Photo: Biofoto/Kjeld Olesen

Christiansborg, home of the Danish Parliament.

Responses and adaptive management

3

Since the mid 1980s high priority has been given to the quality and protection of the aquatic environment in Denmark. The overall goal is to ensure that the waters are clean. The endeavours in this respect are described in Aquatic Environment 1999 (Danish EPA 2000) and summarised in Conley et al. (2002).

These papers state that Danish administrations shall work towards ensuring:

- That watercourses, lakes and marine waters are clean and of a satisfactory quality as regard to health and hygiene.
- That exploitation of water bodies and associated resources takes place in a sustainable manner.
- That the objectives of relevant international agreements will be fulfilled.

The central legal instrument to fulfil these political objectives is the Consolidated Environmental Protection Act, which aims to safeguard the environment, to support a sustainable social development, and to protect flora and fauna (Ministry of Environment and Energy 1998).

The general objectives for Danish marine waters are based on the Consolidated Environmental Protection Act, the 1992 Helsinki Convention on Protection of the Marine Environment in the Baltic Sea Region and the 1992 Convention for the Protection of the Marine Environment of the Northeast Atlantic. More specific objectives are:

- Anthropogenic pollution and human activities may only insignificantly or slightly affect fauna and flora.
- Nutrient levels have to be at or close to natural levels.
- Clarity of the water has to be normal or close to normal.
- Unnatural blooms of toxic planktonic algae must not occur.
- Pollution-dependent macroalgae must not occur.
- Oxygen deficiency may only occur in areas where this is natural.

Commercial exploitation, i.e. fishery, offshore industry, dumping of seabed material, recreational activities etc. has to be conducted in a manner that is sustainable and respects environmental and natural wealth.

3.1 Principles

The primary means of achieving the quality objectives for surface waters is a reduction in nutrient discharges, losses and emissions.

Photo: Danish Institute of Agricultural Science/Henny Rasmussen

One of the guiding principles in the Danish work on abatement of pollution in general and nutrient enrichment and eutrophication in particular is "strategic environmental planning".

The intentions of the principle is to deal with environmental problems in a coherent way and that policies are to be developed as a process with the following elements:

- Political agreements on goals.
- Implementation of agreed measures.
- Continuous monitoring and regular production of assessment reports, aiming at a higher level of understanding of the actual problem.
- Periodic evaluations and adjustments (if relevant) of goals and measures.

The principle which is illustrated in Figure 3.1 shall ensure that the goals can either be met with the agreed measures or – if goals are not met – that measures should be revised or even supplemented with additional measures. The overall goal is to ensure that environmental policies become more preventive, holistic and target orientated.

The Danish administration put emphasis on that the principles of strategic environmental planning are implemented at all levels and in all actions aiming at a healthier aquatic environment. Danish policies to improve the health of the marine environment have been and will be based on the available information on relations between society and environmental responses to changes, effects of measures and effectiveness of the measures etc.

The Danish policies and strategies to abate eutrophication of the aquatic environment are an illustrative example on how the concept of strategic environmental planning works. The strategies and measures as well as the chronology (1986-2002) are described in Chapter 3.2.

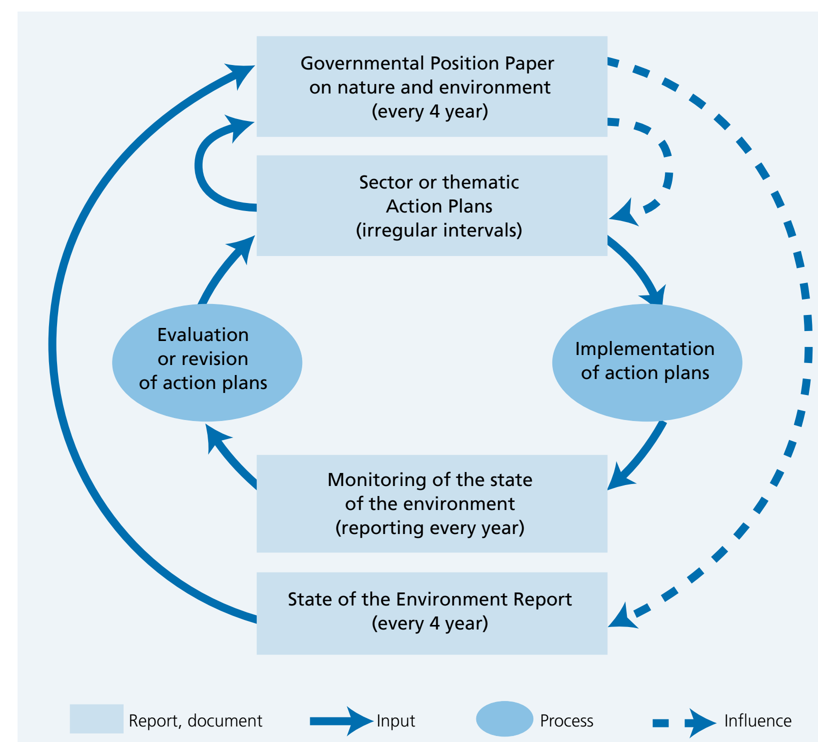


Figure 3.1 Illustration of the concept of strategic environmental planning.

3.2 Nutrient Reduction Strategies in Denmark

The Danish Parliament.

Photo: Scanpix

The primary means of achieving the quality objectives for surface waters is a reduction in nutrient discharges and emissions. In the January 1987 Action Plan on the Aquatic Environment and the April 1987 Report on the Action Plan on the Aquatic Environment the goal of reducing nitrogen and phosphorus loads to the aquatic environment was set to 50% and 80%, respectively. This corresponds to a reduction in annual discharges and losses from a level of around 283,000 tonnes N and 9,120 tonnes P at the time the plan was adopted to a level of ca. 141,600 tonnes N and ca. 1,820 tonnes P (see Table 3.1 for details). The Action Plan covers the 3 major sources: agriculture, municipal wastewater treatment plants and separate industrial discharges.

Tabel 3.1
Sector specific reduction targets for annual discharges and losses of nitrogen (tot-N) and phosphorus (tot-P) to the aquatic environment in Denmark (Danish EPA 2000).

	Nitrogen			Phosphorus		
	1987	÷ Reduction	= Target	1987	÷ Reduction	= Target
Agriculture	260.000	÷ 127.000	= 133.000	4.400[1)]	÷ 4.000	= 400
Municipal WWTPs	18.000	÷ 11.400	= 6.600	4.470	÷ 3.250	= 1.220
Separate industrial discharges	5.000	÷ 3.000	= 2.000	1.250	÷ 1.050	= 200
Total	283.000	÷ 141.400	= 141.600	9.120	÷ 8.050	= 1.820

1) Includes the farmyard load, i.e. does not include losses of phosphorus from agricultural fields.

It should also be noted that losses of phosphorus from cultivated land are not included, because of the uncertainties that are related to these estimates.

Specific reduction targets for the agricultural sector

Since the mid 1980s, a number of action plans and strategies have been adopted by the Danish Parliament to regulate development of the agricultural sector, one of the main sources of nutrients to the aquatic environment, and its impact on the aquatic environment. The action plans include:

- The 1985 NPo (Nitrogen, phosphorus and organic matter) Action Plan.
- The 1987 Action Plan against Pollution of the Danish Aquatic Environment with Nutrients (Action Plan on the Aquatic Environment).
- The 1991 Action Plan for Sustainable Agriculture.
- Parts of the Governments 10-Point Programme for Protection of the Groundwater and Drinking Water from 1994.
- The 1996 Follow-up on the Action Plan for Sustainable Agriculture.
- The 1998 Action Plan on the Aquatic Environment II.

Reduction targets for nitrogen and phosphorus stipulated in the Action Plan on the Aquatic Environment I are an approximate 50% reduction of nitrogen loads and the elimination of the phosphorus farmyard load to avoid unintended eutrophication of the aquatic environment. The reduction targets were to be attained by 1993 through the following measures carried out by the agricultural sector:

- Establishment of sufficient capacity to store 9 months of manure production so that manure can be stored until crop growth season begins.
- Establishment of crop rotation and fertilisation plans to ensure that nitrogen content of fertiliser is optimally exploited.
- Fields must have green cover during winter period.
- Manure has to be ploughed in or in some other way deployed into the soil within 12 hours of application.
- Limits on the amount of livestock manure applied to fields.

It soon became clear that it would not be possible to attain the reduction targets by 1993. The measures stipulated in the Action Plan on the Aquatic Environment I were therefore tightened in 1991 in the Action Plan for Sustainable Agriculture. The reduction target was maintained but the time frame was extended to the year 2000. The measures were:

- Fertilisation accounts so that fertiliser application can be documented.
- More stringent and fixed requirements on utilisation of the nitrogen content of livestock manure.
- All farms must establish sufficient capacity to store 9 months of manure production.
- A ban on the application of liquid manure between harvest time and February except on fields cultivated with winter rape or grass.

After the Action Plan for Sustainable Agriculture, there have been a number of follow-up plans for reducing the impact of the agricultural sector on the aquatic environment, including the Government's 1994 10-Point Programme for Protection of the Groundwater and Drinking Water in Denmark.

The need to further tighten the regulation of agricultural loads of nitrogen has become even more necessary because Denmark must comply with the EU Nitrates Directive by the year 2003. The directive restricts application of livestock manure to 170 kg N $hectare^{-1}$ yr^{-1}. In the case of some types of farms this is less than levels currently permitted. Denmark has sought permission to derogate from the 170 kg N $hectare^{-1}$ rule on cattle holdings so as to enable application of up to 230 kg N $hectare^{-1}$ yr^{-1} on a small number of these holdings.

In February 1998, the Danish Parliament adopted several new instruments aimed at achieving the reduction targets stipulated in the Action Plan on the Aquatic Environment I. As a supplement to the Action Plan on the Aquatic Environment I, the Action Plan on the Aquatic Environment II will reduce nitrogen leaching by a further 37,000 tonnes N yr^{-1} so as to enable the reduction target of 100,000 tonnes N yr^{-1} to be achieved no later than the end of the year 2003 (table 3.2). The following measures have been implemented under the Action Plan on the Aquatic Environment II:

- Re-establishment of 16,000 hectares of wet meadow to help reduce nitrogen leaching to the aquatic environment due to their ability to convert nitrate to N_2.
- Afforestation in Denmark and planting 20,000 hectares forest before the year 2002.
- Agri-environmental measures including financial support to farmers willing to utilise sensitive agricultural areas in a more environmentally sound manner by using less fertiliser or by completely refraining from cultivating the land. There has hitherto been very little interest in this scheme.
- Improved fodder utilisation and changes in feeding practice.
- Implementation of stricter harmony criteria governing livestock density.
- Stricter requirements on utilisation of the N content of livestock manure.
- Converting 170,000 hectares to organic farming; catch crops on a further 6% of a farmers land.
- Reducing the nitrogen norm by 10%, e.g. farmers may now only apply nitrogen in amounts corresponding to 90% of the economically optimal level.

