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Eutrophication in Europe's coastal waters

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1. Summary

The major impacts of eutrophication due to overloading with nitrogen and phosphorus nutrients are changes in the structure and functioning of marine ecosystems, reduced biodiversity, and reduced income from fishery, mariculture and tourism.

The main objective of this report is to evaluate the causes, state and development of eutrophication in European coastal waters, and to identify areas where more monitoring data are needed to improve assessment. In addition, a first evaluation is made of the use of a trophical index for water quality assessment and the use of remote sensing as a eutrophication monitoring tool in northern seas.

Data and information from the marine conventions (AMAP, Helcom, OSPAR, UNEP/MAP, Medpol) and EEA national reference centres have been used, as well as information in grey and scientific literature. However, the data available for the project were scarce and, with the exception of some regions, inadequate for fully assessing the state and trends of eutrophication at a European level. In particular, eutrophication data were missing from the Bay of Biscay, the Iberian coast and the Mediterranean Sea.

Driving forces

The main source of nitrogen is run-off from agricultural land brought to the sea via rivers. Atmospheric deposition of nitrogen may also contribute significantly to the nitrogen load. This nitrogen originates partly from ammonia evaporation from animal husbandry and partly from combustion of fossil fuels in traffic, industry and households. Most of the phosphorus comes from households and industry discharging treated or untreated wastewater to freshwater or directly to the sea, and from soil erosion. Locally, fish farming may also cause eutrophication problems.

Pressures

The main increase in nutrient load took place before monitoring programmes and pollution load compilations were started. According to information in the literature, a conservative estimate of the increase in nitrogen loads from land and atmosphere to the Baltic and North Sea regions is a doubling from the 1950s to the 1980s, and a fourfold increase in the phosphorus load from the 1940s to the 1970s. The development in load to the Mediterranean Sea is unknown, but probably of the same magnitude.

Since the middle of the 1980s the phosphorus load has generally been reduced, in some Helcom and OSPAR areas up to 50 %, due to improved sewage treatment and phosphate-free detergents. The nitrogen load from point sources has also been reduced, but there is no discernible reduction from agriculture as the main diffuse nitrogen source to the North Sea. However, the nitrogen load to the Baltic Sea is assumed to have decreased slightly due to the reduction in the fertiliser usage in the countries in transition in this area.

Atmospheric nitrogen deposition to the Baltic Sea area decreased about 25 % from 1986 to 1995, although this was somewhat less in the transition area, mainly due to reduced production in eastern Europe. No changes have been seen in the wet deposition of nitrogen to the North Sea.

State and impact
The present state of eutrophication is assessed in terms of winter nutrient concentrations, chlorophyll-a and bottom oxygen concentrations. Nutrient concentrations gave the best spatial resolution in the assessment of eutrophication. Analysis of the relationship between nutrients and salinity showed a consistent pattern of eutrophic conditions in areas receiving freshwater input from urban and agricultural catchments. Freshwater from areas less impacted by human activity had in general no effect on the eutrophy of the seas. Chlorophyll-a concentrations showed a weak positive correlation to winter concentrations of nitrogen. Oxygen concentrations in the bottom water were not correlated with any of the other variables and the geographical pattern in hypoxia/anoxia could only be explained by the vertical stratification of the water column.

In agreement with the development in nutrient load, nitrogen and phosphorus concentrations in the Baltic Sea area and the German Bight generally doubled from the late 1960s to the middle of the 1980s. Phytoplankton production and frequency of algal blooms increased, and consequently the silicate concentrations decreased, as did also the transparency and, in stratified areas, the bottom oxygen concentrations. Since the middle of the 1980s phosphorus concentrations have decreased in many estuaries and coastal areas. However, nitrogen concentrations have remained constant or slightly decreased due to variations in run-off. General improvements in biological eutrophication variables are absent or local.

In Arctic waters with very sparsely populated drainage areas, eutrophication from fish farming in sill fiords is the major threat. However, as location of aquacultural plants is regulated, eutrophication is not an issue of concern in European Arctic waters.

The whole coastal as well as open Baltic Sea is affected by eutrophication with enhanced nutrient concentrations and related problems. The anthropogenic nutrient load is at its lowest in the northern forested and sparsely populated Gulf of Bothnia region. The highest load can be found in estuaries and coastal areas close to rivers that drain agricultural and densely populated areas.

In the Greater North Sea eutrophication primarily affects the coastal zone. In particular, in estuaries and fiords, Wadden Sea, German Bight, Kattegat and eastern Skagerrak, nutrient related problems are widespread.

