
| • Benthic invertebrates (DKI) | n.i. | n.i. | 0.53 | 0.73 | ÷ |
| • Oxygen concentrations | ÷ | n.i. | | | |
| **Final classification** | **EPA** | **EPA** | **EPA** | | |

**3. The Kattegat, offshore parts**

The data for COMP2 is the combined score for assessment units 13, 14 and 17. Where there was discrepancies between the assessment, both "+" and "÷" are written. The COMP3 assessment is based on data from Andersen *et al.* (2015).

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | ÷ | + | 5.00 | 5.48 | + |
| • Phosphorus concentrations | | ÷/+ | 0.49 | 0.53 | + |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll a | + | + | 1.50 | 1.12 | ÷ |
| • Secchi depth (summer mean) | n.i. | n.i. | 7.65 | 6.45 | + |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | +/÷ | n.i. | | | n.i. |
| • Benthic invertebrates (DKI) | n.i. | ÷ | 0.68 | 0.70 | ÷ |
| • Oxygen concentrations | + | n.i. | | | n.i. |
| **Final classification** | **EPA** | **EPA** | **EPA** | | |

**3.1 Roskilde Fjord, ydre (1)**

In the COMP1, the fjords in Kattegat were not assessed. In COMP2 an overall assessment of Roskilde Fjord was made, which was not separated into outer and inner parts.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | n.a. | + | | | n.i. |
| • Phosphorus concentrations | | n.i. | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | n.a. | n.i. | 2.1 | 5.3 | + |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | n.a. | + | 4.1 | 4.2 | ÷ |
| • Benthic invertebrates (DKI) | n.a. | + | 0.68 | 0.68 | ÷ |
| • Oxygen concentrations | n.a. | n.i. | | | n.i. |
| **Final classification** | **N.A.** | **EPA** | **EPA** | | |

### 3.2 Roskilde Fjord, indre (2)

In the COMP1, the fjords in Kattegat were not assessed. In COMP2, an overall assessment of Roskilde Fjord was made, which was not separated into outer and inner parts.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | n.a. | + | | | n.i. |
| • Phosphorus concentrations | | n.i. | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | n.a. | n.i. | 3.6 | 4.1 | + |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | n.a. | + | 3 | 2.4 | + |
| • Benthic invertebrates (DKI) | n.a. | + | 0.68 | 0.68 | ÷ |
| • Oxygen concentrations | n.a. | n.i. | | | n.i. |
| **Final classification** | **N.A.** | **EPA** | **EPA** | | |

### 3.3 Kattegat, >20 m (205)

The COMP1 assessment is based on the assessment unit "Kattegat Coastal". The assessment unit used in COMP 2 is "Kattegat southern coastal waters".

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | + | + | | | n.i. |
| • Phosphorus concentrations | | + | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | + | + | 1.6 | 2 | + |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | + | n.i. | 9 | | n.i. |
| • Benthic invertebrates (DKI) | | n.i. | 0.68 | 0.63 | + |
| • Oxygen concentrations | + | n.i. | | | n.i. |
| **Final classification** | **EPA** | **EPA** | **EPA** | | |

### 3.4 Kattegat, <20 (200)

The COMP1 assessment is based on the assessment unit "Kattegat Coastal". The assessment unit used in COMP 2 is "Kattegat southern coastal waters". In the COMP3 assessment the final classification is "EPA". Since just two parameters are assessed and these are classified as "÷", supporting parameters from physical/chemical characteristics within the assessment unit or biological parameters from adjacent assessment units are used (Naturstyrelsen, 2014)

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | + | + | | | n.i. |
| • Phosphorus concentrations | | + | | | n.i |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | + | + | 1.6 | 1.1 | ÷ |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | + | n.i. | 9 | | n.i. |
| • Benthic invertebrates (DKI) | n.i. | n.i. | 0.68 | 0.82 | ÷ |
| • Oxygen concentrations | + | n.i. | | | |
| **Final classification** | **EPA** | **EPA** | **EPA** | | |

### 3.5 Isefjord, ydre (24)

In COMP1 Isefjord is not assessed. In COMP2 just a single station in Isefjorden exists. Therefore the data for COMP 2 is the same for the assessment in the inner and outer part of Isefjorden.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | n.a. | n.i. | | | n.i. |
| • Phosphorus concentrations | | n.i. | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | n.a. | n.i. | 2.1 | 2.6 | + |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | n.a. | ÷ | 5.5 | 5.6 | ÷ |
| • Benthic invertebrates (DKI) | n.a. | n.i. | 0.68 | 0.52 | + |
| • Biomass benthic invertebrate fauna | n.a. | + | | | n.i. |
| • Oxygen concentrations | n.a. | n.i. | | | n.i. |
| **Final classification** | **N.A.** | **EPA** | **EPA** | | |

### 3.6 Sejrø Bugt (28)

The assessment area is not assessed in COMP1 or COMP2.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | n.a. | n.a. | | | |
| • Phosphorus concentrations | | n.a. | | | |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | n.a. | n.a. | 1.6 | 1.4 | ÷ |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | n.a. | n.a. | 9 | 5.9 | + |
| • Benthic invertebrates (DKI) | n.a. | n.a. | 0.68 | 0.80 | ÷ |
| • Oxygen concentrations | n.a. | n.a. | | | |
| **Final classification** | **N.A.** | **N.A.** | **EPA** | | |

### 3.7 Randers Fjord, Grund Fjord (135)

In the COMP2 a single station in Randers fjord exists. The data is therefore the same for the three COMP3 assessment units in Randers Fjord. In COMP2, it is not the annual mean but the summer mean of TN, TP and chlorophyll *a* that are used in the assessment. No information existed for Randers Inner Fjord, and therefore, data from the Marine Strategy Framework Directive (Naturstyrelsen 2012) was used. Naturstyrelsen has classified the area as having a moderate ecological potential (cf. MiljøGIS 2014).