If the measures in the Action Plan on the Aquatic Environment II are implemented as changes in agricultural practice, 20 years of nitrate policy (1985-2003) is likely to result in a 100,000 tonnes N yr^{-1} reduction in leaching from agricultural land. Moreover, consumption of nitrogen in the form of commercial fertiliser will decrease from approximately 400,000 tonnes N yr^{-1} in 1985 to approximately 200,000 tonnes N yr^{-1} in 2003 (Iversen et al. 1998).

In connection with the Action Plan on the Aquatic Environment I it was estimated that nitrogen loads could be reduced by a total of 127,000 tonnes N yr^{-1} by 1993. The reduction targets were 100,000 tonnes N yr^{-1} for the nitrogen load from fields and 27,000 tonnes N yr^{-1} for the farmyard load. In the Action Plan for Sustainable Agri-

Photo: High-light

Tabel 3.2
Summary of measures and estimated reductions (in tonnes N per year) in nitrogen discharges and losses from agriculture, cf. Action Plan on the Aquatic Environment I, Action Plan for Sustainable Agricultural Development, follow-ups hereto, and Action Plan on the Aquatic Environment II.

	1993	2000	2003
1. Action Plan on the Aquatic Environment I (1987):			
Optimal utilisation of livestock manure			
• NPo Action Plan	55,000		
• NPo Subsidy Act	5,000		
• Further initiatives	10,000		
Programme for improved utilisation of fertiliser			
• Systematic fertilisation plans	15,000		
• Improved application methods	5,000		
• Winter green fields – catch crops and ploughing down of straw	20,000		
• Winter green fields – further initiatives	8,000		
Structural measures	9,000		
Total	127,000	50,000	
2. Action Plan for Sustainable Agricultural Development (1991):			
• Improved utilisation of livestock manure		20,000-40,000	
• Reduction in commercial fertiliser consumption		8,000-15,000	
• Protection of groundwater in particularly vulnerable areas		1,000-2,000	
• Reduction in agricultural acreage		17,000-20,000	
• Structural development, other measures		15,000	
Total		77,000	89.900
3. Action Plan on the Aquatic Environment II (1998):			
• Wetlands			5,600
• Sensitive agricultural areas			1,900
• Afforestation			1,100
• Improved fodder utilisation			2,400
• Stricter livestock density requirements			300
• Stricter requirements on utilisation of N content of manure			10,600
• Organic farming			1,700
• Catch crops on a further 6% of the fields			3,000
• 10 % reduction in nitrogen standards for crops			10,500
Total			37,100
Grand total	127,000	127,000	127,000

culture it was estimated that by the year 2000, the measures stipulated in the Action Plan on the Aquatic Environment I would only have reduced nitrogen loads by 50,000 tonnes N yr^{-1} and that further measures were therefore needed to achieve the total reduction of 127,000 tonnes N yr^{-1}.

The existing measures and targets under the Action Plan on the Aquatic Environment I and the Action Plan for Sustainable Agriculture were re-evaluated in 1998 in connection with the preparation of the Action Plan on the Aquatic Environment II. It was concluded that by the year 2003, the existing measures would reduce nitrogen loads by 89,900 tonnes N yr^{-1}. Together with the expected reduction under the Action Plan on the Aquatic Environment II, it was concluded that nitrogen loads would be reduced by 127,000 tonnes N yr^{-1} by 2003.

Not all measures in the Action Plan on the Aquatic Environment II will have taken full effect by 2003. The Action Plan on the Aquatic Environment II also encompasses so-called regional measures. These represent implementation of recommendations of the Drinking Water Committee concerning the protection of groundwater resources considered particularly vulnerable to nitrate pollution.

Photo: CDanmark

Specific reduction targets for municipal wastewater treatment plants

Discharges from municipal wastewater treatment plants are regulated by the Environmental Protection Act, the Urban Wastewater Directive and derivative statutory orders and official guidelines.

The EU Council Directive 91/271/EEC of 21 May 1991 concerning Urban Wastewater Treatment as amended by Commission Directive 98/15/EU of 27 February 1998 - commonly referred to as the Urban Wastewater Directive – is one of the most important legal documents in the EU legislation on the aquatic environment. The purpose of the directive is to protect the environment against negative effects associated with discharge of inadequately treated urban wastewater and biologically degradable industrial wastewater from enterprises within the food processing industry. According to the directive, wastewater discharges have to be subjected to a level of treatment appropriate to the environment at the place in question and the use to which the recipient water bodies in question are put. Denmark implemented the provisions of the directive in Danish legislation in 1994.

The Action Plan on the Aquatic Environment's reduction targets for municipal wastewater treatment plants were adjusted in 1990 on the basis of the results of the Nation-wide Monitoring Programme (Danish EPA, 1991). In the case of nitrogen, annual discharges in treated wastewater are to be reduced from ca. 18,000 tonnes N to ca. 6,600 tonnes N. Phosphorus discharges are to be reduced from ca. 4,470 tonnes P to ca. 1,220 tonnes P. The reduction in nitrogen discharges from municipal wastewater treatment plants corresponds to all new or upgraded plants exceeding 5,000 PE and all existing plants ex-ceeding 1,000 PE having to implement biological treatment with nitrogen removal down to an annual average of 8 mg N l^{-1}. In 1987 this was considered as low as it is practically possible to reach with biological nitrogen removal. As regards to phosphorus, municipal wastewater treatment plants exceeding 5,000 PE have to remove phosphorus down to an annual average of 1.5 mg P l^{-1}.

The reduction target for nitrogen of 6,600 tonnes N yr^{-1} was achieved in 1996, as was the reduction target for phosphorus of 1,200 tonnes P yr^{-1}.

Specific reduction targets for separate industrial discharges

The Environmental Protection Act, the EU Directive on Pollution Prevention and Control (IPPC Directive) and derivative statutory orders and official guidelines regulate separate industrial discharges.

The IPPC Directive aims at integrated prevention and control of pollution by major industries. The directive specifically regulates the energy industry (power stations and refineries, etc.), production and processing of metals, the mineral industry, the chemical industry, waste management plus a number of other activities such as paper manufacturers, textiles pretreatment and dyeing, slaughterhouses and dairies, as well as installations for intensive rearing of poultry and pigs exceeding a certain capacity. The IPPC Directive contains measures designed to prevent or, where that is not practicable, to reduce emissions to the atmosphere, water and land from the above mentioned activities.

Because of large differences between individual enterprises and their discharges of wastewater, the Action Plan on the Aquatic Environment I did not stipulate general discharge requirements for industry as for wastewater treatment plants. Industry was to reduce its discharges through application of BAT understood as the level of treatment that is technically attainable and economically viable for the industry in question.

Reduction targets for other sectors and sources

A number of other sectors and types of sources also contribute to nutrient loading to the aquatic environment. These include freshwater fish farms, mariculture, transport, combustion plants (heat and power production), sparsely built-up areas and stormwater outfalls. The Action Plans on the Aquatic Environment did not specify specific reduction targets for these sectors and types of source but instead describes a number of other measures.

Freshwater fish farms

The Ministry of Environment issued the Statutory Order on Freshwater Fish Farms on 5 April 1989 to reduce nutrient loading. It gives guidelines for the County authorities to stipulate the maximal permitted feed consumption at fish farms, minimum requirements as to treatment measures as well as minimum requirements as to utilisation and quality of feed.

Mariculture (seawater-based fish farming)

In 1987 a moratorium was placed on establishment of new farms and expansion of existing farms until 1990 when Statutory Order No. 640 on mariculture was issued. This stipulated general regulations on feed quality and con-

Photo: Biofoto/Morten Rasmussen

sumption as well as consumption of feed relative to production. In addition, upper limits were placed on nutrient discharges to the surrounding aquatic environment from each individual farm. In 1996 the Danish EPA requested the Counties not to issue any permits for new sea-based or land-based mariculture farms or for extensions of existing farms and were urged to assess whether environmental or operational benefits could be obtained by moving or merging existing farms. In June 2001 the 1996 request was lifted and the Danish EPA published a new strategy to reduce loads of nutrients and organic matter from mariculture. A revision of the existing Statutory Order is being negotiated and is expected to be implemented in 2003.

NO_x emissions

When the Action Plan on the Aquatic Environment was adopted in 1987, the Danish EPA was instructed to prepare a report containing a specific reduction programme for power station NO_x emissions. Regulation of NO_x emissions in Denmark has concentrated on improved combustion technology and flue gas abatement at power stations (e.g. Statutory Order No. 885 of 18 December 1991 on Limitation of Emissions of Sulphur Dioxide and Nitrogen Oxides from Power Stations), enhanced use of natural gas and renewable energy (e.g. the Government's 1990 Energy Action Plan) as well as implementation of the requirement for catalytic converters on cars (e.g. Ministry of Justice Statutory Order on Detailed Regulations for the Motor Vehicle Design and Equipment from 1990). Under the EEC Convention on Transboundary Air Pollution, Denmark has entered into an international agreement to reduce emissions of NO_x by 30% over the period 1986-98. However, the measures needed to meet this goal are inadequate in Europe as regards acidification and eutrophication. In June 1999, the EU Commission, therefore, issued proposals for two directives on acidification and ozone formation at ground level (Proposal for a Directive on National Emission Limits for Certain Polluting Substances and Proposal for a Directive on the Ozone Content of the Air). These two directives stipulate national limits for emissions of NH_3 and NO_x. In the case of Denmark, the proposed directives will limit ammonia (NH_3) emissions to 71,000 tonnes per year and nitrogen oxide (NO_x) emissions to 127,000 tonnes per year from 2010.