In the Celtic Seas eutrophication is restricted to the Bristol Channel, Irish Sea and many estuaries, especially the Mersey estuary, Liverpool Bay, Belfast Lough, Cork Harbour, Dublin Bay and associated estuaries.

In the Bay of Biscay and at the Iberian coast eutrophication problems are restricted to estuaries and coastal lagoons, especially Bay of Vilaine, Arcachon, Ria Formosa and Huelva.

In the Mediterranean Sea eutrophication appears to be limited mainly to specific coastal and adjacent offshore areas. Several and sometimes severe cases of eutrophication are evident, especially in enclosed coastal bays which receive elevated nutrient loads from rivers, together with direct discharges of untreated or poorly treated domestic and industrial wastewater. In the Mediterranean Sea, especially the Adriatic, Gulf of Lion and northern Aegean Sea are areas with enhanced nutrient concentrations and related problems. Discharge of untreated or poorly treated wastewater is a major eutrophication problem in the Mediterranean Sea, in addition to nutrient loads from agriculture and aquaculture.

Responses

The Baltic Sea countries have decided on a 50 % reduction in the nutrient load, while the North Sea countries have decided on a 50 % reduction in the nutrient load to areas affected by or likely to be affected by eutrophication. OSPAR countries have designated areas to which a comprehensive procedure should be applied in order to classify the maritime area in terms of problem areas, potential problem areas and non-problem areas with regard to eutrophication. In addition the EU urban wastewater treatment directive, nitrate directive and water framework directive will reduce eutrophication in European waters, and eutrophication sensitive areas are identified by the Member States.

Trophic index and remote sensing

The trophic index and remote sensing of chlorophyll-a concentrations tested in this study have the potential to be developed further into practicable methods for monitoring and assessing the trophic state and trends of European marine and coastal waters.

2. Introduction

2.1. Definition of eutrophication

Eutrophication refers to an increase in the rate of supply of organic matter to an ecosystem, which most commonly is related to nutrient enrichment enhancing the primary production in the system (Nixon, 1995). Eutrophication levels vary due to natural causes from area to area. The primary productivity in the open Mediterranean Sea is very low, and in the open Baltic Sea relatively low, compared to the coastal areas of the Baltic and the North Sea or upwelling areas, where nutrient-rich deep water comes to the surface.

Nixon (1995) proposes the following definitions for different eutrophication levels based on phytoplankton primary production (measured as carbon (C)):

oligotrophic:	<100 g C m^{-2} y^{-1}
mesotrophic	100–300 g C m^{-2} y^{-1}
eutrophic	301–500 g C m^{-2} y^{-1}
hypertrophic	>500 g C m^{-2} y^{-1}

In this report eutrophication means enhanced primary production due to excess supply of nutrients from human activities, independent of the natural productivity level for the area in question. However, time series on primary production are very few and were not available for the project. Therefore, the analysis is focused on nutrients as causes of eutrophication.

The main nutrients causing eutrophication are nitrogen in the form of nitrate, nitrite or ammonium and phosphorus in the form of ortho-phosphate. In addition, supply of bioavailable organic phosphorus and nitrogen cause eutrophication, since bacteria under oxygen consumption regenerates the organic phosphorus to phosphate and the organic nitrogen to ammonium, which is further oxidised to nitrite and nitrate. Silicate is essential for diatom growth, but it is assumed that silicate input is not significantly influenced by human activity. However, enhanced primary productivity may exhaust silicate and change the phytoplankton community from diatoms to flagellates.

2.2. Impacts of eutrophication

Overloading with nitrogen and phosphorus can result in a series of undesirable effects. Excessive growth of plankton algae increases the amount of organic matter settling to the bottom. This may be enhanced by changes in the species composition and functioning of the pelagic food web by stimulating the growth of small flagellates rather than larger diatoms, which leads to lower grazing by copepods and increased sedimentation. The consequent increase in oxygen consumption can in areas with stratified water masses lead to oxygen depletion and changes in community structure or death of the benthic fauna. Bottom dwelling fish may either die or escape. Eutrophication can also promote the risk of harmful algal blooms that may cause discoloration of the water, foam formation, death of benthic fauna and wild or caged fish, or shellfish poisoning of humans. Increased growth and dominance of fast growing filamentous macroalgae in shallow sheltered areas is yet another effect of nutrient overload which will change the coastal ecosystem, increase the risk of local oxygen depletion and reduce biodiversity and nurseries for fish.