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | n.a. | + | 42.89 | 128 | + |
| • Phosphorus concentrations | | + | 1.29 | 2.9 | + |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | n.a. | + | 9 | 13 | + |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | n.a. | + | | | n.i. |
| • Macroalgae species richness o.p/i.p. | n.a. | ÷/+ | 15 | 3 | + |
| • Benthic invertebrates (DKI) | n.a. | n.i. | | | n.i. |
| • Zoobenthos richness | n.a. | + | 16 | 24 | ÷ |
| • Oxygen concentrations | n.a. | n.i. | | | n.i. |
| **Final classification** | **N.A.** | **EPA** | **EPA** | | |

### 3.8 Randers Fjord, mellem del (136)

In the COMP2, a single station in Randers Fjord exists. The data is therefore the same for the three assessment units in Randers fjord in COMP3. In COMP2, it is not the annual mean but the summer mean of TN, TP and chlorophyll *a* that are used in the assessment.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | n.a. | + | | | n.i. |
| • Phosphorus concentrations | | + | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | n.a. | + | 7 | 8.6 | + |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | n.a. | + | n.r. | | n.r. |
| • Macroalgae species richness o.p/i.p. | n.a. | ÷/+ | | | n.i. |
| • Benthic invertebrates (DKI) | n.a. | | 0.68 | 0.64 | + |
| • Zoobenthos richness | n.a. | + | | | n.i. |
| • Oxygen concentrations | n.a. | | | | n.i. |
| **Final classification** | **N.A.** | **EPA** | **EPA** | | |

### 3.9 Randers Fjord, ydre del (137)

In the COMP2, a single station in Randers fjord exists. The data is therefore the same for the three assessment units in Randers fjord in COMP3. In COMP2, it is not the annual mean but the summer mean of TN, TP and chlorophyll *a* that are used for the assessment.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | n.a. | + | | | n.i. |
| • Phosphorus concentrations | | + | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | n.a. | + | 3.6 | 4.9 | + |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | n.a. | + | n.r. | 0.5 | + |
| • Macroalgae species richness o.p/i.p. | n.a. | ÷/+ | | | n.i. |
| • Benthic invertebrates (DKI) | n.a. | n.i. | 0.68 | 0.64 | + |
| • Zoobenthos richness | n.a. | + | | | n.i. |
| • Oxygen concentrations | n.a. | n.i. | | | n.i. |
| **Final classification** | **N.A.** | **EPA** | **EPA** | | |

### 3.10 Hevring Bugt (138)

The water body Hevring Bugt has not been assessed in COMP1. The COMP2 assessment unit used in this matrix is "South-western coastal waters", no. 16.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | n.a. | + | | | n.i. |
| • Phosphorus concentrations | | + | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | n.a. | + | 1.6 | 1.5 | ÷ |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | n.a. | n.i. | 9 | 4.7 | + |
| • Benthic invertebrates (DKI) | n.a. | + | 0.68 | 0.61 | + |
| • Oxygen concentrations | n.a. | n.i. | | | n.i. |
| **Final classification** | **N.A.** | **EPA** | **EPA** | | |

### 3.11 Farvandet ved Anholt (139)

The assessment unit "Farvandet ved Anholt" was not assessed in COMP1. The COMP2 assessment unit is no. 14 "Kattegat central open waters".

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | n.a. | + | | | n.i. |
| • Phosphorus concentrations | | ÷ | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | n.a. | + | 1.6 | 1.8 | + |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | n.a. | n.i. | 9 | | n.i. |
| • Benthic invertebrates (DKI) | n.a. | ÷ | 0.68 | 0.75 | ÷ |
| • Oxygen concentrations | n.a. | n.i. | | | n.i. |
| **Final classification** | **N.A.** | **EPA** | **EPA** | | |

### 3.12 Farvandet Djursland Øst (140)

The assessment for COMP1 originates from the "Kattegat Coastal areas". The COMP2 assessment unit used in this matrix is no. 16 "South western coastal waters".

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | + | + | | | n.i. |
| • Phosphorus concentrations | | + | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | + | + | 1.9 | 2 | + |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | + | n.i. | 9 | | n.i. |
| • Benthic invertebrates (DKI) | n.i. | + | 0.68 | | n.i. |
| • Oxygen concentrations | + | n.i. | | | n.i. |
| **Final classification** | **EPA** | **EPA** | **EPA** | | |

### 3.13 Farvandet ved Læsø (154)

The water body "Farvandet ved Læsø", was not assessed in COMP1. The COMP2 assessment unit is no. 14 "Kattegat central open water".