Photo: NERI/Helge Rørdam Olesen

Sparsely build-up areas

The relative contribution of nutrients from sparsely built up areas has increased over the past 10 years because of point source reductions from wastewater treatment plants and industry. It is expected that future improvements in treatment of wastewater from sparsely built-up areas will occur resulting from initiatives in connection with the 1997 amendment of the Environmental Protection Act concerning wastewater treatment in rural areas. According to state instructions to the Counties concerning revision of the Regional Plans in 2001, the Countries have specified areas in which the treatment of wastewater from properties in rural areas is to be improved, they must stipulate quality objectives for individual recipient waters in its Regional Plan, identify watercourses and lakes

that are vulnerable to pollution, and based on its knowledge of the environmental state and pollution load on the individual recipient waters, has to assign each individual recipient a maximal environmentally permissible level of pollution.

Rainwater outfalls

Rainwater outfalls are one of the reasons that many watercourses and urban lakes as well as some coastal marine waters fail to meet the agreed quality objectives. Despite the increasing importance, there is a lack of knowedge of how to manage rainwater outflows. Ongoing work by the Wastewater Committee under the Danish Engineering Association and the Danish EPA is intended to result in proposals for guidelines that can be incorporated in official EPA guidelines.

Follow-up on the mid-term evaluation of Action Plan II

The effects for a number of measures in Action Plan II from 1998 are based on an assumed development in agricultural practises. Therefore, the plan was subject to a mid-term evaluation in 2000/2001. This evaluation concluded that the realised changes in agricultural practices could not match the expected changes. The losses of nitrogen from field were estimated to be 93,000 tonnes of N, indicating an annual under-fulfilment of 7,000 tonnes of N. The results of the political mid-term evaluation were presented in May 2001. The conclusions included:

- Changed rules for funding of reestablishment of wetland, in order to make this more attractive.
- Reduction of bread wheat subsidies in order to ensure that the area receiving subsidies matches the needs for bread wheat.
- Revision of nitrogen standards.

The amendments to Action Plan II include an over-fulfilment by 175 tonnes N yr^{-1} compared to the measures agreed in 1997.

An Action Plan III on the Aquatic Environment is on the programme of the Danish Government and is planned to be negotiated in 2003. The parties behind Action Plan I and II have agreed that Action Plan III shall focus on:

- The nitrogen balance of the Danish agricultural sector, in particular on the magnitude of losses from Danish agriculture in the mid 1980s.
- General measures to reduce discharges and losses from the agricultural sector.
- Losses of phosphorus from fields, which so far have been excluded from action plans.
- Possibilities to implement regional measures in order to protect specific regional waters.

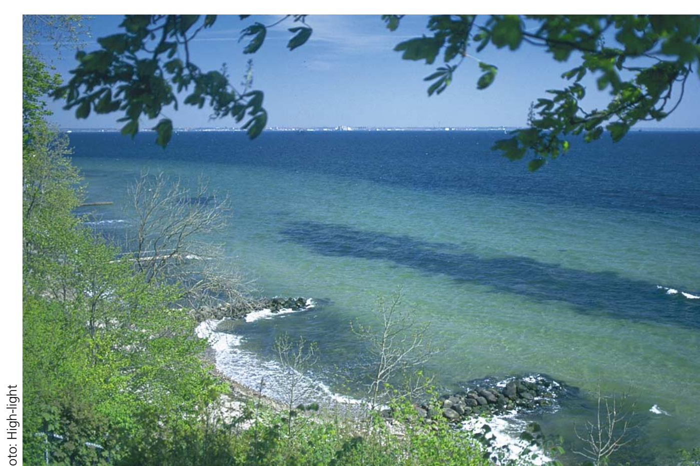
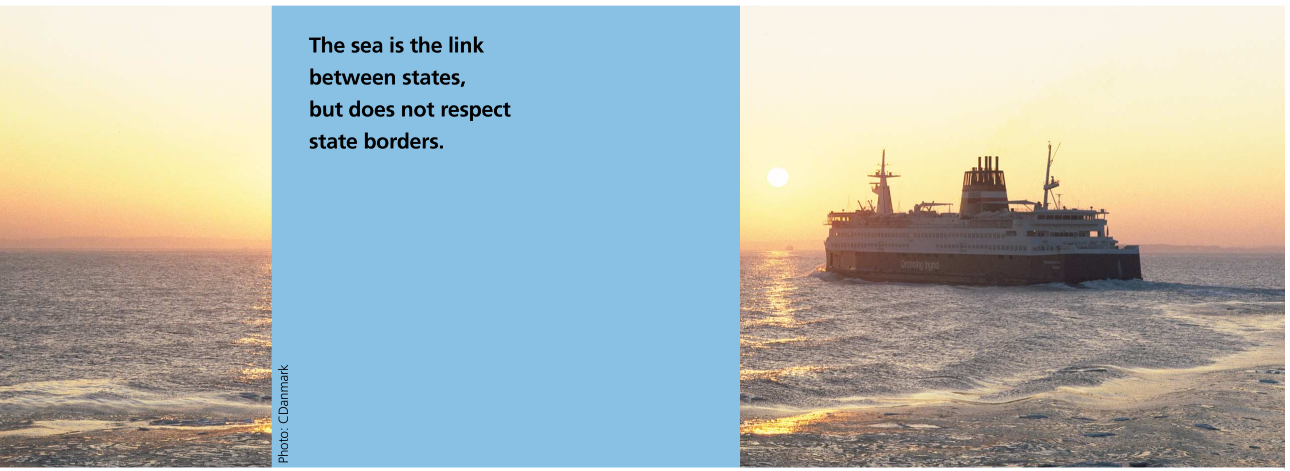


Photo: High-light

3.3 International co-operation to abate marine eutrophication



The sea is the link between states, but does not respect state borders.

Photo: CDanmark

Eutrophication of the Danish parts of the Wadden Sea, along the west coast of Jutland and in open parts of Kattegat and the Baltic Sea is to a large extent caused by inputs from adjacent waters and to deposition from the atmosphere. The nutrients causing eutrophication originate from discharges, emissions and losses in other areas and are transported to Danish waters where they add to discharges and losses from Danish sources. International co-operation is essential to abate the problem in these areas. The efforts and results due to the Danish Action Plans on the Aquatic Environment, therefore, must be supplemented by parallel activities in neighbouring countries.

A number of international initiatives have been agreed and are likely to reduce the transport of nutrients to Danish waters.

At the North Sea Conference in London in November 1987, the countries of the North Sea adopted the goal of reducing nitrogen and phosphorus inputs by ca. 50% over the period 1985-95 in areas where these inputs are likely, directly or indirectly, to cause pollution. At ministerial conferences in The Hague (1990), Esbjerg (1995) and Bergen (2002), these reduction targets were reiterated and the need to take action against wastewater discharges and losses from agriculture was specified.

In June 1988, the Paris Commission adopted a 50% reduction target for nutrient inputs to marine waters susceptible to eutrophication and also adopted a programme to achieve the reductions. In 1989, the reduction target was specified in relation to specific sectors. In 1992, it was decided to integrate the Oslo and Paris Conventions, both of which aimed to prevent marine pollution from dumping and land-based sources of pollution. The objective of the successor – the OSPAR Convention – is to protect the marine environment of the Northeast Atlantic region. As a follow-up on the 1988 decision, the 1998 OSPAR Ministerial Meeting adopted a strategy to combat eutrophication. Included in the strategy is adoption of achieving a healthy marine environment where eutrophication does not occur by 2010.

At a ministerial meeting in February 1988, HELCOM adopted a declaration specifying a 50% reduction target for discharges of nutrients etc. over a 10-year period. In the Communiqué from the ministerial meeting in 1998, the ministers confirm that they have committed themselves to attaining the strategic goal from 1988 and to defining specific objectives that have to be achieved before the year 2005.

Comparing reduction targets of the Danish action plans with agreed reduction targets in OSPAR and the North Sea Conference, there are some differences. The Danish reduction targets make a total reduction of discharge and losses of nitrogen on the order of 50% and phosphorus on the order of 80% from three sectors, agriculture (only nitrogen), industry, and municipal wastewater plants. The OSPAR and North Sea Conference agreed reduction targets make a total reduction on the order of 50 % of the inputs of both phosphorus and nitrogen into areas where these inputs are likely, directly or indirectly to cause pollution.

Marine monitoring and assessment is another important area of international co-operation.

In connection with adoption of the Action Plan for the Aquatic Environment in 1987, a national monitoring programme was established to demonstrate the effectiveness of measures

The bridge in The Sound between Denmark and Sweden.