The major impacts of eutrophication are thus:

- changes in the structure and functioning of the marine ecosystems;
- reductions in biodiversity;
- reductions in the natural resources of dermersal fish and shellfish;
- reduced income from maricultures of fish and shellfish;
- reduced recreational value and income from tourism;
- increased risk of poisoning of animals including humans by algal toxins.

2.3. Objectives of report and data used

The main objectives of this report prepared by the European Topic Centre on the Marine and Coastal Environment (ETC/MCE) are:

- to evaluate the state of eutrophication in marine community waters on the basis of existing data and information, and to present the information on maps;
- to evaluate the causes and development of eutrophication;
- to identify areas where further monitoring is needed;
- to evaluate the use of a trophical index for water quality assessment;
- to assess the use of remote sensing as a eutrophication monitoring tool.

In assessing marine eutrophication at the European level, there is a need for a harmonised way to evaluate the state and development of the eutrophication. All European seas are covered by different international sea conventions:

- AMAP: Arctic monitoring and assessment programme;
- Helcom(*): Baltic Marine Environment Protection Commission;
- OSPAR(*): Commission of the Convention for the Protection of the Marine Environment of the North-East Atlantic;
- UNEP/MAP/Medpol: Mediterranean action plan/Mediterranean pollution monitoring and research programme.

(*) Kattegat is covered by both Helcom and OSPAR, but in this report it is most often regarded as part of OSPAR Region II, the Greater North Sea.

Together the conventions have the largest set of quality assured and comparable data covering the European seas. Most of the data used in this report were made available by the conventions in a previous task (EEA, 2001). OSPAR and Helcom data were supplied by the International Council for the Exploration of the Sea (ICES). Additional data from at least two estuaries per country were supplied by the EEA national reference centres of Denmark, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Norway and Sweden.

Information from both assessment reports and papers delivered from the marine conventions, as well as from grey and scientific literature, is also used in this report.

2.4. Data coverage

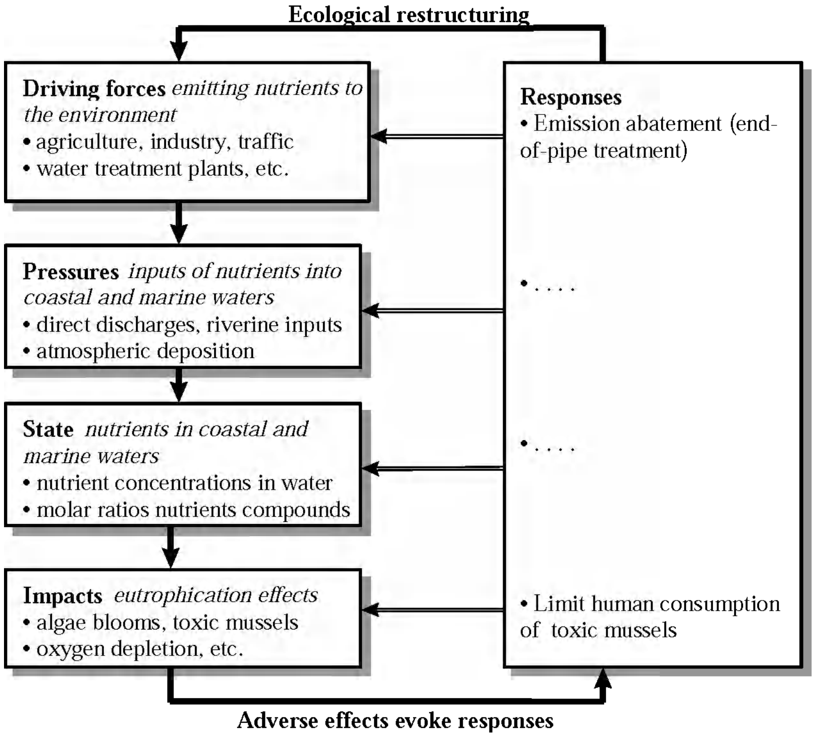
The data provided cover the period 1985 to 1997/98. The data are median, maximum and minimum values for a selected set of eutrophication parameters on a winter, summer or year-round basis. The ICES data are medians per 10 x 10 km squares within 20 km from the coast. The data coverage of eutrophication variables was highest for winter surface concentrations of inorganic nitrogen (DIN, sum of NO_3, NO_2 and NH_4) and phosphate (DIP) and somewhat lower for summer chlorophyll concentrations. The data coverage of other eutrophication parameters was low, and these parameters are only briefly dealt with in this report.