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | n.a. | + | | | n.i. |
| • Phosphorus concentrations | | ÷ | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | n.a. | + | 1.6 | 0.5 | ÷ |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | n.a. | n.i. | 9 | 5.6 | + |
| • Benthic invertebrates (DKI) | n.a. | ÷ | 0.68 | 0.67 | + |
| • Oxygen concentrations | n.a. | n.i. | | | n.i. |
| **Final classification** | **N.A.** | **EPA** | **EPA** | | |

### 3.14 Kattegat, Aalborg Bugt (222)

The data for the COMP1 column originates from the assessment unit "Kattegat coastal areas". The data for the COMP2 column originates from the assessment unit "Kattegat, western coastal waters". In COMP3, the coastal zone of Kattegat is separated in two areas, here the assessment unit "Aalborg Bugt" no. 222 is used.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | + | + | | | n.i. |
| • Phosphorus concentrations | | ÷ | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | + | + | 1.6 | 1.1 | ÷ |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | + | n.i. | 9 | 2.4 | + |
| • Benthic invertebrates (DKI) | n.i. | n.i. | 0.68 | 0.63 | + |
| • Oxygen concentrations | + | n.i. | | | n.i. |
| **Final classification** | **EPA** | **EPA** | **EPA** | | |

### 3.15 Kattegat, Ålbæk Bugt (225)

The data for the COMP1 column originates from the assessment unit "Kattegat coastal areas". The data for the COMP2 column originates from the assessment unit "Kattegat, western coastal waters". In COMP3, the coastal zone of Kattegat is separated in two areas, here the assessment unit "Ålbæk Bugt" no. 225 is used.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | + | + | | | n.i. |
| • Phosphorus concentrations | | ÷ | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | + | + | 1.9 | 1.9 | ÷ |
| | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | + | n.i. | 9 | 4.6 | + |
| • Benthic invertebrates (DKI) | n.i. | n.i. | 0.68 | 0.62 | + |
| • Oxygen concentrations | + | n.i. | | | n.i. |
| **Final classification** | **EPA** | **EPA** | | | |

### 3.16 Vestlige Limfjord (156)

The area was not assessed in COMP1. For this comparison the assessment unit "Limfjorden central parts" no. 10 from COMP2 has been used.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | n.a. | n.i. | | | n.i. |
| • Phosphorus concentrations | | n.i. | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | n.a. | n.i. | 3.6 | 8.4 | + |
| C3+C4: Indirect/ other effects | | | | | |
| • Secchi depth limit | n.a. | + | | | n.i. |
| • Eelgrass (*Zostera marina*) depth limit | n.a. | + | 4.1 | 2.7 | + |
| • Benthic invertebrates (DKI) | n.a. | + | 0.68 | 0.49 | + |
| • Oxygen concentrations | n.a. | n.i. | | | n.i. |
| **Final classification** | **N.A.** | **EPA** | **EPA** | | |

### 3.17 Centrale og sydlige Limfjord (157)

This assessment unit was not included in COMP1. The COMP2 assessment is based on the assessment unit "Limfjorden southern parts" no. 11.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | n.a. | + | | | n.i. |
| • Phosphorus concentrations | | n.i. | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | n.a. | n.i. | 6 | 11.1 | + |
| C3+C4: Indirect/ other effects | | | | | |
| • Secchi depth limit | n.a. | + | | | n.i. |
| • Eelgrass (*Zostera marina*) depth limit | n.a. | + | 4.1 | 1.8 | + |
| • Benthic invertebrates (DKI) | n.a. | + | 0.68 | 0.58 | + |
| • Oxygen concentrations | n.a. | n.i. | | | n.i. |
| **Final classification** | **N.A.** | **EPA** | **EPA** | | |

### 3.18 Hjarbæk Fjord (158)

The area was not assessed in COMP1. The COMP2 assessment is based on the assessment unit "Limfjorden southern parts" no. 11.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | n.a. | + | | | n.i. |
| • Phosphorus concentrations | | n.i. | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | n.a. | n.i. | 9 | 44.5 | + |
| C3+C4: Indirect/ other effects | | | | | |
| • Secchi depth | n.a. | + | | | n.i. |
| • Eelgrass (*Zostera marina*) depth limit | n.a. | + | 4.1 | 0.2 | + |
| • Benthic invertebrates (DKI) | n.a. | + | 0.68 | | n.i. |
| • Oxygen concentrations | n.a. | n.i. | | | n.i. |
| **Final classification** | **N.A.** | **EPA** | **EPA** | | |

### 3.19 Mariager Inderfjord (159)

The COMP 2 assessment unit is no. 19. "Mariager fjord". There is not distinguished between outer and inner fjord, so the assessment is the same as in Mariager inner fjord COMP2.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | n.a. | + | | | n.i. |
| • Phosphorus concentrations | | n.i. | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | n.a. | n.i. | 3.6 | | n.i. |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | n.a. | n.i. | 3.6 | 0.8 | + |
| • Benthic invertebrates (DKI) | n.a. | + | 0.68 | 0.57 | + |
| • Oxygen concentrations | n.a. | n.i. | | | n.i. |
| **Final classification** | **N.A.** | **EPA** | **EPA** | | |

### 3.20 Mariager Yderjord (160)

The COMP 2 assessment unit is no. 19. "Mariager fjord". There is not distinguished between outer and inner fjord, so the assessment is the same as in Mariager outer fjord

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | n.a. | + | | | n.i. |
| • Phosphorus concentrations | | n.i. | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | n.a. | n.i. | 6 | 19.5 | + |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | n.a. | n.i. | 3.1 | 0.8 | + |
| • Benthic invertebrates (DKI) | n.a. | + | 0.68 | 0.47 | + |
| • Oxygen concentrations | n.a. | n.i. | | | n.i. |
| **Final classification** | **N.A.** | **EPA** | **EPA** | | |

### 3.22 Isefjord, indre (165)

The waterbody "Isefjord indre" was not assessed in COMP1. In COMP2 just a single station in Isefjorden exists. Therefore the data for COMP 2 is similar in the inner and outer parts.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | n.a. | n.i. | | | n.i. |
| • Phosphorus concentrations | | n.i. | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | n.a. | n.i. | 2.1 | 5.5 | + |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | n.a. | ÷ | 5.1 | 3.6 | + |
| • Benthic invertebrates (DKI) | n.a. | n.i. | 0.68 | | n.i. |
| • Oxygen concentrations | n.a. | + | | | n.i. |
| **Final classification** | **N.A.** | **EPA** | **EPA** | | |

**4. The Sound, offshore parts**

In COMP1 there is only a single station in the sound. Data from this station is therefore used as the COMP1 assessment for all the COMP3 assessment units in The Sound. In COMP 2, The Sound was not assessed. The COMP3 assessment is based on Andersen *et al.* (2012).