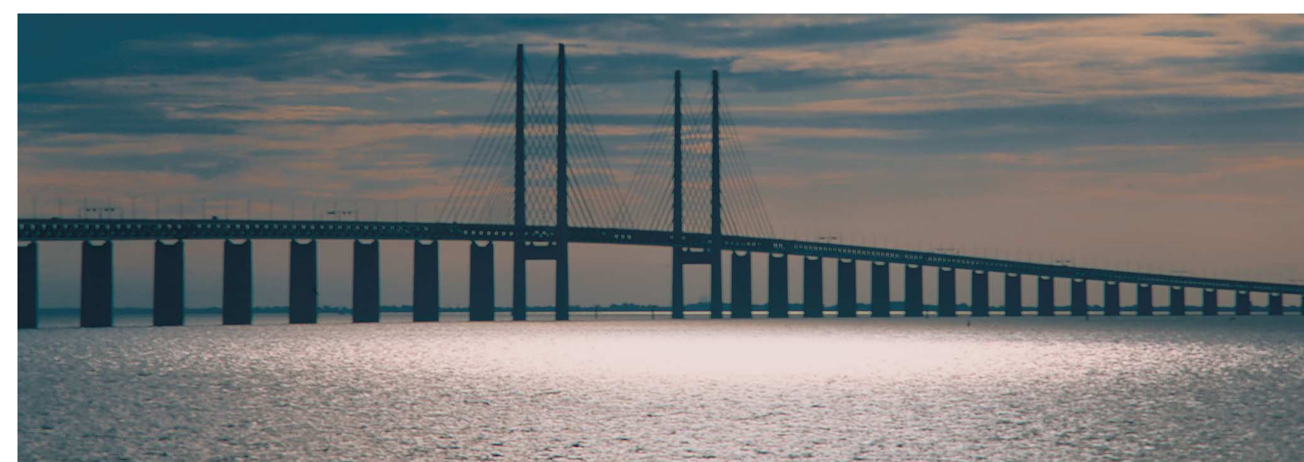


Photo: Biofoto/Lars Gejl

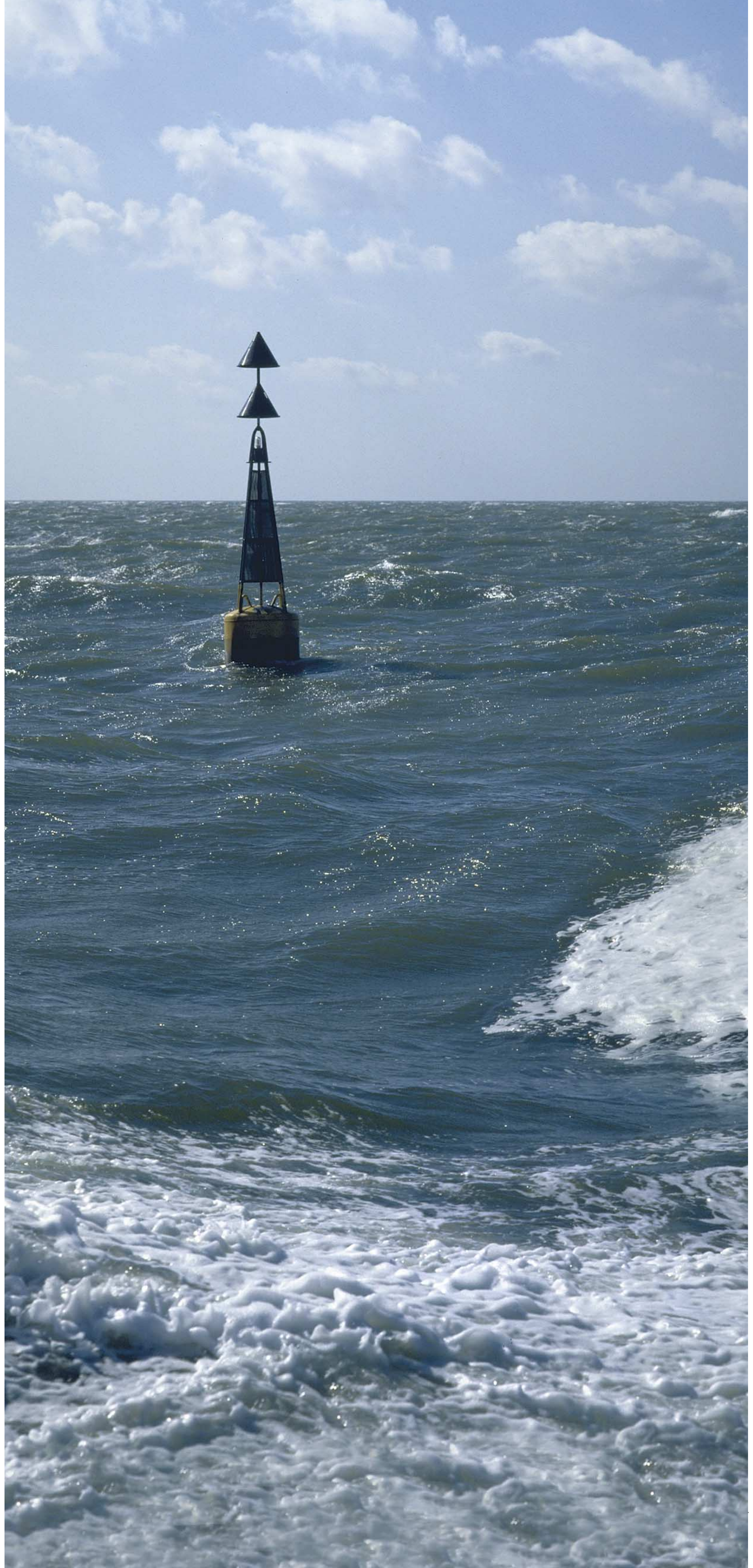


Photo: CDanmark

contained in the plan. The nation-wide programme was revised in 1992 and the latest revision in 1997–1998 resulted in implementation of the Danish Aquatic Monitoring and Assessment Programme 1998–2003 commonly referred to as NOVA–2003.

The monitoring and assessment-programme has been planned and designed on the basis of national and international obligations and the needs agreed by the Danish Parliament, OSPAR and HELCOM. The existing programme implements all national or international agreed monitoring and assessment activities, including parameters, numbers of stations, frequencies, quality assurance, data handling and reporting.

The Danish monitoring cruises are co-ordinated at different levels:

- Between counties.
- Between counties and NERI.
- Between NERI and Swedish, Norwegian and German institutions.

This added value of co-ordination reduces sailing time in many coastal and open waters. The stations sampled and methods are identical to the extent possible and the monitoring frequency of sampling a station are at a level which makes it possible to assess the eutrophication status of marine waters on a year-to-year and in some cases on a season-to-season basis.

The outcome of the Danish monitoring and assessment programme is evaluated and reported annually. County authorities are responsible for assessment of local areas and, wherever relevant, they include an assessment as to what extent the regional quality objectives for the aquatic environment have been met. Based on the regional reports and information from other national and international monitoring activities, NERI prepares a nation-wide assessment of discharges and environmental state. Oxygen depletion reports in August, September and October and crosscutting theme reports supplement the annual assessment. The annual assessment reports are also the basis for the Danish contribution to various international conventions and organisations.

Denmark and most countries bordering the North Sea and the Baltic Sea have so-far not been able to achieve the agreed reductions in the inputs of nutrients to the marine waters.

Biofoto/Jesper Plambech

Summary, conclusions and the future

4

The summary is based on the eutrophication status in the years 2000 and 2001, and the development since implementation of the Danish National Monitoring and Assessment Programme in 1989, the latter being an integral part of the Danish Action Plan on the Aquatic Environment from 1987.

Degree of nutrient enrichment

Nutrient load

Detailed nutrient load compilations to Danish waters were initiated in 1989, although the main increase in nutrient loads from land and atmosphere actually took place long before. As an example, the estimated annual riverine load of N to Danish coastal waters in the 1960s was about 60% of that in the 1980s and the P load increased four fold in the Baltic Sea, North Sea regions from the 1940s to the 1970s. A growing number of sewage treatment plants have reduced the Danish point source loads of P to surface waters (fresh and marine) since the late 1980s by nearly 90% and the total land based P load to marine waters has been reduced by 60% from 1990 to 2001. The improved sewage treatment has also reduced the overall N load by about 14%, while decrease in leaching from agricultural soils has reduced the N load with about 21%. All figures are corrected for variations in runoff.

Atmospheric deposition of inorganic nitrogen is important on large sea surfaces as Kattegat and the Belt Sea where atmospheric N deposition makes up about 30% of total N load from surrounding land and atmosphere. During the period 1989–2001 there was a decrease in the air concentration of N bound in particles and a tendency to a decreasing deposition of about 15%.

Nutrient concentrations

The assessment of trends in nutrient concentrations in Danish waters is based on indices for mean annual concentrations of DIN, TN, DIP and TP in the upper mixed layer developed for estuaries-coastal waters and the open Kattegat–Belt Sea.

The decreasing nutrient load to Danish waters is reflected in the nutrient concentrations. The nitrogen concentrations in 2001 were the lowest observed during the period 1989-2001 and at the same level as in the very dry years 1996 and 1997, even though the runoff was about normal. In the open waters of the Kattegat and Belt Sea the runoff corrected nitrogen concentrations shows a steady decrease since 1989. In the estuaries and coastal waters, a significant decrease was observed after 1997. In the estuaries and coastal waters, the phosphorus concentrations have stabilised at a low level after significant decreases in the beginning of the 1990s.

N/P ratio

The optimal N/P-ratio, the Redfield ratio, for phytoplankton growth is 16:1. In the open Belt Sea and Kattegat the winter DIN/DIP-ratio did not deviate much from the Redfield ratio and there was no general trend in annual mean N/P-ratio during the period 1989–2001.

In estuaries the winter DIN/DIP-ratio is high (>25) to very high (>100). Annual mean N/P-ratios in the estuaries-coastal waters showed an increase from 1989 to 1998 parallel to the reduction in phosphorus load, and then a decrease to 2001 parallel to the decrease in nitrogen load per runoff.

In the North Sea the N/P-ratio was generally high ranging between 25 and 60, except in the saline central North Sea water. Also in the Skagerrak N/P-ratios were high at salinities lower than 33.

Direct effects

Chlorophyl concentrations

Since 1980 absolute concentrations of chlorophyll *a* in Danish open sea areas have been >50% above background concentrations given by OSPAR. At first chlorophyll *a* concentrations seem to have decreased in open sea areas since 1980. However, year-to-year variations have been substantial. Chlorophyll *a* index values adjusted for variations in climatic conditions shows that chlorophyll *a* values were very constant in the period 1987-2001.

In estuaries and coastal waters chlorophyll *a* concentrations have decreased since the late 1980s. The chlorophyll *a* index values adjusted for variations in climatic conditions for 1993–2001 were at a consistent and decreasing lower level than that found in the mid 1980s.

Submerged aquatic vegetation

The colonisation depth of eelgrass reflects differences in water quality and physical setting along estuarine gradients. In the deeper, more protected waters, reductions in eelgrass abundance towards the lower depth limit correlate with light attenuation and are therefore more directly coupled to changes in eutrophication. During the period 1989-2000 eelgrass colonisation depth showed no significant trend and did not reflect the slight amelioration of water clarity observed through the same period. During the period 1989-2001 eelgrass cover deeper than 2 meters showed no significant trend, but the cover of shallow populations was significantly reduced in inner estuaries and along open coasts. There is no obvious explanation for this pattern. Though eelgrass colonisation depth and abundance from intermediate depths towards deeper waters are likely to be better response parameters to eutrophication than the abundance of shallow populations.

In 2001 many Danish estuaries still had an abundant cover of nuisance macroalgae. While there seemed to be a decrease in the relative cover of nuisance species at 0-1 and 1-2 meter depths since 1997, there was an increase in cover from 1998 to 2001 at 2-4 meters. In general, there where no significant changes during the period 1993 to 2001. The tendency of a reduction in relative cover was not true for some estuaries where relative cover had actually increased.

Photo: Fyn County/Nanna Rask

Results from 2001 showed that total cover of upright vegetation on reefs in open waters tended to increase according to the mean of the period 1994–2001. In general, algal coverage was low in years with relatively high runoff and high in years of low runoff during the period. Accordingly, there was no over all trend in the distribution on the monitored reef stations.

