Nutrients and Eutrophication in Danish Marine Waters

Gunni Ærtebjerg, Jesper H. Andersen & Ole S. Hansen
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A Challenge for Science and Management

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A Challenge for Science and Management

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See data sheet on page 126 for details.

Preface

The objective of this assessment report is to describe and document the effects and degree of nutrient enrichment and eutrophication status in all Danish marine waters by addressing the following questions:

- What is nutrient enrichment and eutrophication?
- What are the causes and actual effects?
- Temporal trends: what is natural variation and what is due to human activities?
- What has been done so far in Denmark to reduce eutrophication in Danish marine waters?
- How can the findings be used and transformed into an informed management strategy?

The assessment is written in order to fulfil the Danish obligations in relation to the OSPAR Common Procedure. However, the assessment covers not only the OSPAR areas: the North Sea, Skagerrak and Kattegat, but all Danish marine waters, including the transitional waters (the Sound and Belt Sea) between the Kattegat and the Baltic Sea, as well as the western parts of the Baltic Sea. This is because:

1) the outflow from the Baltic Sea has a large influence on the Kattegat – Belt Sea ecosystems, and
2) the eutrophic state and development of the Kattegat and Belt Sea runs in parallel and is interrelated.

The assessment focuses on factors and parameters that cause, control or respond to eutrophication. Special attention is put on ecological status and temporal trends. Seasonal variations and more system-orientated descriptions of the fluxes and turnover of nutrients have been mitigated. The assessment is not a comprehensive assessment of the health of the marine environment in Denmark or a textbook in marine ecology. The assessment is more or less an extended summary of more than 13 years of monitoring and subsequent production of different assessments reports on the state of the marine environment within the framework of the Danish National Monitoring and Assessment Programme (1988-2003).

Chapter 1

presents background information, definitions and descriptions of the cause-effect relationships as well as a brief reference to the Danish National Monitoring and Assessment Programme, which is the major source of data for this assessment.

Chapter 2

includes the technical and scientific assessment of the eutrophication status of the Danish marine waters and is structured according to the principles and guidelines adopted by OSPAR. Focus is on the state of the marine waters compared to the ecological quality objectives. The temporal trend is also addressed, both with respect to the observed data and indices corrected for variations in climate (run-off, temperature, insolation etc.).

Chapter 3
describes existing national strategies and measures implemented to abate nutrient enrichment and eutrophication.

Chapter 4
summarises the findings of sections 1, 2 and 3, assesses the overall eutrophication status of the Danish marine waters and discusses possible future actions.

The assessment includes a glossary and a list of acronyms in order to reach readers without a professional background in marine ecology or oceanography.

Suggestions for further reading as well as links to relevant web-sites on eutrophication and the health of the marine environment can be found at the end of the report.

A map of Danish marine waters mentioned in the assessment can be found at page 122.

Contents

All people in Denmark have less than 55 km to the sea.

Photo: CDanmark

Background, definition, causes and effects

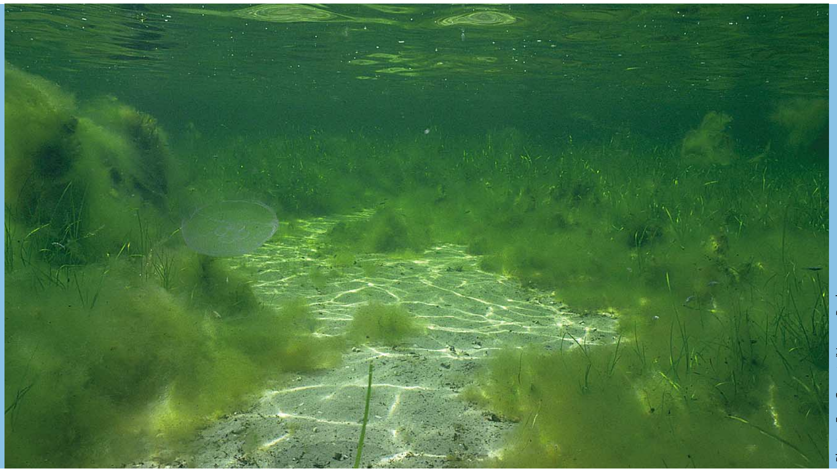
1

For more than 30 years, nutrient enrichment has been one of the major threats to the health of marine ecosystems and resources (Ryther & Dunstan 1971, Danish EPA 1984, Nixon 1995, Elmgren 2001). When nutrients are discharged or transported to the sea their inherent characteristics as plant nutrients affect and modify the structure and function of the ecosystem. The response to nutrient enrichment is called eutrophication.

Photo: NERI/Peter Bondo Christensen

Photo: NERI/Jan Damgaard

1.1 Definition



Eelgrass covered with filamentous green algae, a sign of nutrient enrichment.

Photo: Fyn County/Nanna Rask

There is no single and globally accepted definition of marine eutrophication. The word "eutrophication" has its roots in Greek where "eu" means "well" and "trope" means "nourishment".