The geographical data coverage is best for the Helcom and OSPAR areas. Data from the northern Atlantic, the Biscay and the Iberian coast are sparse, and the Mediterranean Sea is generally poorly covered.

2.5. Structure of this report

The structure of the report generally follows the DPSIR assessment framework, where D = driving forces, P = pressures, S = state, I = impacts and R = responses. The DPSIR framework for marine eutrophication is illustrated in Figure 1. Driving forces and source apportionment are not main topics and are only briefly mentioned in this report, which concentrates on pressures, state, impacts and responses.

Figure 1. DPSIR assessment framework for eutrophication in coastal waters



Source: EEA (2001).

In Chapter 3 a brief characterisation of the different European seas is compiled concerning drainage areas, run-off, major surface currents and water exchange components.

In Chapter 4 an overview of the data material used for the present report is presented, with a focus on the amount of eutrophication variables reported and their spatial and temporal extent. The aim is to identify areas where reporting of monitoring data needs to be improved in order to assess the state of eutrophication and to determine the presence of trends.

In Chapter 5 the pressures causing eutrophication are described from available nutrient load data. The present load with nitrogen and phosphorus as well as the recent and historic development of the nutrient load is analysed.

In Chapter 6 the dataset is analysed to give the present state of eutrophication along the European coasts where data have been available. The main emphasis is on analyses of nutrient concentrations in different sub-areas of the European seas, relative to salinity, in order to evaluate the influence of enhanced riverine loads. Levels of nutrients, chlorophyll-a and oxygen along the European coasts are shown on GIS maps in Annex 1.

In Chapter 7 the impacts of eutrophication in the different European seas are described, and the recent and historic development analysed. The responses of the international communities to combat eutrophication are described, and scenarios for the effects of reduced nutrient loads are compiled.

In Chapter 8 a first evaluation is made on the applicability in northern coastal waters of a trophical index developed for Mediterranean waters. In Chapter 9 the use of estimates of 'chlorophyll-a-like pigments' from satellite data in evaluation of eutrophication in European marine and coastal waters is evaluated.

In Chapter 10 conclusions and recommendations are presented.

2.6. Acknowledgements

We would like to offer our sincere thanks to the Swedish Meteorological and Hydrological Institute, Oceanographic Laboratory, and the Norwegian Marine Research Institute, Research Station Floedevigen, for allowing us to use their monitoring data in the evaluation of the trophical index TRIX and satellite derived chlorophyll-a concentrations in the Kattegat/Skagerrak/North Sea area. The authors would also like to thank the SeaWiFS Project and the Distributed Active Archive Center at the Goddard Space Flight Center, Greenbelt, for the production and distribution of the SeaWiFS data, respectively. These activities are sponsored by NASA's 'Mission to planet Earth' programme. We would also like to thank Anne van Acker, NERI, for editing and creating the final layout of this report.