Indirect effects

Oxygen concentrations

Analyses of the development in bottom water oxygen concentrations during late summer/autumn in the Kattegat-Belt Sea from the 1970s to late 1980s/1990s showed significant decreases in all areas with a stratified water column. The decrease was especially pronounced from the mid 1970s to the late 1980s. There was no general development in the summer/autumn bottom water minimum oxygen concentration in the period 1989–2001. However, there was a tendency for an increase in minimum oxygen concentrations in spring (April–June). Nevertheless, at the end of August 2002 an unusually widespread and serious oxygen deficiency was observed in large areas of the inner Danish marine waters and common Danish-Swedish and Danish-German waters. In many areas of the southern Kattegat, the Sound and the Belt Sea oxygen levels in bottom waters were reduced to a level seldom or never seen before.

Macrozoobenthos

General trends in abundance of macrozoobenthos in the Sound, Kattegat and Belt Sea follow a bimodal pattern over the last 20 years with peaks in the beginning of the 1980s and in the middle of the 1990s. During the period 1998–2001 biomass and essentially total abundance of macrozoobenthos in the open waters showed the lowest values since the measurements started two decades ago. Some evidence indicates that reduced N-nutrient concentrations, and possibly reduced diatom abundance, when corrected for runoff, may have reinforced the decrease in zoobenthos stocks in recent years.

Correlation analyses between biological variables and the North Atlantic Oscillation index and runoff of freshwater from Denmark, showed significant positive correlations with 1 or 2 years time lag, thereby indicating that climate also influences variations in benthic macrofauna. In particular winter nutrient input, and likely the spring phytoplankton bloom, did influence benthic abundance.

The number of coastal areas with increasing species diversity were about the same as those with decreasing diversity during the period 1998–2001. Local factors like oxygen deficiency is a possible reason for these differences. During the same period there was no general change in abundance, biomass or number of species in coastal areas.

Photo: NERI/Peter Bondo Christensen

A Coastal areas	1998	1999	2000	2001	NC	MO	BF	SAV	NM	OD
					Assessment criteria in 2001					
1. North Sea and										
2. Skagerrak										
• North Sea, coastal parts	÷	÷	÷	÷	x	x				
• Ringkjøbing Fjord	÷	÷	÷	÷	x			x	x	
• Nissum Fjord	÷	÷	÷	÷	x	x		x		
• Vadehavet	÷	÷	÷	÷	x	x		x	x	
• Skagerrak, coastal parts	+/÷	+/÷	+/÷	+/÷	x					
3. Kattegat										
• Isefjord	÷	÷	÷	÷	x		x		x	x
• Limfjorden	÷	÷	÷	÷	x	x	x	x		x
• Mariager Fjord	÷	÷	÷	÷	x	x	x	x	x	x
• Randers Fjord	÷	÷	÷	÷	x		x	x		
• Roskilde Fjord	÷	÷	÷	÷	x	x	x	x		
• Kattegat, coastal southern parts	÷	÷	÷	÷	x	x			x	
• Kattegat, coastal western parts	÷	÷	÷	÷	x		x	x	x	
4. Northern Belt Sea										
• Horsens Fjord	÷	÷	÷	÷		x	x	x		x
• Odense Fjord	÷	÷	÷	÷	x	x		x	x	x
• Sejerø Bugt	÷	÷	÷	÷			x		x	x
• Århus Bugt/Kalø Vig	÷	÷	÷	÷	x	x	x	x		x
5. Little Belt										
• Augustenborg Fjord	÷	÷	÷	÷				x	x	
• Flensborg Fjord	÷	÷	÷	÷				x		x
• Kolding Fjord	÷	÷	÷	÷		x	x	x		
• Vejle Fjord	÷	÷	÷	÷		x	x	x		
• Åbenrå Fjord	÷	÷	÷	÷				x		x
6. Great Belt										
• Kertinge Nor	÷	÷	÷	÷	x		x		x	
• Kalundborg Fjord	÷	÷	÷	÷			x		x	x
• Korsør Nor	÷	÷	÷	÷			x		x	x
• Sydfynske Øhav	÷	÷	÷	÷	x		x		x	x
• Karrebæk Fjord	+/÷	+/÷	+/÷		x			x	x	x
• Karrebæksminde Bugt	+	+	+	+			x	x	x	x
• Dybsø Fjord	+	+	+	+	x			x	x	x
7. The Sound										
• Øresund, northern part	÷	÷	÷	÷				x	x	
• Køge Bugt	÷	÷	÷	÷			x	x	x	
8. Southern Belt Sea and										
9. Baltic Sea										
• Bornholm, coastal waters	÷	÷	÷	÷	x			x		
• Hjelm Bugt	÷	÷	÷	÷	x	x		x	x	x
• Præstø Fjord	÷	÷	÷	÷	x			x	x	x

B Open sea areas	1998	1999	2000	2001	NC	MO	BF	SAV	NM	OD
					Assessment criteria in 2001					
1. North Sea and										
2. Skagerrak										
• North Sea, open parts	+	+	+	+	x					
• Skagerrak, open parts	+	+	+	+	x					
3. Kattegat										
• Kattegat, northern open parts	+/÷	+/÷	+/÷	+/÷	x			x		
• Kattegat, central open parts	+/÷	+/÷	+/÷	+/÷	x			x		
4. Northern Belt Sea										
• Belt Sea, northern open parts	÷	÷	÷	÷	x					x
5. Little Belt										
• Little Belt, northern open parts	÷	÷	÷	÷		x	x	x		x
• Little Belt, southern open parts	÷	÷	÷	÷			x	x		x
6. Great Belt										
• Great Belt, open parts	÷	÷	÷	÷	x					x
7. The Sound										
• Øresund, northern part	÷	÷	÷	÷				x	x	x
• Køge Bugt	÷	÷	÷	÷			x	x	x	
8. Southern Belt Sea and										
9. Baltic Sea										
• Southern Belt Sea, open parts	÷	÷	÷	÷	x			x	x	x
• Arkona Bassin	÷	÷	÷	÷	x	x				x
• Baltic Sea, east of Bornholm	(÷)	(÷)	(÷)	(÷)	x	x				x

Table 4.1 A + B
Fulfilment of objectives and assessment criteria in selected coastal areas (A) and selected open sea areas (B) from 1998–2001. The assessment criteria are:
NC – Nutrient concentrations
MO – Mass occurrence of algae
BF – Benthic fauna
SAV – Submerged aquatic vegetation
NM – Annual nuisance macroalgae
OD – Oxygen depletion

EQOs impaired	÷
EQOs close to fulfilment	+/÷
EQOs fulfilled	+

Based on Ærtebjerg et al. 2002.

Photo: CDanmark

Effectiveness of strategies and measures

The national target of an 80% reduction of phosphorus from sewage plants and industry to fresh and marine waters was achieved already by 1996. The reductions of nitrogen discharges from sewage treatment plants have also been successful. The remaining and still unsolved problem is related to losses of nutrients from the agricultural sector in Denmark, even a 30% reduction in losses from the root zone has been achieved. However, this is not only the case in Denmark, as almost all countries bordering the North Sea and the Baltic Sea have so-far not been able to achieve the agreed reductions in the losses from agriculture.

It has been estimated that the Danish Action Plans on the Aquatic Environment in 2003 will result in a change in agricultural activities, which together with the reductions of discharges from industries and municipal waste water treatment plants, is likely to reduce discharges from these sources by nearly 50% (Grant et al. 2000). This corresponds to a reduction of nitrogen inputs to marine areas by at least 35%. The actual reductions in inputs to marine waters due to reductions in other sources and sectors (atmospheric emissions, scattered settlements, stormwater overflows, freshwater aquaculture, and mariculture) will be somewhat higher.

Photo: CDanmark

Despite the achieved reductions in the nutrient inputs to marine waters, the quality status of the majority of marine waters still does not fulfil the general quality objective with no or only a slight impact on flora and fauna. However, improvements can be seen in local areas.

The Danish government has in autumn 2002 taken initiatives to start discussions on new measures to be taken to combat eutrophication. The discussions are expected mainly to focus on discharges and losses of nitrogen and phosphorus from agriculture. Until recently, phosphorus from agriculture has not been considered an important source, as most of the phosphorus was considered to be retained in the root zone. However, improved knowledge on the phosphorus cycle indicates a greater loss of phosphorus from agriculture than taken into calculation in the previous action plans.

The strategies and measures to reach the goal of a healthy marine environment must focus on a reduction of discharges, emissions and losses for all relevant sources and on ecological quality objectives for the marine environment. With regard to reductions, the Danish Action Plans on the Aquatic Environment focus on the major sources in order to achieve cost/effective reductions. However, future action plans should include all relevant sources. With regard to ecological quality objectives, the Danish objectives from 1984 are normative. They have to be operational and expressed as numbers and values. This will be done as an integral part of the Danish implementation of the Water Framework Directive. This directive is a major player in the years to come. A successful implementation is a prerequisite for an informed management of marine eutrophication. The implementation process should not overlook the Habitat Directive and the work within HELCOM and OSPAR together with the future EU Marine

EQO-eutro ↓

OSPAR COMP	Non-Problem Area		Problem Area		
Danish AEPS	Compliance		Non-Compliance (or Accommodated)		
EU WFD	High	Good	Moderate	Poor	Bad
EU Habitats Directive	Favourable Conservation Status		Unfavourable Conservation Status		
EU Urban Wastewater Directive	Less sensitive		Sensitive areas		
EU Nitrates Directive	Less vulnerable zones		Vulnerable zones		
EU Marine Strategy	Compliance with goals		Impaired ecosystem health		

↑ EQO-eutro

Figure 4.1
Suggested identity between eutrophication related Ecological Quality Objectives (EQOs) according to OSPAR Comprehensive Procedure (COMP), the existing Danish Aquatic Environmental Planning System (AEPS), the Water Framework Directive (WFD), the Habitat Directive and the future EU Marine Strategy. (Modified from OSPAR ETG 01/7/1, Annex 6, 2001; Henriksen et al. 2001 and Pedersen et al. 2001).

Strategy. The quality objectives should be parallel as illustrated in Figure 4.1.