Nixon (1995) defines marine eutrophication as "an increase in the supply of organic matter". The supply is not restricted to pelagic primary production, but also includes bacterial production, primary production of submerged aquatic vegetation, inputs of organic matter from land via rivers and point sources as well as the net advection from adjacent waters. The advantage of this definition is that it is short, simple and does not confuse causes and effects. The limitations of the definition are 2 fold. It does not take structural or qualitative changes due to nutrient enrichment into account, and it is difficult to make fully operational since the majority of existing marine monitoring programmes seldom include all the variables needed to estimate the total supply of organic matter to a given body of water.

Gray (1992) focuses on the direct effects of nutrient enrichment on productivity, the secondary effects where the produced organic material is not consumed by grazers, and the extreme and ultimate effects, which includes the growth of macroalgae, oxygen depletion and mortality of species. Richardson & Jørgensen (1996) focus both on the process, the associated effects of nutrient enrichment and natural versus cultural caused eutrophication. Prudently, Richardson & Jørgensen point out that when we speak of eutrophication it is cultural eutrophication or that, which is caused by anthropogenic activities, which is of interest.

The definition of eutrophication by OSPAR is: "Eutrophication means the enrichment of water by nutrients causing an accelerated growth of algae and higher form of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned, and therefore refers to the undesirable effects resulting from anthropogenic enrichment by nutrients" (OSPAR 1998). A number of EU Directives also defines eutrophication. In the Urban Wastewater Treatment Directive eutrophication means: "The enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned" (EU 1991). The Nitrates Directives definition is almost identical, except that it is restricted to eutrophication from agriculture (EU 1991).

The differences between the various definitions leave the definition open for interpretation. However, this is not critical, as long as there is a common understanding of the effects and agreement upon the acceptable levels of deviations from a healthy marine environment. Eutrophication should be seen both as a process and as a continuum, since the background values may vary from area to area due to natural causes. For example, the productivity in the open Baltic Sea is relatively low compared to the southern and eastern parts of the North Sea. Therefore, when speaking of eutrophication, both the initial process and direct effects (sensu Nixon) and the derived primary and secondary effects should be taken into account, cf. box 1.

BOX 1 Definition of eutrophication

Eutrophication is the enhanced inputs of nutrients and organic matter leading to changes in primary production, biological structure and turnover and resulting in a higher trophic state. The causative factors are: elevated inputs of nutrients from land, atmosphere or adjacent seas, elevated winter DIN- and DIP concentrations, and increased winter N/P-ratios compared to the Redfield Ratio. In the case of marine waters, the primary or direct effects include: increased primary production, elevated levels of biomass and chlorophyll *a* concentrations, shift in species composition of phytoplankton, and shift from long lived macroalgae to short lived nuisance species. The secondary or indirect effects include increased or lowered oxygen concentrations, and changes in species composition and biomass of zoobenthos. Low oxygen concentrations in the bottom water (oxygen depletion, hypoxia) can further affect the fish, benthic invertebrates and plants. Total oxygen depletion (anoxia) can result in the release of hydrogen sulphide from the sediment, causing extensive death of organisms associated with the sea floor. As only a few species can survive these extreme conditions, and as it takes time for plants and animals to recolonise damaged areas, eutrophication can result in impoverished biological communities and impaired conditions.

1.2 Causes

Liquid manure spread on field in February.

Photo: Biofoto/Bent Lauge Madsen

The essential nutrients causing eutrophication are nitrogen in the form of nitrate or ammonium and phosphorus in the form of phosphate. In addition, inputs of bioavailable organic phosphorus and nitrogen can cause eutrophication, as bacteria can mineralise the organic phosphorus to phosphate and the organic nitrogen to ammonium, which is further oxidised to nitrite and nitrate.

Marine waters receive dissolved and particulate nutrients and organic matter from land via rivers and direct discharges, from the atmosphere and from adjacent seas (see Figure 1.1). In Denmark the most important direct sources are:

1) agriculture,
2) discharges from urban wastewater treatment plants, and
3) separate discharges from industries,