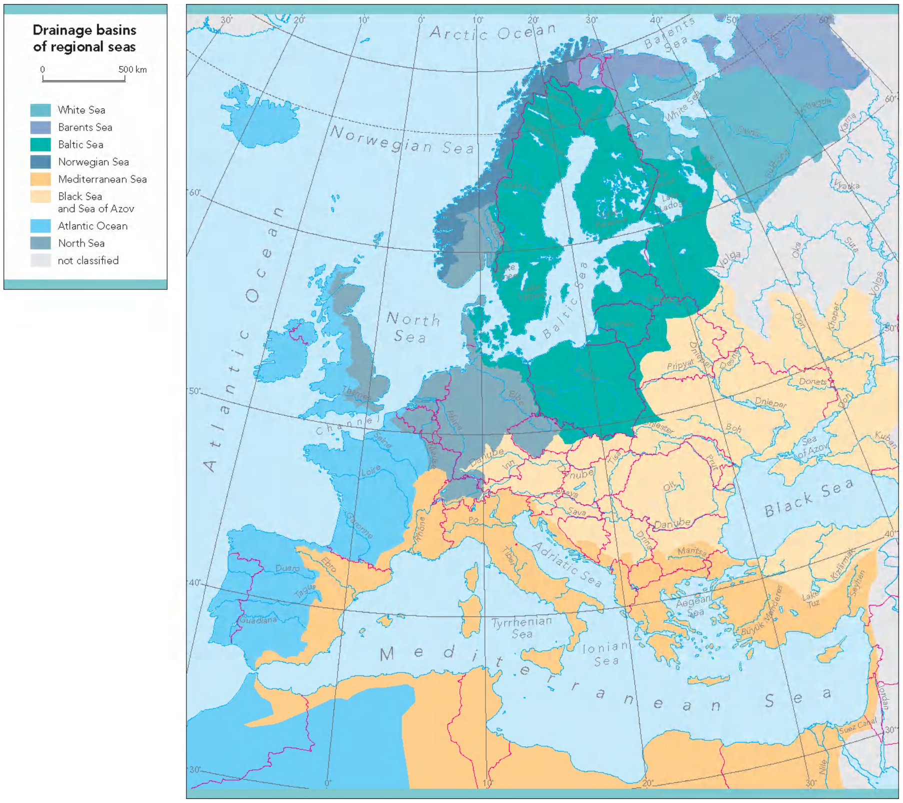
3. The seas of Europe

Nutrients are brought with freshwater from land via rivers, pipes and groundwater seepage to the coastal margin of the marine environment and via the atmosphere to the surface water of the seas. Figure 2 shows the catchment areas of the different European regional seas.

The sensitivity of an area to the nutrient load is to a large extent determined by the hydrography. The sensitivity increases with the residence time and the strength of the stratification of the water column. Over time and in space the nutrient-rich freshwater is mixed with marine water bodies by water exchange, tidal currents, local coastal currents and large-scale circulation currents. Stratified water columns can prevent mixing of oxygen-rich surface water with the bottom water for parts of the year or in certain areas permanently. Background levels in imported waters to coastal areas and upwelling phenomena also play a role, as also the high turbidity of the water in shallow tidal areas.

This report focuses on eutrophication in coastal areas. For that reason this chapter does not include a description of deep waters and deep-water current systems, except in cases where important upwelling takes place. A comprehensive description of water masses and current circulation patterns in the different seas can be found in OSPAR Commission QSR 2000, Region IV (2000), Helcom (1996) and EEA (1999c).

Figure 2. Catchment areas and drainage basins of regional seas



Source: EEA, 1999a.

3.1. Baltic Sea

The Baltic Sea is the largest brackish water area in the world and consists of several sub-basins separated by sills. The transition area (the Belt Sea and Kattegat) to the North Sea is narrow and shallow with a sill depth of 18 m. At irregular intervals, major inflows supply large volumes of highly saline and oxygen-rich water to the Baltic Sea. Only these inflows are able to renew the stagnant bottom water of the deep basins of the Baltic Proper. In the period 1983–92 no such inflows were recorded, and anoxic conditions prevailed in the deep basins. The latest important inflow of saline water from the Kattegat happened in 1993/94 (Helcom, 1996; Helcom, 1999). This inflow event was moderate in volume but the only important one since the major event in 1977. A new moderate inflow took place in December 1999.

The Baltic Sea is shallow (mean depth 52 m, maximum depth 459 m) with a water volume of 21 700 km^3 and a surface area of 415 000 km^2, including the transition area. The overall residence time is 25 to 35 years. The mean maximum ice coverage in winter is about 150 000 km^2. In general, ice covers the northern part for about four to six months, but sea ice also occurs in some winters also in the rest of the Baltic Sea area.

The drainage area is 1 745 136 km^2 (Figure 2). The mean net outflow from the Baltic Sea is 15 000 m^3 s^{-1} (= 476 km^{3}y^{-1}: run-off 436 km^3 + precipitation 224 km^3 — evaporation 184 km^3). The mean inflow of saltwater to the Baltic Proper, mostly intruding at intermediate depths and not renewing the deep water, is calculated to 471 km^3 y^{-1}, resulting in an overall mean outflow of 947 km^3. The in- and outflows have shown very large fluctuations from year to year in the past century.

A huge part of the Baltic Proper with water depth larger than 50 to 60 m and in the transition area larger than 20 m is strongly stratified all year round. In the summer a thermocline is established in about 20 m depth in the Baltic Proper. In the Gulf of Bothnia the stratification is weak and occurs only in summer. The salinity in the surface water is very low in the eastern and northern gulfs of the Baltic Sea (< 5 psu) gradually increasing to 8 psu at the entrance to the Belt Sea. Due to the low salinity the biodiversity is lower than both in more saline waters and in freshwaters, and many species live at the edge of their ability. Large-scale mixing of Baltic surface water and saline North Sea water takes place in the Belt Sea and Kattegat (Helcom, 1996).