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | + | n.a. | 12.26 | 18.39 | + |
| • Phosphorus concentrations | | n.a. | 0.39 | 0.59 | + |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | + | n.a. | 2.55 | 3.70 | + |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | + | n.a. | | | n.i. |
| • Benthic invertebrates (DKI) | n.i. | n.a. | | | n.i. |
| • Oxygen concentrations | + | n.a. | | | n.i. |
| **Final classification** | **EPA** | **N.A.** | **EPA** | | |

**4.1 Øresundstragten (4)**

In the common procedure 1, there is only a single station in the sound. Data from this station is therefore used as the COMP1 assessment for all the COMP3 assessment units in The Sound. In COMP 2, The Sound was not assessed.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | + | n.a. | | | n.i. |
| • Phosphorus concentrations | | n.a. | | | n.i |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | + | n.a. | 1.6 | 1.1 | ÷ |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | + | n.a. | 9 | | n.i. |
| • Benthic invertebrates (DKI) | n.i. | n.a. | 0.68 | 0.82 | ÷ |
| • Oxygen concentrations | + | n.a. | | | |
| **Final classification** | **EPA** | **N.A.** | **EPA** | | |

**4.2 Nordlige Øresund (6)**

In COMP1 there is only a single station in the sound. Data from this station is therefore used as the COMP1 assessment for all the COMP3 assessment units in The Sound. In COMP 2, the Sound was not assessed.

| Assessment criteria | COMP1 | COMP2 | COMP3 | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | T | M | A |
| • Nitrogen concentrations | + | n.a. | | | n.i. |
| • Phosphorus concentrations | | n.a. | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | + | n.a. | 1.7 | 1.5 | ÷ |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | + | n.a. | 9 | 5.8 | + |
| • Benthic invertebrates (DKI) | n.i. | n.a. | 0.68 | | n.i. |
| • Oxygen concentrations | + | n.a. | | | n.i. |
| **Final classification** | **EPA** | **N.A.** | **EPA** | | |

**4.3 Københavns Havn (9)**

In COMP1 there is only a single station in the sound. Data from this station is therefore used as the COMP1 assessment for all the COMP3 assessment units in The Sound. In COMP 2, the Sound was not assessed. The COMP3 is highly modified and classified as having moderate ecological potential (cf. MiljøGIS 2014)

| **Assessment criteria** | **COMP1** | **COMP2** | **COMP3** | | |
|---|---|---|---|---|---|
| C 1: Nutrient levels | | | **T** | **M** | **A** |
| • Nitrogen concentrations | + | n.a. | | | n.i. |
| • Phosphorus concentrations | | n.a. | | | n.i. |
| C2: Direct effects | | | | | |
| • Phytoplankton – chlorophyll *a* | + | n.a. | 1.7 | | n.i. |
| C3+C4: Indirect/ other effects | | | | | |
| • Eelgrass (*Zostera marina*) depth limit | + | n.a. | 8.1 | | n.i. |
| • Benthic invertebrates (DKI) | n.i. | n.a. | 0.68 | | n.i. |
| • Oxygen concentrations | + | n.a. | | | n.i. |
| **Final classification** | **EPA** | **N.A.** | **N.A.** | | |

# Appendix C. EO-based mapping of Problem and Non-Problem Areas in the North Sea and Skagerrak

**Aim**

As described in 2.4 over satellite measurements of chlorophyll *a* concentrations were used to determine the extent of the area of the North Sea and Skagerrak which can be classified as Non-Problem Area. This is done by finding the area where average chlorophyll *a* concentration over the period 2002-2012 did not exceed 3.5 $\mu g\ l^{-1}$.

Before using the satellite data, they were first corrected by comparison with measurements of chlorophyll *a* in water samples.

**In-situ measurements for comparison with satellite data**

Satellite observations were compared with *in-situ* measurements of chlorophyll *a* concentrations. This was done by taking annual averages of chlorophyll *a* values from the MERIS L3 product processed by the C2R-CC algorithm (Case 2 Regional - CoastColour) on the Calvalus portal (http://www.coastcolour.org/ccprocessing/calvalus.jsp) extracted at positions corresponding to sampling stations in the Danish marine monitoring program.

Using measurements from the monitoring data, the following criteria were applied to select *in-situ* observations for comparison with satellite measurements:

a. Data used is from monitoring stations located on the West coast of Jutland, since we are concerned with estimating chlorophyll *a* concentration in the North Sea.

b. Stations should be located at least 5 km from the coastline, to avoid interference from land signals (adjacency effects).

c. We are comparing annual averages from MERIS with annual averages from in-situ data. In order to calculate an annual average for a station, there should be an observation in at least 10 out of 12 months of the year in question.

d. The MERIS signal is related to surface concentrations of chlorophyll *a* , TSM and CDOM (optical properties). Using Secchi disc depth as a proxy for this surface layer, observations from depths greater than the Secchi disc depth were discarded. In practice, this meant that only observations from 1 m depth were used, with the exception of 1 observation from station RKB44 sampled at a depth of 2.9 m.