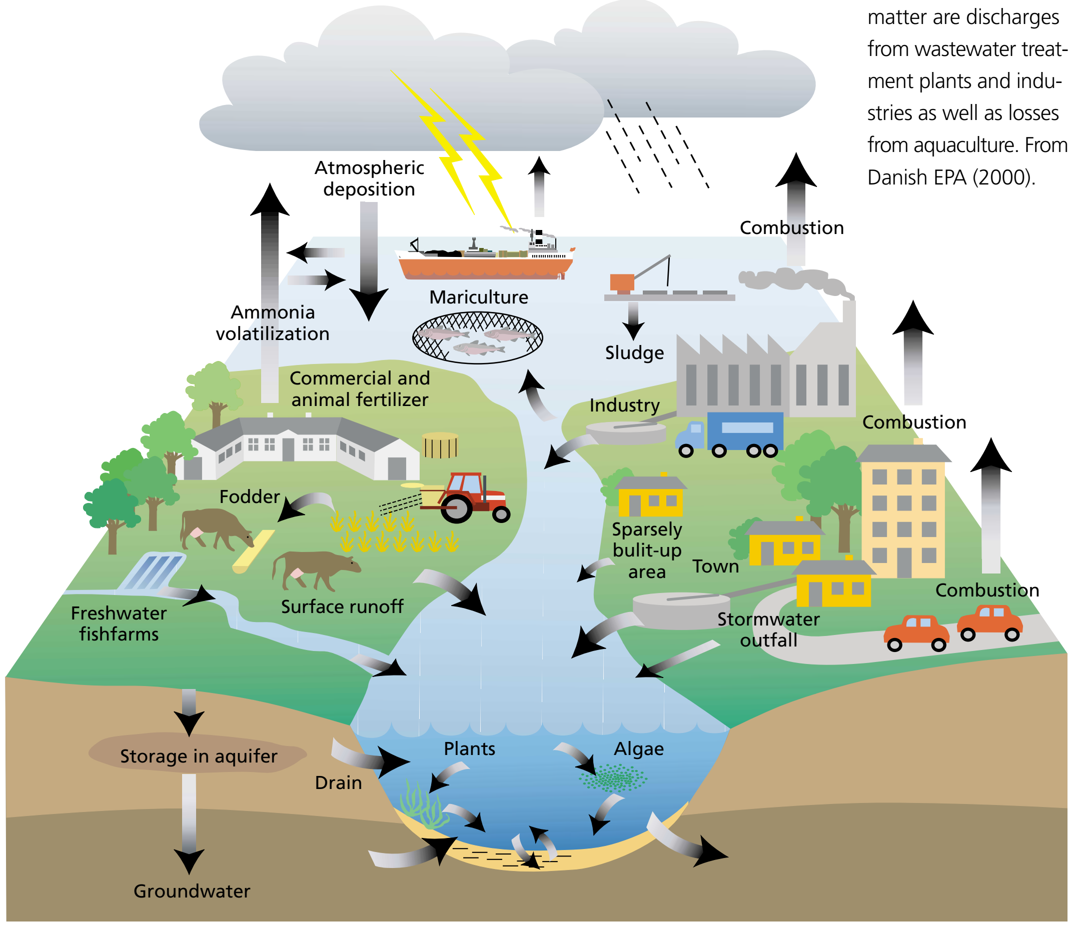
the first being the most important diffuse source. Discharges from point sources, losses from agriculture and atmospheric deposition are monitored as an integrated part of the National Aquatic Monitoring and Assessment Programme and reported annually (Conley et al. 2002).

The inputs from adjacent seas are also monitored within the national monitoring programme. There are three major avenues of advective transport of nutrients that must also be considered:

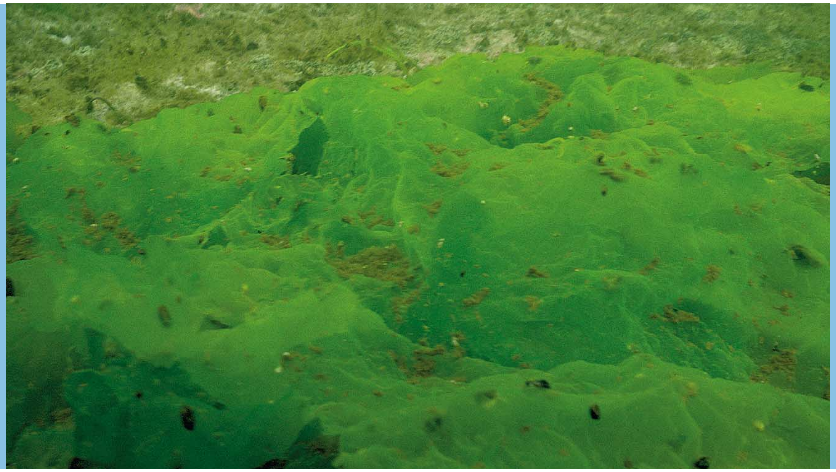
1) Inputs from the German Bight to the waters along the west coast of Jutland.
2) Inputs of inorganic nutrients from Skagerrak to the Kattegat bottom water.
3) Inputs of surface waters from the Baltic Sea to the Danish Straits and Kattegat.

All three sources have influence on the marine environment by supplying additional nutrients. The waters from the German Bight and the Baltic Sea have already received high inputs of nutrients. The input from the Baltic Sea differs from the two firsts because it actually dilutes bioavailable nitrogen concentrations in the Danish Straits and the Kattegat. The median winter surface concentrations of nitrate (1986–1993) in the water from the Baltic is 4.6 µM compared to the median concentrations in the waters in the Danish Straits and Kattegat, which are 7.3 (6.5–8.8) µM and 7.4 (6.0–9.7) µM, respectively.

Figure 1.1
The nitrogen cycle in the aquatic environment. All relevant sources are shown. The major difference between the nitrogen and phosphorus cycles is that phosphorus is not emitted to the air and that there consequently is no anthropogenic deposition. The main anthropogenic sources of organic matter are discharges from wastewater treatment plants and industries as well as losses from aquaculture. From Danish EPA (2000).



1.3 Effects and consequences



Growth of the nuisance algae *Ulva* sp. is stimulated by high nutrient concentrations.

Overloading with nitrogen, phosphorus and organic matter can result in a series of undesirable effects. The major impacts of eutrophication include changes in the structure and functioning of marine ecosystems and reduction of biodiversity.