3.2. Norwegian Sea

Central and northern Norway borders the Norwegian Sea as the only mainland. The Norwegian catchment area covers 168 000 km^2 of mainly mountainous areas with little anthropogenic input (Figure 2). Two surface current systems run more or less parallel north-east up the coastline. The Norwegian coastal current runs near shore. When it enters the Norwegian Sea from the south-west, it transports approximately 1 million m^3 s^{-1} and has a salinity that generally exceeds 30 psu (OSPAR Commission QSR 2000, Region I, 2000). The water mass is a mixture of low saline Baltic water, North Sea water and Atlantic water mixed in the Kattegat and Skagerrak. The North Atlantic current has two branches each bringing warm and high saline water masses to the Norwegian Sea. Modified North Atlantic water enters the Norwegian Sea between Iceland and Faeroes and is somewhat colder and less saline than the main stream entering between Faeroes and Scotland. The total input of the North Atlantic current in the Norwegian Sea is 8 million m^3 s^{-1} (OSPAR Commission QSR 2000, Region I, 2000; AMAP, 1998). In addition to the water masses transported by the two current systems near and offshore there are a number of different water masses found in fiords and other estuaries along the coastline. Wide ranges of water characteristics are found, depending on estuary type, residence time, freshwater input, mixing conditions, etc.

3.3. Greater North Sea

The Greater North Sea covers approximately 750 000 km^2 and has a volume of about 94 000 km^3. Without strict boundaries it is often divided into seven sub-areas: the southern North Sea, the central North Sea, the deeper northern North Sea, the Norwegian Trench, Skagerrak and finally the shallow Kattegat as a transition zone to the Baltic Sea and the Channel as a transition zone to the north-east Atlantic. The shallow southern North Sea includes the large Wadden Sea tidal area, the German Bight and the southern Bight.

The catchment area for rivers discharging to the North Sea is 850 000 km^2 (Figure 2). The total run-off of freshwater is on average 300 km^3 y^{-1}; however there are large year-to-year differences in run-off (OSPAR Commission QSR 2000, Region II, 2000). The most important rivers are the Rhine, Weser, Meuse, Scheldt, Seine and Elbe draining central and northern Europe. The Thames and Humber rivers drain east England and Goeta drains large parts of western Sweden. However, the largest freshwater source to the North Sea is the Baltic Sea (476 km^3 y^{-1}).

A branch of the North Atlantic current sweep into the northern North Sea transporting approximately 1 million m^3 s^{-1}. Most of the Atlantic inflow circulates in the deeper part of the northern North Sea, the Norwegian Trench and Skagerrak, before it enters the Norwegian Sea. A small proportion of water enters the North Sea through the English Channel. The flushing time for the entire North Sea is estimated to be in the range of between 365 and 500 days (OSPAR Commission QSR 2000, Region II, 2000).

Tidal currents are the most energetic features in the North Sea. In the Channel and the shallow southern part of the North Sea it affects the whole water column preventing stratification all year around. Stratification occurs from spring to autumn in the central and northern North Sea, while the water column is well mixed during wintertime. Year round stratification persists in the Norwegian Trench, Skagerrak and the deep parts of Kattegat due to the strong outflow of less saline Baltic water. The same salinity induced stratification is found in seaward river mouths. In periods with westerly wind low saline water, carrying nutrients from the rivers in the southern North Sea, is carried up the Jutland west coast by the Jutland coastal current to the Skagerrak (OSPARCOM QSR, Region II, 2000).

3.4. Bay of Biscay, Iberian west coast and Gulf of Cadiz

The catchment area that drains into the western Atlantic Ocean is 700 000 km^2 (Figure 2), with an average annual run-off of 180 km^3. More than half of the run-off takes place in the Bay of Biscay. The four most important rivers responsible for more than half the loading are the Loire and Gironde that drain into the Bay of Biscay, and Miño and Douro that drain into the Atlantic at the Iberian west coast (OSPAR Commission QSR 2000, Region IV, 2000).

Most of the surface waters found in the area have an Atlantic origin. Deeper water masses may also be a mixture of Atlantic and Mediterranean water masses. A warm saline continental slope current runs northward along the Iberian west coast pass the Bay of Biscay before entering the Celtic Sea in the north. The current is most pronounced in late autumn, but is weak or non- existent in the surface from spring to autumn along the Iberian coast. Along the Cantabrian slope the current has maximum transport values in wintertime and northward of the Celtic slope it is most pronounced in late summer. The mean monthly transport in the upper 500 m of the water column is of the order of 1.5 million $m^3 s^{-1}$. Near shore in the Bay of Biscay a northward shelf residual circulation exists with less saline water driven by Coriolis forces. Seasonal variability in run-off and wind directions greatly affects this coastal current system. Small river run-offs and a narrow shelf make density stratification less persistent off the Iberian coast compared to the shelf in the Bay of Biscay (OSPAR Commission QSR 2000, Region IV, 2000).