Applying these criteria, it was possible to calculate 18 annual average chlorophyll *a* values for 4 monitoring stations. The locations of these 4 monitoring stations are shown in Figure C.1.

The variation in annual averages from 2002 to 2012 for the satellite observations is shown in Figures C.4 and C.5.

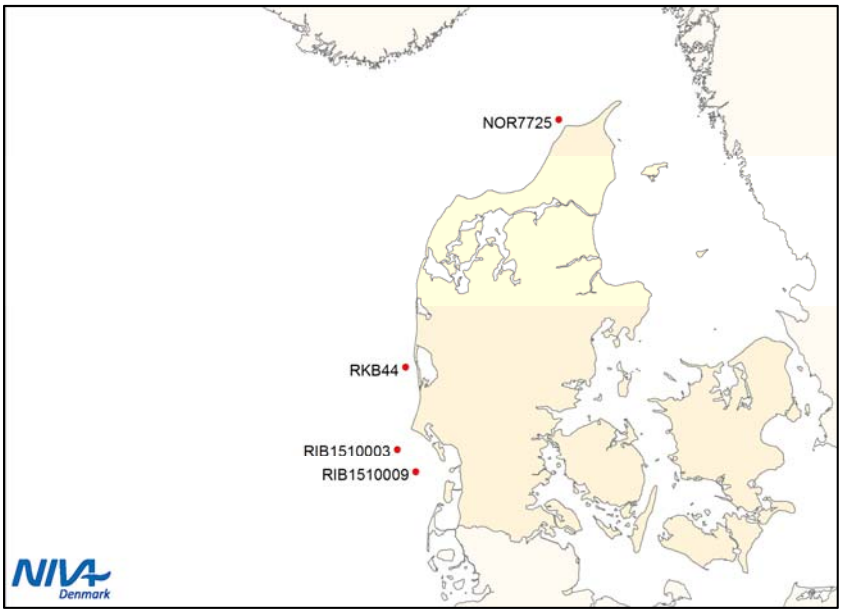


**Figure C.1:** *Location of monitoring stations used for comparison of satellite with in-situ Chl a observations.*

**Comparison of Satellite and in-situ annual averages**

In-situ annual averages were regressed on the MERIS L3 CC annual averages. The regression was made using log-transformed chlorophyll *a* concentration (Figure C.2)

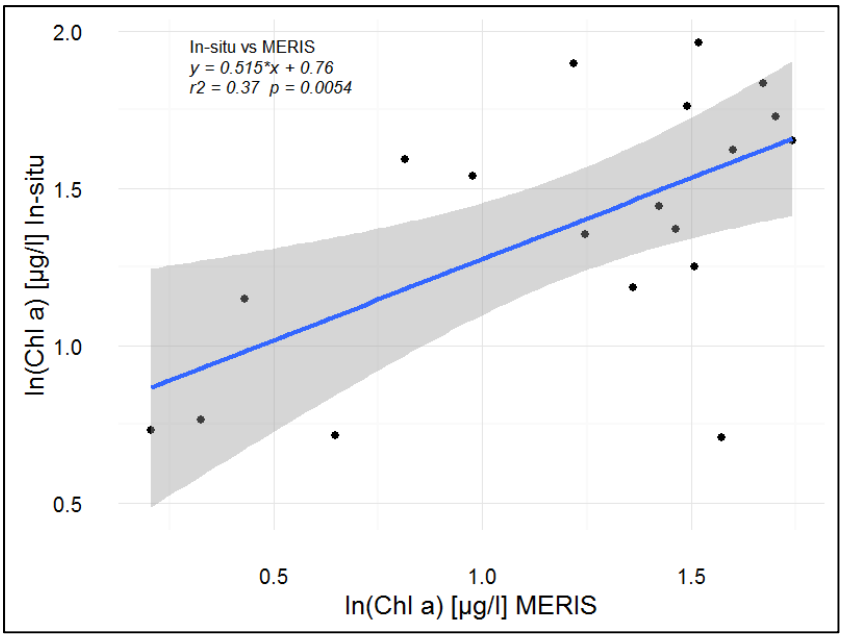


**Figure C.2:** *Regression of log-transformed annual averages of in-situ Chl a on MERIS L3 CC Chl*

The relationship found between *in-situ* and satellite measurements of chlorophyll *a* gave the following function which was applied to the uncorrected satellite measurements.

$$Chl_{corrected} = 2.14 \cdot Chl_{MERIS}^{0.515} \qquad (1)$$

Figure C3 shows the spatial variation of within the Danish parts of the North Sea of the average MERIS chlorophyll *a* concentration for 2002-2012 both before and after the applied correction. With the corrected averages, the boundary of the region where chlorophyll *a* concentration does not exceed 3.5 µg $l^{-1}$ is then used to identify the boundary between problem and non-problem areas.