Conclusions

Eutrophication effects have been documented in all Danish marine waters every year since the beginning of the 1980s. At present it can be concluded that quality criteria has only been fulfilled in a restricted number of Danish estuaries, coastal and open water areas. The few coastal areas that meet the criteria are generally non-stratified shallow water areas with a relatively restricted load from land based sources. The causes for not fulfilling the criteria are primarily the effects of nutrient load and oxygen depletion.

With corrections for variations in precipitation, run off and other climatic related conditions it can be concluded that:

Nutrient loads

Since 1990 land based inputs of nitrogen and phosphorus to estuaries and coastal areas have been reduced by 35% and 60%, respectively. The reduction in nitrogen (21%) is mainly caused by reduced loses from agricultural soils while the reduction in phosphorus is due to extension of sewage treatment. Atmospheric nitrogen deposition to Danish marine waters seems to have declined about 15% since 1989.

Nutrient concentrations

Nitrogen concentrations in estuarine and coastal areas have decreased significantly after 1997 and since 1989 in the open waters. Concentrations of phosphorus have stabilised after a significant decrease in the beginning of the 1990s.

Direct effects

Water clarity increased and phytoplankton biomass and production decreased significantly in estuaries and coastal areas until the mid 1990s. The changes are less pronounced in open waters, although water clarity was higher and diatom biomass as well as phytoplankton production were lower in the 1990s than in the 1980s.

During the period 1989-2001 eelgrass cover at water depths above 2 meters increased in the outer part of the estuaries, but was significantly reduced at shallow depths in inner estuaries and along open coasts. The depth distribution has not increased, but in the inner estuaries actually decreased, possibly due to oxygen depletion.

The amount of nuisance macroalgae has been reduced (though this is not always noted in the cover) at shallow depths. Macroalgae cover at open water reefs shows no trends since 1994.

Indirect effects

The biomass of macrozoobenthos in open waters has decreased through the 1990s following a reduction in the biomass of diatoms and phytoplankton production. Macrozoobenthic communities in estuaries and coastal areas show large inter annual variations, which seem to be caused by recurrent oxygen depletion.

The future

The experience from the years 1996 and 1997, when precipitation and runoff were very low and the 50% reduction target for nitrogen reduction was actually met, clearly shows that the reduction target of 50% in the input to the marine area considerably improves the quality status of the marine environment. The 50% reduction in nitrogen inputs, therefore, needs to be met in order to reduce eutrophication problems in marine areas.

Trends in nutrient reductions are on the right track, both with respect to the reduction of discharges, emissions and losses of nutrients to marine waters and to the quality of the marine environment. But the road to fulfilment of eutrophication quality criteria is long and winding. The existing criteria and the acceptable deviations from reference conditions should be regarded as a starting point. The variability found for different parameters is naturally large. It might therefore be reasonable to develop global or type-specific assessment criteria and, taking these as a starting point, to develop site-specific assessment criteria.

Focusing on national reductions in inputs is reasonable. But inputs from adjacent seas should also be taken into account. It is likely that these inputs will decrease. However, future enlargement of the European Union is likely to result in a development of the agricultural sector in Poland and the Baltic States. This may result in an increase in losses form cultivated farmland and eventually an increase in inputs to the Baltic Sea, and thus an increase in the inputs to Danish waters from the Baltic Sea.

However, nutrient enrichment, eutrophication and oxygen depletion are naturally occurring phenomena. It is the extent in space and the duration and strength that is affected by human activities. These undesirable effects in our marine waters can not be avoided, but the anthropogenically induced strengthening of these phenomena should be reduced.

The implementation of the Water Framework Directive has to take the Habitat Directive and EU Marine Strategy into account, especially with regard to the objectives on ecological and conservation status. If not, the management of the ecosystems and resources in the Danish marine water will face different protection levels and thus be complicated beyond reason.

It is likely that the implementation of the Water Framework Directive will lead to supplementary measures in catchment areas to specific coastal waters as vulnerable and sensitive estuaries and enclosed bays. The combination with legally binding quality objectives and integrated strategic management should make it possible to calculate backwards from the normative definition of good ecological status to concentrations, inputs, and other human activities affecting eutrophication status of marine waters. The key question in the future is whether diffuse sources can and will be adequately managed.

Photo: NERI/Gunni Ærtebjerg

Photo: High-light

GLOSSARY AND ABBREVIATIONS

Advection – the transfer of heat or matter by horizontal movement of water masses.
Aerobic – with the presense of oxygen. Is used to describe chemical processes or organisms that require oxygen. See also anaerobic.
Algae – a large assemblage of lower plants, formerly regarded as a single group, but now usually classified in eight separate divisions or phyla, including the blue-green algae (Cyanophyta), green algae (Chlorophyta), brown algae (Phaeophyta), red algae (Rhodophyta), diatoms and (Chrysophyta). Marine macroalgae are commonly known as seaweeds.
Ammonia (NH_3) – a colourless gas formed by decomposition of protein, nitrogenous bases and urea. It is easy soluble in water and its pungent smell is well known from ammonia water.
Ammonium (NH_4^+) – a nitrogen compound, an ion derived from ammonia.
Anaerobic – without the presense of oxygen. Is used to describe chemical processes or organisms that does not require oxygen. See also aerobic.
Anoxic – the state of oxygen depletion with absence of oxygen. Anoxic sediments and anoxic bottom waters are commonly produced where there is a depletion of oxygen, owing to very high organic productivity, and a lack of oxygen replenishment to the water or sediment, as in the case of stagnation or stratification of the body of water.
Aquatic – growing or living in or near water.
ASP – short for Amnesic Shellfish Poisoning. The poisoning is caused by intake of shellfish which has accumulated certain algal toxins.
Atmospheric deposition – deposition of nutrients, heavy metals and other pollutants from the atmosphere.
Autotroph – an organism which builds complex organic molecules from simple inorganic compounds. Also used to name organisms using photosynthesis in this process.
BAT – Best Available Techiques, means the most advanced activities, processes, and operating methods and the methods most effective in preventing or limiting pollution from a given sector.
Benthos – those organisms attached to, living on, in or near the sea bed, river bed or lake floor.
Bio-available – matter that is available for primary production or will become available within the residence time of the water in a given marine area.
Biomass – the weight of organisms in a

certain area either described with reference to volume or area.
Bluegreen algae – marine and freshwater unicellular, colonial or filamentous bacteria. Resembles algae in the way that they have chlorophyll pigments and can perform photosynthesis.
Brackish water - water with a salt concentration between 5-18ppt.
C – carbon, see carbon biomass.
Carbon biomass – biomass as the amount of carbon (C) in a given area or volume.
CHARM – an EU funded project which has been developed to provide a scientific foundation for fulfilling the requirements of the EC Water Framework Directive in Baltic coastal waters.
Chl *a* – see Chlorofyll *a*.
Chlorophyll *a* – *a* specific plant pigment essential for photosynthesis. It is quantitatively the most important pigment found in all photosynthetic phytoplankton cells.
Chlorophyll – any of several green pigments found in the chloroplasts of plants and in other photosynthetic organisms. They mainly absorb red and violet-blue light energy for the chemical processes of photosynthesis.
Cladoceran – water flea. A small crustacean with a carapace that forms a bivalved shield. The cladocerans are suspension feeders and collect food with fine bristles on the trunk appendages.
Ciliate – a diverse group of one celled animal like organims. They possess cilia for locomotion and in many species for suspension feeding.
Contaminants – are substances that are toxic to living organisms. Most of them are hard to degrade in a natural environment
Copepod – a small free-living or parasitic crustacean. One of the most abundant marine zooplankton organisms.
Cyanobacteria – see bluegreen algae.
Denitrification – reduction of nitrates to free nitrogen (N_2) by certain bacteria.
Deposition – see atmospheric deposition
Detritus – small pieces of dead and decomposing plant and animal material, i.e. organic material.
Diatom – a unicellular algae with silicified walls. Diatoms often make up the majority of the spring bloom phytoplankton biomass.
Diffuse sources – larger geographical area, excluding city areas, from which nutrients or contaminants are washed out to the sea (see also point sources).
DIN – dissolved inorganic nitrogen. The sum of nitrate, nitrite and ammonium i.e. nitrogen that can be absorbed by plants.
Dinoflagellate – any of numerous minute, chiefly marine protozoans of the order Dinoflagellata, characteristically having two flagella and a cellulose covering and forming one of the chief constituents of plankton. They include bioluminescent forms and forms that produce red tides.
DIP – dissolved inorganic phosphorus. The chemical form in which phosphorus can be absorbed by plants.
DSP – short for Diarrhetic Shellfish Poisoning. The poisoning is caused by intake of shellfish that has accumulated certain algal toxins.
Eelgrass (*Zostera marina*) – a submerged flowering plant that grows along the major part of the Danish coasts.
Emission – release of chemicals to the atmosphere.
EQO – Ecological Quality Objective.
Estuary – the transition area between a river and the sea, i.e. an estuary is a body of water that is formed when fresh water from rivers flow into and mixes with salt water from the ocean. In estuaries, the fresh river water is blocked from directly entering the open ocean either by the surrounding mainland, peninsulas, barrier islands, or fringing salt marshes.
EU – European Union.