Coastal upwelling is a dominant process in summertime off the Iberian west coast and in the south-western part of the Bay of Biscay. Upwelling takes place in rather narrow bands, so called filaments, along the coast (OSPAR Commission QSR 2000, Region IV, 2000).

3.5. Celtic Seas

This area includes the Celtic Sea located south of Ireland, Saint George's Channel, the Irish Sea and North Channel between Ireland, Wales, England and Scotland, and finally the shelf areas west of Ireland and Scotland. The total catchment area is shown in Figure 2.

During summer the North Atlantic water is found offshore Ireland and a band of less saline water is found around the island. In wintertime the Atlantic water mass is close to the West Coast of Ireland. On the Marlin shelf off Scotland there are three water masses. The main body is high saline Atlantic water. Then there is a water mass with slightly lower salinity coming from the Irish Sea and inshore of this lies coastal water with an even lower salinity due to run-off of freshwater.

Stratification, primarily due to surface heating, develops especially in the western part of the Irish Sea, in the Celtic Sea and in the Marlin shelf area during late spring and summer. Inshore the thermal stratification is weaker. In the Minch and Sea of the Hebrides stratification does not take place even in summer leading to development of fronts. Strong western wind and strong tide in the Bristol Channel and in the eastern part of the Irish Sea ensure intense vertical mixing (OSPAR Commission QSR 2000, Region III, 2000).

The continental slope current, also described for the Biscay area, follows the slope edge to the south-west of Ireland. On average there is a northward water movement through the Irish Sea and 30 000 to 100 000 $m^3 s^{-1}$ are transported through the North Channel, but transport fluctuations are huge due to wind conditions. On the Marlin shelf west of Scotland the water masses continue the same overall residual northerly direction, but the flow direction and transport are strongly dependent on the wind regime in the area (OSPAR Commission QSR 2000, Region III, 2000).

Based on transport models and radionuclide distributions it is estimated that the flushing time is 150 to 300 days in the Bristol Channel, one to two years in the Irish Sea and four and half to six months in the Marlin shelf area. Storm events are known to change those rates considerably (OSPAR Commission QSR 2000, Region III, 2000).

In addition to the water masses in the open areas there are a number of different waters found in fiords and other estuaries along the west coast of Scotland and the Scottish islands. Wide ranges of water characteristics are found, depending on estuary type, residence time, freshwater input, mixing conditions, etc. (OSPAR Commission QSR 2000, Region III, 2000).

3.6. Mediterranean Sea

Data on the total size of the Mediterranean catchment area were not found. The Nile has the largest catchment area of all rivers entering the Mediterranean Sea with 335 000 km^2 (Figure 2). However, because of the construction of the Aswan dam an average of only 5 km^3 water is discharged into the sea per year. Other important rivers are all located in the northern part of the Mediterranean. With a few exceptions all river systems discharging into the Mediterranean Sea are small. The Rhone, Ebro and Po have catchment areas extending to 96 000, 84 000 and 69 000 km^2. The discharge of freshwater from the 50 main rivers is about 255 km^{3}y^{-1}. Net inflow from the Black Sea amounts to 163 km^3 per year.

Evaporation exceeds precipitation and freshwater load. As a result there is a net inflow of 1 700 km^3 water from the Atlantic Ocean per year and the overall effect is a very high salinity in the Mediterranean Sea. The actual annual inflow of Atlantic water is much higher. Chou and Wollast (1997) estimate that 53 000 km^3 pass the Strait of Gibraltar as a surface current. This inflow is compensated by export of high saline water from the Mediterranean Sea at the bottom. The export is estimated at 50 500 km^3, giving a net water transport that is 800 km^3 higher per year than the figure given in the Mediterranean assessment report (EEA, 1999c).

The Mediterranean is divided into two basins separated by the Sicilian Channel about 150 km wide and with a maximum water depth of 400 m. The water depth averages 1 500 m and shelf areas are narrow and separated from the deeper parts by steep continental shelf breaks.

The inflow current of Atlantic water continues as a surface current from west to east of the Mediterranean Sea. On its way east in the central part of the sea, this current drives a number of gyres effecting the coastal areas (EEA, 1999c). The inflow of Atlantic water keeps the surface salinity at between 36.2 psu in the western part and 38.6 psu in the eastern part. The intermediate water found only in the eastern basin has salinity between 38.4 and 39.1 psu. The deep-water salinity in the two basins ranges from 38.4 in the west to 38.7 in the east (EEA, 1999c). Deep-water formation takes place in wintertime each year in a few isolated areas in both basins predisposed to convection overturning.