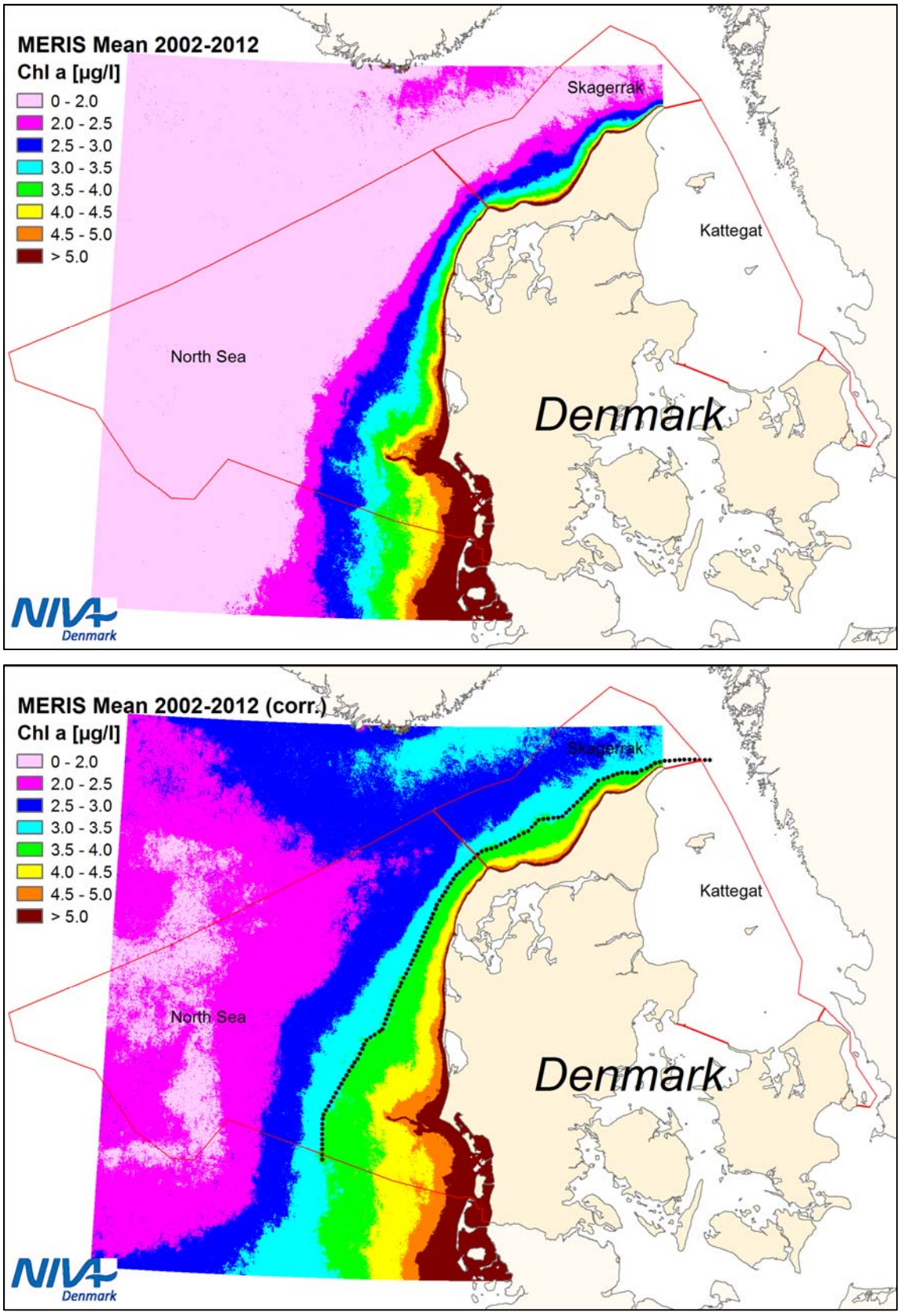


**Figure C.3:** *MERIS Chlorophyll a Concentrations, averaged for the period 2002-2012, Top: uncorrected, Bottom: corrected using the function Chl_corr = 2.14*Chl_MERIS^0.515. The black dotted line in the bottom figure indicates the boundary of the region where Chlorophylla concentration does not exceed 3.5 µg l-1.*