Nutrient concentrations

Eutrophication as nutrient enrichment means elevated and/or increased trends in inputs of nutrients from land, atmosphere or adjacent seas. And consequently elevated dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) concentrations during winter.

Changes in N:P:Si ratio

The optimal DIN:DIP ratio (N/P-ratio) for phytoplankton growth is 16:1 (based on molar concentrations) and called the Redfield ratio. Significant lower deviations of the N/P-ratios indicate potential nitrogen limitation and higher N/P-ratios potential phosphorus limitation of phytoplankton primary production. Deviations from the Redfield ratio limit phytoplankton primary production, and affect phytoplankton biomass, species composition and consequently food web dynamics. Redfield ratios for diatoms for Si:N and Si:P ratios are 1:1 and 16:1, respectively (based on molar concentrations), and the abundance of silicate relative to nitrogen and phosphorus effect the growth of diatoms.

Phytoplankton primary production and biomass

Primary production is most often limited by the availability of light and nutrients. Nutrient enrichment will therefore increase phytoplankton primary production. Consequently there will be an increase in phytoplankton biomass. Elevated phytoplankton production and biomass will increase sedimentation of organic material. Changes in the pelagic ecosystem could enhance the sedimentation. See microbial loop below.

Microbial loop and the pelagic system

The microbial loop may be enhanced by changes in the species composition and functioning of the pelagic food web when growth of small flagellates rather than diatoms is stimulated. The shift in phytoplankton cell size leads to lower grazing by copepods and possibly an increased sedimentation. The smaller cells will on the other hand increase the relative importance of grazing by ciliates and heterotrophic dinoflagellates. A larger fraction of the primary production is consequently channelled through the protozooplankton before it is available to the copepods.

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 primary production.
2) Microbial food webs dominate versus linear food chains.
3) Non-siliceous phytoplankton species dominate versus diatom species.
4) Gelatinous zooplankton (jellyfish) dominate versus crustacean zooplankton.

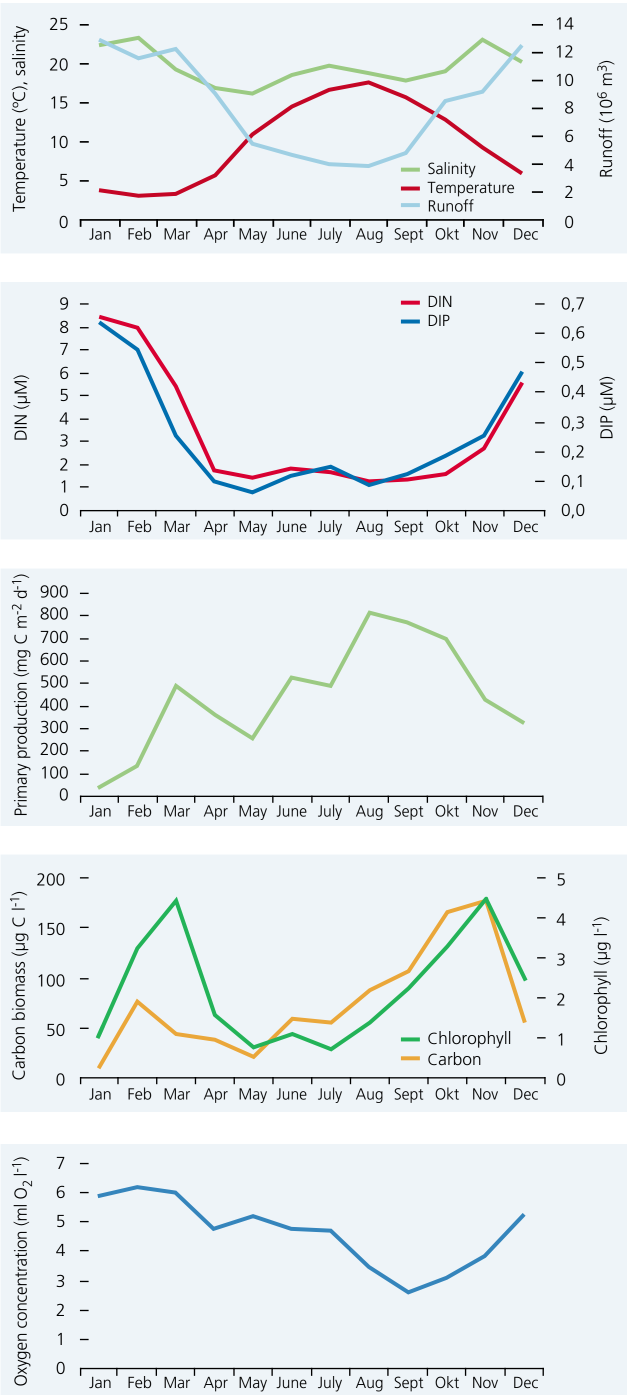
Light and sedimentation

The Secchi depth, a measure of the turbidity and light penetration in the water column, is negatively affected by chlorophyll. Increased trends in inputs of nutrients increase phytoplankton biomass and reduce the Secchi depth. This decreases the colonisation depths of seagrasses and macroalgae.