Euphotic zone – the upper, illuminated zone of aquatic ecosystems. The zone of effective photosynthesis. In marine ecosystems it is much thinner than the deeper aphotic zone which is below the level of effective light penetration. It typically reaches 20–30 meters in coastal waters but extending to 100–200m in open ocean waters.
Eutrophication – eutrophication is enhanced inputs of nutrients and organic matter. Eutrophication can be a natural process, but is most often caused by humans. See also box 1.
Fauna – animal organisms.
Flagellates – microscopic unicellular organisms in aquatic systems. They move by the use of one or more flagella, a string-like extension from the cell. Amongst the flagellates are both heterotophs, autotrophs and mixotrophs.
Flora – plant organisms.
Food chain – refers to direct links between organisms that describes how food energy is transfered through the ecosystem from the smallest primary producers to top predators. An example from the marine ecosystem is planktonic algae → copepods → fish → seal.
Food web – a description of who eats who in an ecosystem. In its most simple form a food chain, but more commonly a net of organisms where several organisms are capable of eating the same food item.
Grazing – literally to feed on growing grasses and herbage the term refers to feeding habits of animals in the terrestrial environment. In the aquatic environment the analogue is organisms feeding on plant or plant like organisms. An example is copepods that graze on phytoplankton.
Halocline – a zone in which there are rapid, vertical changes in salinity. The halocline is usually well-developed in coastal regions where there is much freshwater input from rivers producing surface waters of low salinity, a zone where salinity increases rapidly with depth (the halocline) and a deeper zone of more saline, denser waters.
HELCOM – the Helsinki Commission.
Heterotroph – an organism that cannot synthesise its own food and is dependent on complex organic substances for nutrition. That is, it eats other organisms.
H_2S – hydrogensulfide.
Hypoxia – see oxygen depletion.
ICES – International Council for the Exploration of the Sea.
Inorganic – a chemichal substance that does not involve neither organic life nor the products of organic life, i.e. hydrocarbon groups.
K_s – half-saturation constant. Nutrient concentration at which the phytoplankton nutrient uptake rate is reduced to half the maximum uptake rate.
Macroalgae – macroalgae are plants that lack true roots, stems, leaves, and flowers. They mostly live attached to a hard substrate.
Macrozoobenthos – animals larger than 1 mm living attached to, on, in or near the sea bed, river bed or lake floor.
Marine – of, or pertaining to, the sea, the continuous body of water covering most of the earth's surface and surrounding its land masses. Marine waters may be fully saline, brackish or almost fresh.
Mesozooplankton – animal plankton of the size 0.2 – 2.0 mm.
Metabolism – the chemical change, constructive and destructive, occuring in living organisms.
Metazooan – multicellular, motile animal organisms with cells organized into tissues and controlled by a nervous system.
Microbial loop – a part of the pelagic planktonic food web consisting of bacteria,

flagellates and ciliates. Organisms in the microbial loop transfers energy from dissolved organic carbon back to the copepods.
Microzooplankton – animal plankton of the size 0.02 – 0.2 mm.
Mixotroph – an organism which is capable of performing photosynthesis as well a living partly as a heterotroph. Mixotrophy is commonly found among dinoflagellates. The mixotrophy appears to have different functions in different dinoflagellates; in some primarily phototrophic dinoflagellates feeding appears to be a mechanism for obtaining limiting inorganic nutrients, in some primarily heterotrophic dinoflagellates photosynthesis appears to be a mechanism for supplementing carbon metabolism.
Molar – designating a solution that contents one mole of solution per litre.
μ (prefix) – micro, 10^{-6}.
N – see nitrogen.
NAO – North Atlantic Oscillation is an index that is based on the difference in atmospheric pressure between the Azores and Iceland.
Nitrate (NO_3) – an important nitrogen containing nutrient. The chemical form in which plants uptake most of their nitrogen. It is the salt of nitric acid.
Nitrogen (N) – is a chemical element that constitutes about 80% of the atmosphere by volume. Nitrogen is an important part of proteins and is essential to living organisms.
Oxides of Nitrogen (NO_x) – chemical compounds, gases, formed by nitrogen and oxygen. NOx are formed by the combustion of oil, gasoline, coal and gas. NOx is soluble in water and reacts with water or substances in water to form nitrate.
Nutrient – chemical elements which are involved in the construction of living tissue that are needed by both plants and animals. The most important in terms of bulk are carbon, hydrogen and oxygen, with other essential ones including nitrogen, potassium, calcium, sulphur and phosphorus.
Oligotrophic – applied to waters or soils that are poor in nutrients and have low primary productivity. (See also eutrophic).
Organic – organic compounds contain the element carbon. Of, relating to, or derived from living organisms.
Organism – an individual form of life. An animal, plant or bacteria.
OSPAR – the Oslo and Paris Commission.
Oxygen – a non-metallic element constituting 21 percent of the atmosphere by volume. Oxygen is produced by autotrophic organisms and is vital to oxygen breathing organisms.
Oxygen depletion – a situation where the demand for oxygen has exceeded the supply of oxygen leading to low concentrations of oxygen. Low oxygen concentrations are normally found in the water close to the sea bottom. In Denmark, concentrations below 4 mg O_2 per liter are defined as oxygen depletion and concentrations below 2 mg O_2 per liter are defined as severe acute oxygen depletion.
P – see phosphorus.
Parthenogenesis – litterally it means virgin descent and refers to production og offspring where the female has not been fertilized by a male.
Pelagic – the open-water environment, or water column, as distinct from the bed or shore, inhabited by swimming marine organisms.
Phosphate (PO_4) – is an important phosphorus containing nutrient. It is the chemical form in which plants uptake phosphorus.
Phosphorus (P) – a non-metallic chemical element.
Photosynthesis – the process in green plants and certain other organisms by which carbohydrates are synthesised from carbon dioxide and water using light as an energy source. Most forms of photosynthesis release oxygen as a by-product.
Phytoplankton – the plant plankton and primary producers (i.e. drifting, more or less microscopic, photosynthetic organisms) of aquatic ecosystems.
Plankton – free passively floating organisms (animals, plants, or microbes) in aquatic systems.
Point source – discharge from one point. The sources are sewage treatment plants, industrial plants, storm water runoff, fresh water aquaculture and mariculture.
Population – all the organisms that constitute a specific group or occur in a specified habitat.
Predator – an organism that lives by preying on other organisms.
Primary production – the production by autotrophs.
Protozooplankton – zooplankton consisting of only one cell.
Rotifer – or rotatoria commonly called wheel animals. A microscopic aquatic animal with at ciliated organ called a corona, which looks like a rotating wheel. Mostly a freshwater animal although some marine species exist.
Runoff – that part of rainfall that is not absorbed in soil but falls on or flows directly into streams and rivers.
Salinity – a measure of the total quantity of dissolved substances in water, in parts per thousand (ppt, per mille) by weight, when all organic matter has been completely oxidised, all carbonate has been converted to oxide, and bromide and iodide to chloride. The salinity of ocean water is in the range 33-38 ppt, with an average of 35 ppt.
Secchi depth – a measure of the clarity of the water.
Sediment – any material transported by water that will ultimately settle to the bottom after the water loses its transporting power. Fine waterborne matter deposited or accumulated in beds. Includes mobile or soft substrates such as cobbles, pebbles, sand and mud.
Stratification – in the sea it is a boundary between two water masses of different specific gravity. The stratification is typically formed by differences in temperature or salinity or both.
Tot-N – see TN.
Tot-P – see TP.
TN – total nitrogen, which includes dissolved inorganic nitrogen and organically bound nitrogen.
TP – total phosphorus, which includes dissoleved inorganic phosphorus and organically bound phosphorus.
Water column – the open-water environment, as distinct from the bed or shore, which may be inhabited by swimming marine or freshwater organisms. (See pelagic).
Wet deposition – deposition of matter by rain.
WFD – EU Water Framework Directive.
Zooplankton – small planktonic animals in fresh- or sea water with almost none or no swimming capacity. They are, therefore, transported randomly by water movements.

Where can I read more?

Relevant links

- OSPAR: http://www.ospar.org
- HELCOM: http://www.helcom.fi
- Department of Marine Ecology, NERI: http://www.dmu.dk/1_om_dmu/2_afdelinger/3_hav/default_en.asp
- Annual assessment reports on the status of the marine environment in Denmark: http://www.dmu.dk/1_Om_DMU/2_tvaer-funk/3_fdc_mar/publikationer.asp
- CHARM: http://charm.dmu.dk
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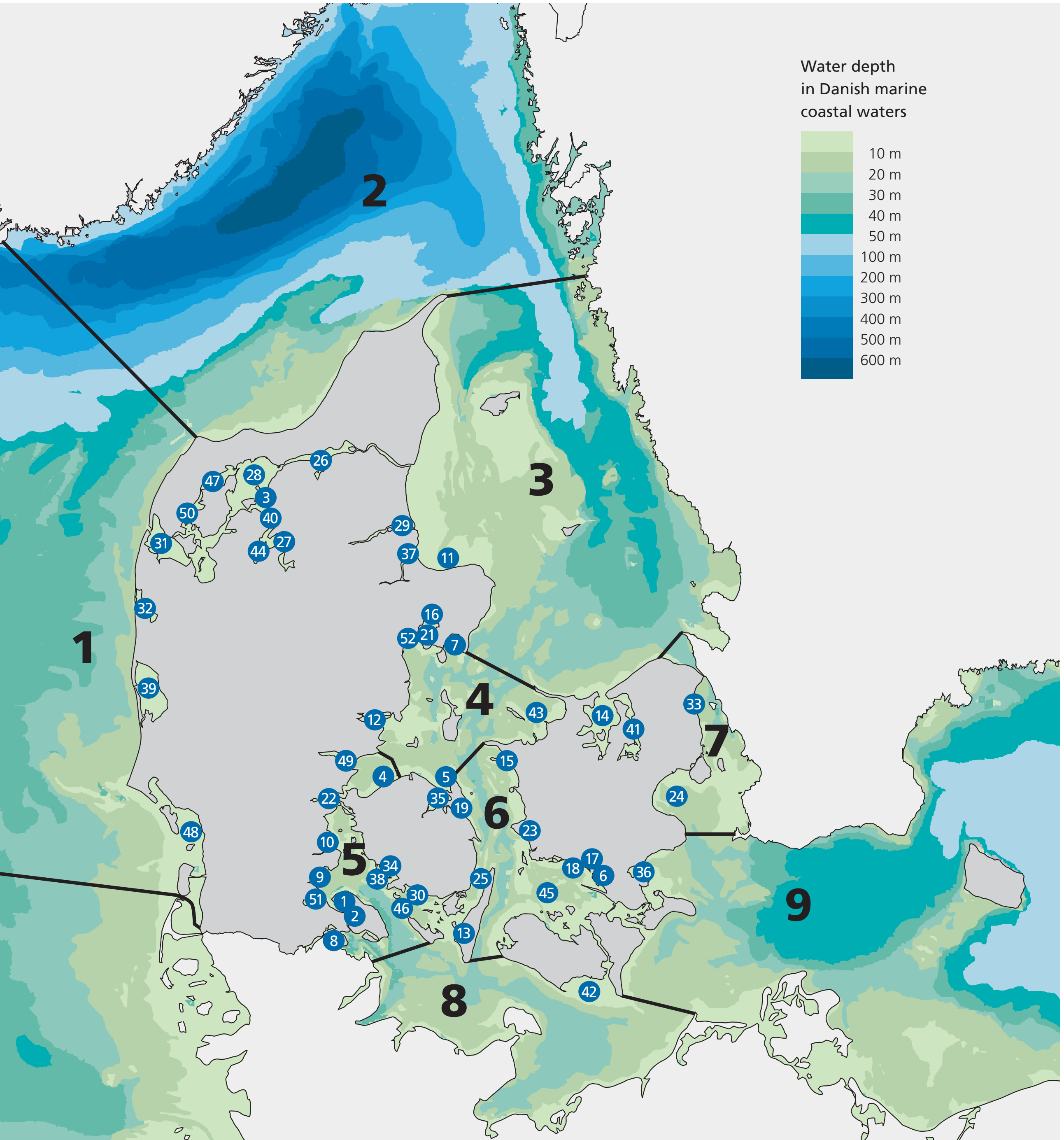

ANNEXES

MAP OF THE DANISH MARINE WATERS

The estuaries, coastal waters and open marine waters mentioned in the report are indicated on the map on the opposite page. Names referring to the numbers on the map are listed below. The translation of the Danish names to English are: "Bredning" – a broad; "Bugt" – a bay; "Bælt" – a belt; "Bælthav"– a belt sea; "Fjord" – an inlet, but often used as a general term for estuaries and should not be confused with the definition of a classical fjord with a sill; "Nor" – a cove; "Sund"– a strait or sound; "Vig" – a cove; "Øhav" – archipelago; "Farvand" – waters.