**Annual averages**

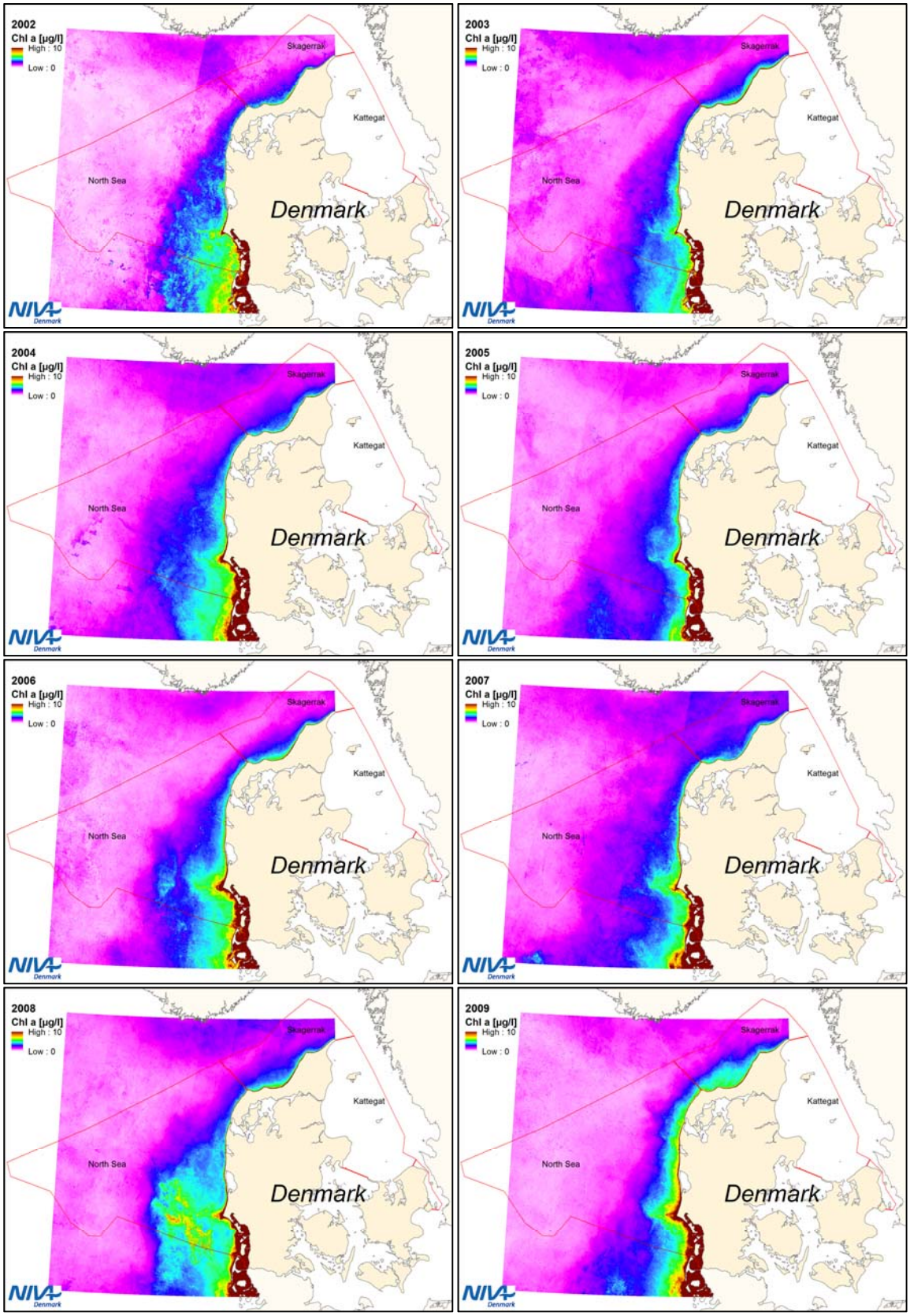


**Figure C.4:** *MERIS Average Chlorophylla Concentrations 2002-2009.*

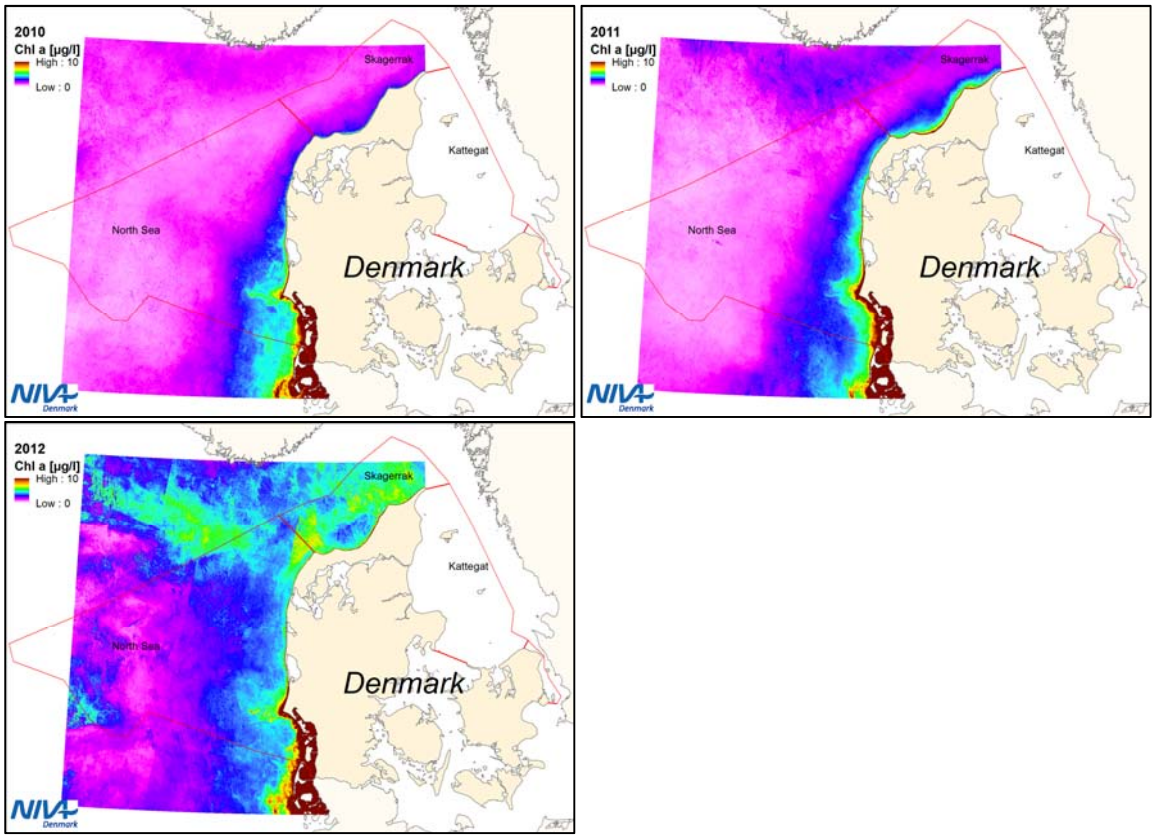


**Figure C.5:** *MERIS Average Chlorophyll a Concentrations 2010-2012.*

# Appendix D. Nutrient concentrations

In order to support the analysis to determine the location of the boundary between Problem and Non-Problem using satellite chlorophyll *a* measurements (Appendix C), work was also done to examine the concentrations of nutrients in the North Sea, Skagerrak and Kattegat, focusing on dissolved inorganic nitrogen (DIN).

**Method and results**

Data on DIN concentrations was retrieved from the ICES Oceanography data portal[1]. Data for the period 2006-2013 for winter months only (December, January and February) were selected. The average surface winter DIN concentration was calculated at 837 sampling stations. Stations located within fjords were not included in the analysis.