Oxygen concentrations

Increased animal and bacterial activity at the bottom due to increased amounts of organic matter settling to the bottom increases the total oxygen demand. The increase can lead to oxygen depletion and release of H_2S from the sediment. This will induce changes in community structure or death of the benthic fauna. Bottom dwelling fish may either escape or die.

Phytoplankton respond rapidly to changes in nutrient concentrations and can be used as an indicator of eutrophication status.



Seasonal signals

Many of the eutrophication effects as well as some of the driving forces have a pronounced seasonal variation. Freshwater run-off, temperature and salinity have a strong seasonal signal. The same is the case for inorganic nutrient concentrations, phytoplankton primary production, chlorophyll *a* concentrations, phytoplankton biomass and oxygen concentration in bottom water. The seasonal variations are illustrated in Figure 1.2. This assessment report will, as mentioned in the preface, neither analyse the role of eutrophication on the seasonal succession in these parameters nor the changes in turn-over or fluxes of nutrients during spring, summer and autumn.

Figure 1.2
Seasonal variation at the station "Gniben" located in south-western Kattegat. Monthly averages during the period 1998-2001.

A – Runoff, salinity and temperature
B – N- and P-concentrations
C – Primary production
D – Chlorophyll *a* + Carbon-biomass
E – Oxygen concentration in bottom water

Sediments

In the Danish marine areas a significant portion of the primary production during the spring sediments to the sea bottom. An increase in primary production means that the sediment will experience elevated inputs of organic material. This leads to increased bacterial activity, hence an increase in oxygen demand.

Submerged aquatic vegetation

Eutrophication in general affects submerged vegetation in two different ways. Reduced light penetration and shadowing effect from phytoplankton can reduce the depth distribution, biomass, composition and species diversity of the plant community. Increased nutrient levels favour opportunistic macroalgae species. The stimulated growth of filamentous and annual nuisance species at the expense of perennials will result in a change in macroalgae community structure with reduced species diversity and reduced nurseries for fish. The dominance of filamentous macroalgae in shallow sheltered areas will increase the risk of local oxygen depletion.

Benthic fauna

The increased load of organic material to the bottom affects the macrozoobenthic community. The enrichment will enhance growth and increase species diversity and biomass. A change in community structure will follow favouring suspension and burrowing detritus feeders. Reduction in species diversity and biomass will follow at progressively higher levels of organic load, and opportunistic species will be favoured. Oxygen depletion will lead to a further reduction in species diversity, and mass mortality of most organisms, especially due to production of H_2S in sediments.

Social consequences

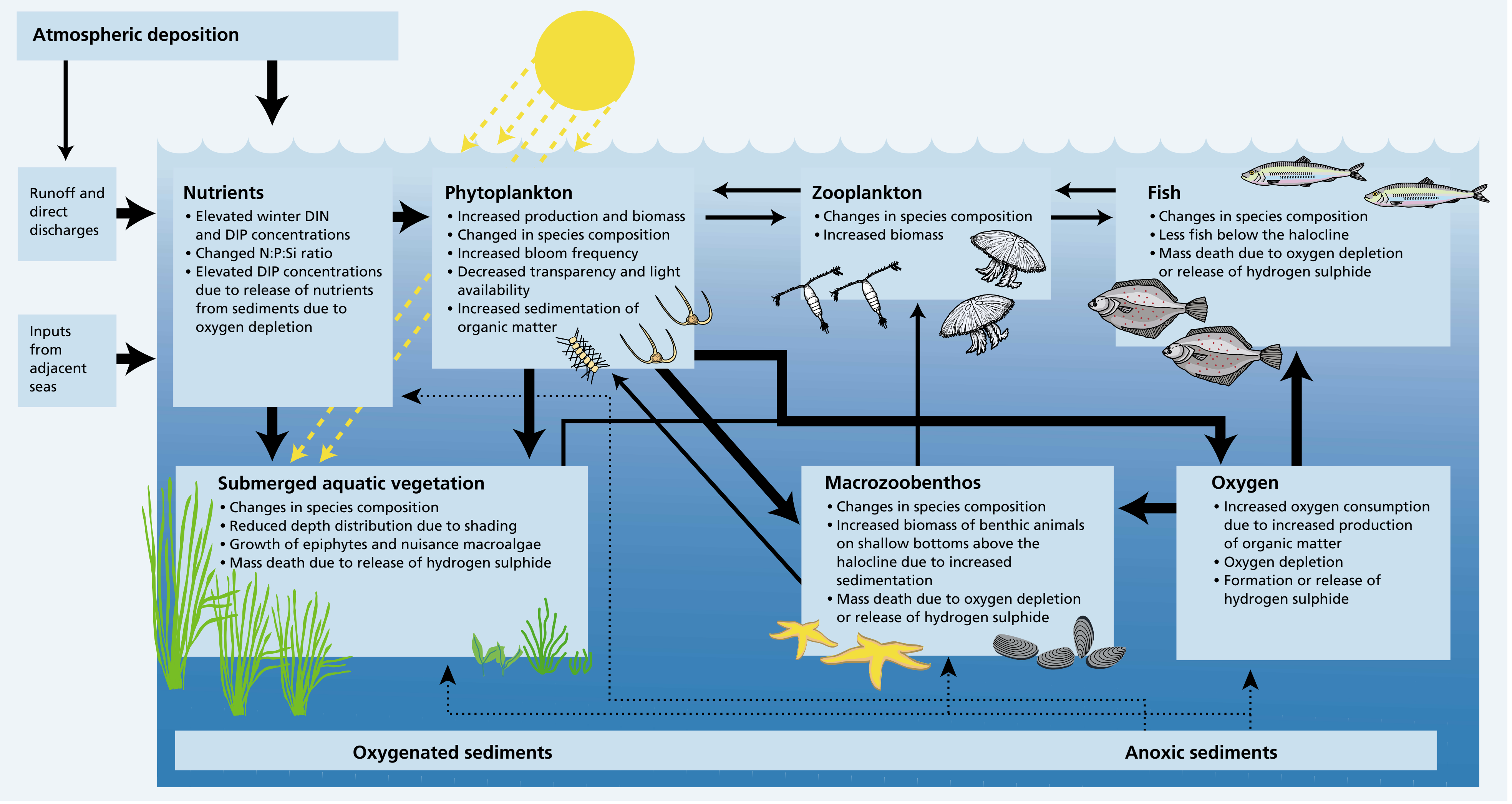
Reductions in dermersal fish and shellfish due to oxygen depletion and harmful algal blooms will reduce harvests. In the case of commercial fisheries these changes have large economic implications. The increased risk of toxic and harmful blooms will also affect mariculture, which can also be influenced by oxygen depletion. Another consequence of toxic algal blooms is the risk of shellfish poisoning of humans by algal toxins. The recreational value of beaches especially for swimming is reduced due to reduced water quality induced by discoloration and foam formation by algal blooms or decaying rotting macroalgae. This could particularly impact tourism at beaches.