Danish marine sub areas

1 North Sea
2 Skagerrak
3 Kattegat
4 Northern Belt Sea
5 Little Belt
6 Great Belt
7 The Sound
8 Southern Belt Sea
9 Baltic Sea

Estuaries and coastal waters

1 Als Sund
2 Augustenborg Fjord
3 Bjørnsholm Bugt
4 Båring Vig
5 Dalby Bugt
6 Dybsø Fjord
7 Ebeltoft Vig
8 Flensborg Fjord
9 Genner Fjord
10 Haderslev Fjord
11 Hevring Bugt
12 Horsens Fjord
13 Hovvig
14 Isefjord
15 Kalundborg Fjord
16 Kalø Vig
17 Karrebæk Fjord
18 Karrebæksminde Bugt
19 Kertinge Nor
20 Kieler Bugt
21 Knebel Vig
22 Kolding Fjord
23 Korsør Nor
24 Køge Bugt
25 Langelandssund
26 Limfjorden
27 Lovns Bredning
28 Løgstør Bredning
29 Mariager Fjord
30 Nakkebølle Fjord
31 Nissum Bredning
32 Nissum Fjord
33 Nivå bugt
34 Nørrefjord
35 Odense Fjord
36 Præstø Fjord
37 Randers Fjord
38 Ringgård Bassin
39 Ringkøbing Fjord
40 Risgårde Bredning
41 Roskilde Fjord
42 Rødsand
43 Sejrø Bugt
44 Skive Fjord
45 Smålandsfarvandet
46 Sydfynske Øhav
47 Thisted Bredning
48 Vadehavet
49 Vejle Fjord
50 Visby Bredning
51 Åbenrå Fjord
52 Århus Bugt

OVERALL CLASSIFICATION

KEY TO THE TABLE AT PAGE 124 AND 125

NI	Riverine total N and total P inputs and direct discharges
DI	Winter DIN and/or DIP concentrations
NP	Increased winter N/P ratio
Ca	Maximum and mean Chlorophyll *a* concentration
Ps	Region/area specific phytoplankton indicator species
Mp	Macrophytes including macroalgae
O_2	Degree of oxygen deficiency
Ck	Changes/kills in zoobenthos and fish kills
Oc	Organic carbon/organic matter
At	Algal toxins (DSP/PSP mussel infection events)
+	Increased trends, elevated levels, shifts or changes in the respective assessment parameters

Area	Category I Degree of nutri- ent enrichment	Category II Direct effects	Category III and IV Indirect effects/ other possible effects	Initial classification	Appraisal of all relevant information (concerning the harmonised assessment criteria their respective assessment levels and the supporting environmental factors)	Final classification	Assessment period
Baltic Sea	NI + DI + NP +	Ca + Ps + Mp +	O_2 + At ? Ck Oc	Problem area	Blooms of *Nodularia spumigena, Aphanizomenon*, oxygen depletion	Problem area	1989–2001
Southern Belt Sea	NI + DI + NP +	Ca + Ps + Mp +	O_2 + At ? Ck + Oc	Problem area	Elevated inputs and/or increased trends of nutrients. Elevated concentrations of DIN. Elevated chlorofyll *a* concentrations, Blooms of *Nodularia spumigena, Aphanizomenon, Karenia mikimotoi, Pseudo-nitzschia, Prorocentrum minimum* and *Chrysochromulina*, decreased depth limit of eelgrass, oxygen depletion	Problem area	1989–2001
Little Belt	NI + DI + NP +	Ca + Ps + Mp +	O_2 + At + Ck + Oc	Problem area	Elevated inputs and/or increased trends of nutrients. Elevated concentrations of DIN. Elevated chlorofyll *a* concentrations, Blooms of *Nodularia spumigena, Aphanizomenon, Dictyocha speculum, Karenia mikimotoi, Pseudo-nitzschia, Prorocentrum minimum* and *Chrysochromulina*, decreased depth limit of eelgrass, oxygen depletion and algae toxins found in mussels in some areas.	Problem area	1989–2001
Great Belt	NI + DI + NP +	Ca + Ps + Mp +	O_2 + At ? Ck Oc	Problem area	Elevated inputs and/or increased trends of nutrients. Elevated concentrations of DIN. Elevated chlorofyll *a* concentrations, Blooms of *Nodularia spumigena, Aphanizomenon, Karenia mikimotoi, Pseudo-nitzschia, Prorocentrum minimum* and *Chrysochromulina*, decreased depth limit of eelgrass, oxygen depletion	Problem area	1989–2001
The Sound	NI + DI + NP +	Ca + Ps + Mp +	O_2 + At ? Ck Oc	Problem area	Elevated inputs and/or increased trends of nutrients. Elevated concentrations of DIN. Elevated chlorofyll *a* concentrations, Blooms of *Nodularia spumigena, Aphanizomenon, Karenia mikimotoi, Pseudo-nitzschia, Prorocentrum minimum* and *Chrysochromulina*, decreased depth limit of eelgrass, oxygen depletion	Problem area	1989 - 2001
Northern Belt Sea	NI + DI + NP +	Ca + Ps + Mp +	O_2 + At + Ck + Oc	Problem area	Elevated inputs and/or increased trends of nutrients. Elevated concentrations of DIN. Elevated chlorofyll *a concentrations*, Blooms of *Nodularia spumigena, Karenia mikimotoi, Pseudo-nitzschia, Prorocentrum minimum* and *Chrysochromulina*, decreased depth limit of eelgrass, oxygen depletion and algae toxins found in mussels in some areas.	Problem area	1989–2001
Kattegat Coastal areas	NI + DI + NP +	Ca + Ps + Mp +	O_2 + At + Ck + Oc	Problem area	Elevated inputs and/or increased trends of nutrients. Elevated concentrations of DIN. Elevated chlorofyll *a* concentrations, Blooms of *Chatonella, Karenia mikimotoi, Pseudo-nitzschia, Gymnodinium chlorophorum, Prorocentrum minimum* and *Chrysochromulina*, decreased depth limit of eelgrass, oxygen depletion and algae toxins found in mussels in some areas (Limfjorden).	Problem area	1989–2001
Kattegat Open areas	NI + DI – NP –	Ca + Ps + Mp +/–	O_2 + At – Ck + Oc	Problem area	Elevated inputs and/or increased trends of nutrients. Elevated concentrations of DIN. Elevated chlorofyll *a* concentrations, Blooms of *Chatonella, Karenia mikimotoi, Gymnodinium chlorophorum* and *Chrysochromulina*. Oxygen depletion.	Problem area	1989–2001
Skagerrak Coastal area	NI + DI + NP +	Ca + Ps + Mp +	O_2 – At – Ck – Oc	Problem area	Concentration of N and P elevated due to transboundery input (Jutland Coastal Current from German Bigth). Elevated concentrations of DIN. Elevated chlorofyll *a* concentrations, Blooms of *Chatonella, Karenia mikimotoi* and *Gymnodinium chlorophorum*	Problem area	1989–2001
Skagerrak Open area	NI – DI – NP –	Ca + Ps + Mp	O_2 – At – Ck Oc	Problem area	Elevated chlorofyll *a* concentrations, Blooms of *Chatonella* and *Karenia mikimotoi*.	Problem area	1989–2001
North Sea Coastal area	NI + DI + NP +	Ca + Ps + Mp +	O_2 – At – Ck – Oc	Problem area	Concentration of N and P elevated due to transboundery input (Jutland Coasta Current from German Bigth). Blooms of *Phaocystis, Pseudo-nitzschia, Karenia mikimotoi* and *Chatonella*. The western limit of the area to be defined.	Problem area	1989–2001
Central North Sea	NI – DI – NP –	Ca ? Ps ? Mp ?	O_2 – At – Ck – Oc	Non problem area	No elevated nutrient concentrations. The limit between the open area and the coastal area needs to be specified. A possible potential problem area in between the coast and the open sea area should also be identified.	Non problem area	All available data
Wadden Sea	NI + DI + NP +	Ca + Ps – Mp +	O_2 – At + Ck – Oc	Problem area	Concentration of N and P elevated due to local and transboundery input (Jutland Coastal Current from German Bigth). Mass occurrence of algae, including annual nuissance macroalge. Algae toxins found in mussels in some areas.	Problem area	1989–2001

Data sheet

Title: Nutrients and Eutrophication in Danish Marine Waters
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Abstract: Eutrophication – or nutrient over-enrichment – of Danish marine waters can to a large extent be attributed to excess nutrients flowing from upstream watersheds into coastal waters. The nutrient enrichment can result in algae blooms, oxygen depletion, kills of fish and organisms living at the seabed as well as other undesired effects. The result is impairment of environmental and habitat quality objectives. This assessment report explains technical aspects of eutrophication and assesses the present situation. In addressing abatement strategies, the assessment discusses the importance of developing normalised indices and setting ecological quality objectives. The assessment also reviews the National Action Plans on the Aquatic Environment from 1987 and 1997 and other policy options for reducing the losses and discharges of nutrients.

Keywords: Eutrophication, nutrient enrichment, coastal waters, estuaries, nitrogen, phosphorus, oxygen depletion, phytoplankton, submerged aquatic vegetation, zoobenthos, Action Plan on the Aquatic Environment, environmental protection, management of aquatic resources

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