The Kernel interpolation function in ArcGis was used to interpolate concentrations between data points. Using this function, interpolation is made around land barriers and not across them. The resulting spatial distribution of surface DIN concentration is shown in **Figure D.4.**

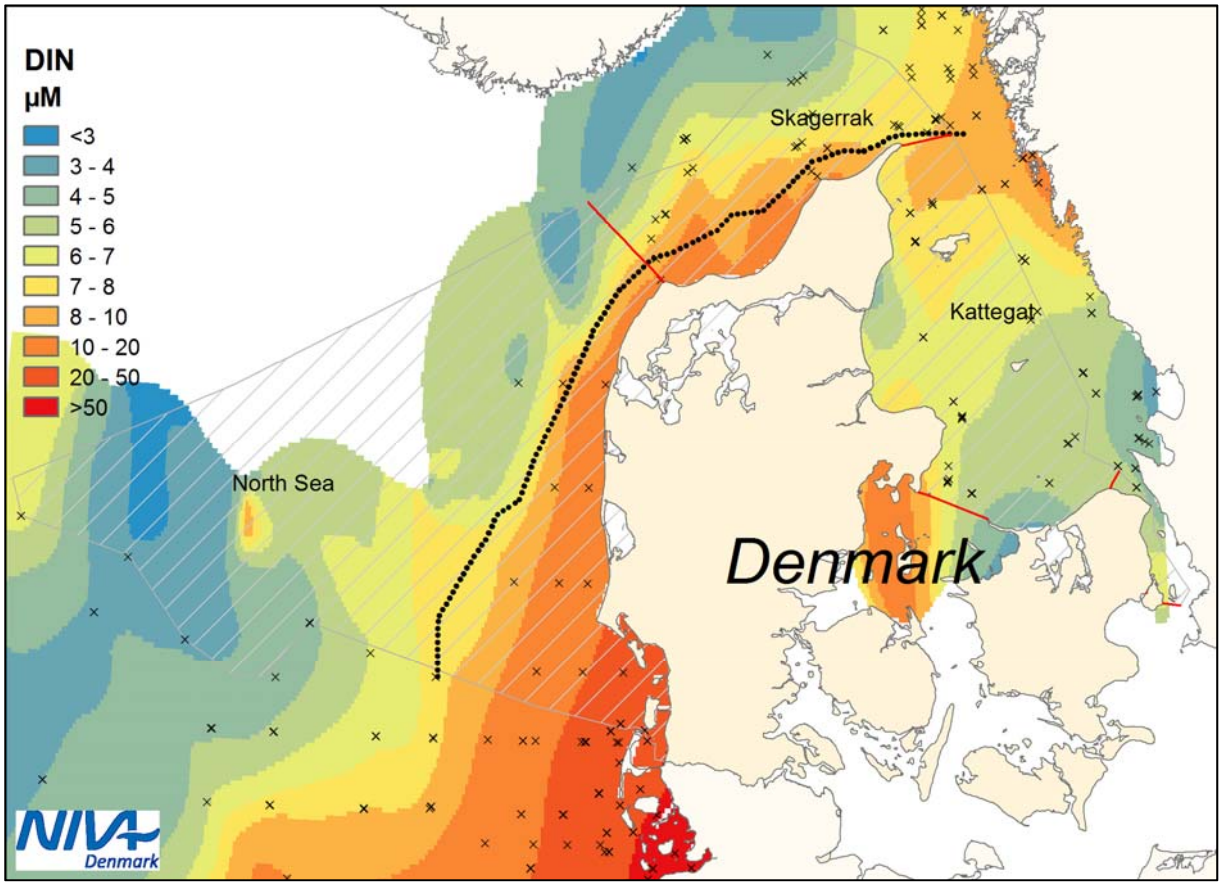


**Figure D.4:** *Interpolated average surface (0-5m) DIN concentrations [µmol l$^{-1}$] for winter (Dec, Jan, Feb) 2006-2013, showing locations of sampling stations* (x). *The heavy dotted black line indicates the boundary for Non-Problem and Problem Areas, as determined by analysis of EO chlorophyll a measurements.*

**Conclusion**

There appears to be a good agreement between the distribution of DIN and boundary between Problem and Non-Problem Areas as determined by analysis of satellite measurements.

[1] ICES Dataset on Ocean Hydrography. The International Council for the Exploration of the Sea, Copenhagen. 2014 http://www.ices.dk/marine-data/data-portals/Pages/ocean.aspx

## NIVA Denmark is the name, water is our game

NIVA Denmark Water Research is a regional office of the Norwegian Institute for Water Research (NIVA) and has just recently been established to resolve environmental issues concerning the freshwater and marine systems that relate to Denmark.

NIVA Denmark has primary focus on research-based implementation of a number of EU's directives *inter alia* the Water Framework Directive and the Marine Strategy Framework Directive together with international conventions (HELCOM, OSPAR, BDC). We occasionally provide consultancy to authorities and small and medium-sized companies.

NIVA Denmark is a a place for practice, observation, testing and synthesis. Key research and test areas include eutrophication, hazardous substances, biodiversity, and ecosystem health as well as the implications of multiple human activities in marine waters and in streams, rivers and lakes. We develop indicators, monitoring methods and tools to assess the state of an ecosystem in order to carry out analyses and contribute to evidence based and sustainable solutions to the challenges we and the environment face.

NIVA Denmark, as a regional office to NIVA has thus the backing of more than 200 dedicated researchers and experts.

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