Photo: NERI/Britta Munter

Conceptual understanding of eutrophication

Figure 1.3 illustrates in a simplified way the effects and consequences of nutrient enrichment and eutrophication in the marine environment.

Figure 1.3
Conceptual model of marine eutrophication with lines indicating interactions between the different ecological compartments. A balanced system in Danish marine waters is supposedly characterised by:
1) A short pelagic food chain (phytoplankton → zooplankton → fish)
2) Natural species compositions of planktonic and benthic organisms
3) A natural distribution of submerged aquatic vegetation
Nutrient enrichment results in changes in the structure and function of marine ecosystems as indicated with bold lines. Dashed lines indicate release of hydrogen sulphide (H_2S) and phosphorus, which is positively linked to oxygen depletion. Based on OSPAR 2001 and Rönnberg 2001.



The health of the Danish marine environment is of great public interest.

Photo: CDanmark

Technical-scientific assessment

2

This assessment is based on data from the Nationwide Aquatic Monitoring Programme (1988–1997) and the National Aquatic Monitoring and Assessment Programme (1998–2003) (See Danish EPA 2000 for details). The data used for this assessment covers the period 1989–2001 (in some cases only 1989–2000). In a limited number of analyses other data have been included for support.

The national monitoring programme is run in collaboration between the Danish Counties and NERI. The counties are responsible for the activities within the coastal waters. NERI carries out most of the monitoring of the open marine waters, co-ordinates the programme, runs the national marine database and produces annual reports on the state of the marine environment.

Marine eutrophication is an international problem and can only be solved by co-ordinated national and international efforts. The same principle applies for assessment of eutrophication status of marine waters receiving and transporting nutrients from different countries. Therefore, it is important that Denmark and the neighbouring countries (Germany, Norway, and Sweden) have almost harmonised ways of assessing the eutrophication status of common waters. Such common understanding of principles and criteria are discussed and agreed within OSPAR and HELCOM.

The OSPAR Strategy to Combat Eutrophication is together with the monitoring activities among the main drivers of the assessment process (OSPAR 1998). The strategy has the aim of identifying the eutrophication status of all parts of the convention area by the year 2002. The Common Procedure for the Identification of the Eutrophication Status of the Maritime Area is a main element of the strategy. The Common Procedure includes a checklist of qualitative assessment criteria to be used when assessing eutrophication status. In addition, a set of quantitative criteria has been developed in order to assist a harmonised assessment (OSPAR 2001). These assessment criteria fall into the following four categories:

I: Degree of nutrient enrichment.
II: Direct effects of nutrient enrichment.
III: Indirect effects of nutrient enrichment.
IV: Other possible effects of nutrient enrichment.

The harmonised assessment criteria and the assessment levels are summarised in Box 2.

Assessments of eutrophication status of the marine environment should be based on knowledge of how the situation would be without any anthropogenic influence. Two factors are important when assessment criteria are developed:

- What are the reference conditions for the given parameter?
- What are an acceptable deviation from reference conditions?

The principle of assessing the actual state of the environment in relation to the reference conditions is important. However, the critical factor is not the definition of background conditions but the decision on acceptable deviation from background values. The OSPAR assessment criteria acknowledge this and give the countries the opportunity to establish national, regional or even site-specific criteria.

Recent work in relation to the national implementation of the Water Framework Directive and the Habitat Directive has focused on reference conditions and classification of ecological quality for eelgrass and macroalgae and the parameters controlling the growth of submerged aquatic vegetation (chlorophyll, Secchi depth, runoff, nutrient concentrations, depth etc.). The on-going work with regard to classification of ecological quality shows:

- The acceptable deviation should be 15-20%, cf. Henriksen et al. 2001.
- A generally acceptable deviation of 25% will result in a limited number of false positive situations when compared to the existing Danish assessments principles, cf. Krause-Jensen et al. (subm.).
- The Swedish assessment criteria (Swedish EPA 2000) for macroalgae will be met almost every year, even in wet years with high anthropogenic inputs of nutrient, to the marine environment, cf. Henriksen et al. 2001.
- A 50% deviation from reference conditions for macrovegetation at reefs in Kattegat suggests that the reefs are not subject to eutrophication at all, cf. Henriksen et al. 2001.

The OSPAR eutrophication assessment criteria have therefore been adjusted at a national level. The Danish assessment criteria are:

- The acceptable deviation for winter DIN and DIP concentrations is 25%, cf. Henriksen et al. 2001.
- The acceptable deviation for maximum and mean chlorophyll *a* is 25%, cf. Henriksen et al. 2001. The growing season covers the period March – October.
- The acceptable deviation for macrophytes including macroalgae is 25%, cf. Krause-Jensen et al. (subm.) and Henriksen et al. 2001.
- The Danish oxygen depletion criteria are: severe acute oxygen depletion: 0-2 mg O_2 l^{-1}, oxygen depletion: 2-4 mg O_2 l^{-1}. These values have been national assessment criteria since the mid-1980s. The OSPAR criteria are: < 2 mg l^{-1} and 2-6 mg l^{-1}. These criteria are not applicable for Danish marine waters, where the oxygen concentrations due to natural reasons may be 5-6 mg l^{-1}. Such values are region specific and due to strong stratification in summer and autumn, which prevents the saline, cold bottom waters from being mixed with the brackish and oxygenated surface waters. The Danish assessment criteria match the natural effect criteria. Fish will try to avoid waters with oxygen concentrations below 4 mg l^{-1}. Fish and benthic invertebrates can only survive concentrations below 2 mg l^{-1} for a limited time.


Photo: NERI/Britta Munter

Box 2 summarises the OSPAR eutrophication quality objectives (EQO-eutro) and the Danish criteria used in this assessment.

Background data describing reference conditions when anthropogenic inputs of nutrients were at natural levels are scarce. Hence descriptions of ecological structure and function before the enrichment took place is subject to an element of uncertainty. Box 3 summarises the current understanding of the reference conditions in Danish marine waters.

The implementation of the EU Water Framework Directive and the development of Ecological Quality Objectives (EQOs) defining the ecological status of all European coastal waters will represent a major step forward. The descriptions of ecological status will be based on commonly agreed definitions of reference conditions. The basis for assessing the ecological status will change from expert judgements to operational and numeric quality classes.

An EU funded R&D project "Characterisation of the Baltic Sea Ecosystem: Dynamics and Function of Coastal Types" (CHARM) will be a major contribution to this in the Baltic Sea/Kattegat Area. One of the products of the CHARM project, which runs for the years 2002-2004, is descriptions of reference conditions for nutrients, phytoplankton, submerged aquatic vegetation and macrozoobenthos.

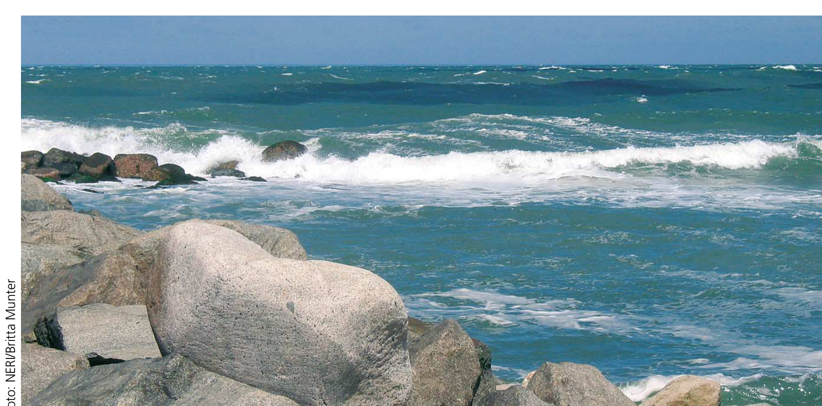


Photo: NERI/Britta Munter

BOX 2 The OSPAR eutrophication quality objectives (ECO-eutro) and the Danish criteria used in this assessment

OSPAR EAC	Danish ECO-eutro	See page
I: Degree of nutrient enrichment (causative factors)		
1 Riverine total N and total P inputs and direct discharges (RID) *Elevated inputs and/or increased trends (compared with previous years)*	**25 %**	**28–35**
2 Winter DIN- and/or DIP concentrations *Elevated level(s) (defined as concentration > 50 % above salinity related and/or region specific background concentration)*	**25 %**	**36–41**
3 Increased winter N/P ratio (Redfield N/P = 16) *Elevated cf. Redfield (>25)*	✔	**43–44**
II: Direct effects of nutrient enrichment (growing season)		
1 Maximum and mean Chlorophyll *a* concentration in March–October *Elevated level (defined as concentration > 50 % above spatial (offshore) / historical background concentrations)*	**25 %**	**46–51**
2 Region/area specific phytoplankton indicator species *Elevated levels (and increased duration)*	✔	**41–53**
3 Macrophytes including macroalgae (region specific) *Shift from long-lived to short-lived nuisance species (e.g. Ulva)*	✔	**68–76**
III: Indirect effects of nutrient enrichment (growing season)		
1 Degree of oxygen depletion *Decreased levels (<2 mg O_2 l^{-1}: acute toxicity; 2-6 mg O_2 l^{-1}: deficiency)*	**< 2 and 2–4 mg l^{-1}**	**58–76**
2 Changes/kills in zoobenthos and fish kills *Kills (in relation to oxygen depletion, H_2S and/or toxic algae)* *Long term changes in zoobenthos biomass and species composition*	✔	**76–79, 80–83**
3 Organic Carbon/Organic Matter (in sediments) *Elevated levels (in relation to III.1) (relevant in sedimentation areas)*	✔	**62–67**
IV: Other possible effects of nutrient enrichment (growing season)		
1 Algal toxins (DSP/PSP mussel infection events) *Incidence (related to Category II.2)*	✔	**52–53**

BOX 3 Background or reference conditions

Nutrients
Background winter concentrations for DIN in the Kattegat, the Skagerrak and the North Sea and in the Wadden Sea has within OSPAR provisionally been estimated to 4-5, 10, and 6.5 µmol l^{-1}, respectively. Winter DIP concentrations have been estimated to 0.4, 0.6 and 0.5 µmol l^{-1}, respectively.

Phytoplankton biomass and production
Chlorophyll *a* background concentration for offshore areas in the Skagerrak has within OSPAR been estimated to <1.25 µg l^{-1}, and for the North Sea coast to 2-10 µg l^{-1}. The phytoplankton primary production in the Kattegat and Belt Sea has increased from 80-100 mg C m^{-2} $year^{-1}$ in the 1950s – 1960s to 120-290 mg C m^{-2} $year^{-1}$ in the 1970s – 1980s (Ærtebjerg Nielsen et al. 1981; Richardson & Christoffersen 1991; Heilmann et al. 1994, Richardson & Heilmann 1995).

Oxygen
From scattered measurements of oxygen concentrations in Danish waters from the period 1902–1975 and more systematic measurements since then it seems that the major decrease took place from the 1960s to the late 1980s. In the Kiel Bight the bottom water oxygen concentration in July-August decreased from about 8 mg O_2 l^{-1} in the late 1950s to about 4 mg O_2 l^{-1} in the late 1980s (Babenerd 1991). Trend analysis of bottom water oxygen concentrations in late summer – autumn in the Kattegat and Belt Sea area generally shows a decrease of 1.5-2.2 mg O_2 l^{-1} during the period from mid 1970s to about 1990 (Ærtebjerg et al. 1998).

Eelgrass
In 1900, eelgrass was widely distributed in Danish coastal waters, and covered approximately 6726 km^2 or 1/7 of all Danish marine waters. In the 1930s, the world wide wasting disease substantially reduced eelgrass populations, especially in north-west Denmark. In 1941, eelgrass covered only 7% of the formerly vegetated areas, and occurred only in the southern, most brackish waters and in the low saline inner parts of Danish estuaries. Analyses of aerial photos from the period 1945–1990s, reveal an initial time lag of more than a decade before substantial re-colonisation of the shallow eelgrass populations began. The photos also show that large populations had recovered in the 1960s. Today eelgrass again occurs along most Danish coasts but has not reached the former area extension. Comparisons of eelgrass area distribution in two large regions, the Sound and Limfjorden, in 1900 and in the 1990s, suggest that the present distribution area of eelgrass in Danish coastal waters constitutes approximately 20-25% of that in 1900. Reduction in area distribution is partly attributed to loss of deep populations. In 1900 colonisation depths averaged 5-6 m in estuaries and 7-8 m in open waters, while in the 1990s the colonisation depths were about halved to 2-3 m in the estuaries and 4-5 m in open waters.

Macrozoobenthos
There have been changes of macrozoobenthos communities in the Kattegat area over the last 100 years. The reference material is mainly the large-scale mapping performed by C.G.J. Petersen at the end of the 19th and the beginning of the 20th century. Comparisons in the 1980s and 1990s indicate that biomass, and then probably secondary production, has increased with at least a factor of 2. Main contribution to the increase in deeper waters is from the suspension-feeding brittle star *Amphiura filiformis* and some polychaetes, whereas some amphipod crustaceans have decreased in importance. In shallower waters it is likely that biomass of bivalves have increased as has been documented from the eastern and southern Baltic Sea. Local reductions of benthic faunal biomass due to hypoxia seems to have occurred at times in recent decades both in the southern Kattegat, the Belt seas and some Danish estuaries.