Coastal sea level variations are generally limited to tens of centimetres. Tidal amplitudes are small in the Mediterranean.

4. Spatial and temporal coverage of data

Monitoring is a prerequisite to assess the state of the environment. Measurements for such an assessment are subject to uncertainty, due to natural variability of the measurement variable and variability in the conduct of the measurement. Therefore, the number of measurements available determines the certainty of the statements in an assessment. This chapter provides an overview of the data material used in the present report. The focus is on the amount of eutrophication variables reported and their spatial and temporal extent. The aim is to identify areas where monitoring data need to be improved in order to assess the state of eutrophication and to determine the presence of trends.

The results of this report are based on eutrophication variables collected from:

- EEA national reference centres (NRCs);
- ICES (International Council for Exploration of the Seas), which includes data reported to Helcom and OSPAR.

An overview of contributed data is given in EEA (2001). Each country was requested to select at least two coastal zones, estuaries, deltas or fiords for this report. In the following coastal zones, estuaries, deltas and fiords will all be referred to as estuaries and coastal waters. Table 1 shows the number of estuaries chosen by each country. A total of 46 estuaries and coastal waters have been reported.

Table 1. Number of estuaries and coastal waters reported by NRCs

Country	Coastal zones	Estuaries	Deltas	Fiords	Total
Belgium					0(1),(2)
Denmark		5			5
Finland		3			3
France		2	1		3
Germany	4	3			7
Greece	7				7
Ireland		1			1
Iceland					0(1)
Italy	12(4)				12(4)
Netherlands	2	2			4
Norway				3	3
Portugal					0(1)
Spain					0(1)
Sweden		2			2
United Kingdom					0(1),(3)

(1) These countries have not reported any data from selected estuaries for compilation of the report.

(2) Belgium has only one coastal zone and one relevant estuary.

(3) Data from the UK was delivered after the deadline for the report.

(4) Data from Italy represent the average of several stations within 12 different coastal areas.

Data from ICES were delivered as metadata, where measurements have been aggregated within squares of 10 x 10 km (20 x 20 km for Iceland and parts of the Irish Sea). The metadata were limited to a coastal zone extending 20 km from the shoreline. The following eutrophication variables are available from the ICES databank: NO_2-N, NO_3-N, NH_4-N, PO_4-P, SiO_3-Si, TN, TP, O_2 and chlorophyll-a. Eutrophication data from the Mediterranean Sea besides the selected estuaries in Table 1 are scarce, as Medpol does not support these data.

The national reference centres were asked to deliver a total of 29 eutrophication variables, which can be divided into the following categories:

- nutrients: TP (year round and winter), PO_4 (winter), TN (year round and winter), NO_3 (winter), NO_2 (winter), $NO_3 + NO_2$ (winter), NH_4 (winter), TN/TP (year round) and SiO_3 (winter);
- oxygen level: dissolved oxygen concentration or saturation in bottom water layer;
- transparency: Secchi depths (summer);
- phytoplankton: algal blooms, toxic algae, *Phaeocystis sp.*, diatom/flagellate ratio (spring and summer) and chlorophyll-a (summer);
- benthic vegetation: seagrasses (cover and maximum depth occurrence) and seaweeds (cover and maximum depth occurrence); micro-phytobenthos biomass;
- benthic fauna: macro-zoobenthos biomass;
- watershed input: TN, TP and TC entering the water system.

Table 2. Eutrophication variables reported by 10 NRCs

Country	Nutrients	Oxygen	Transparency	Chloro-phyll-a(1)	Benthic vegetation	Benthic fauna	Watershed information
Denmark	5/5	5/5	5/5	5/5	5/5		4/5
Finland	3/3	3/3		3/3			3/3
France	3/3			3/3			1/3
Germany	6/7	6/7		2/7			7/7(2)
Greece	7/7	1/7		4/7			
Ireland	1/1	1/1		1/1			
Italy	8/12	12/12	11/12	12/12			
Netherlands	4/4	4/4		4/4	2/4		4/4
Norway	2/3	1/3	3/3	3/3			
Sweden	2/2	2/2		2/2			2/2

Note: Data presented are number of sites with reported eutrophication variables out of total number of reported estuaries and coastal waters.

(1) The majority of phytoplankton data were reported as chlorophyll-a.

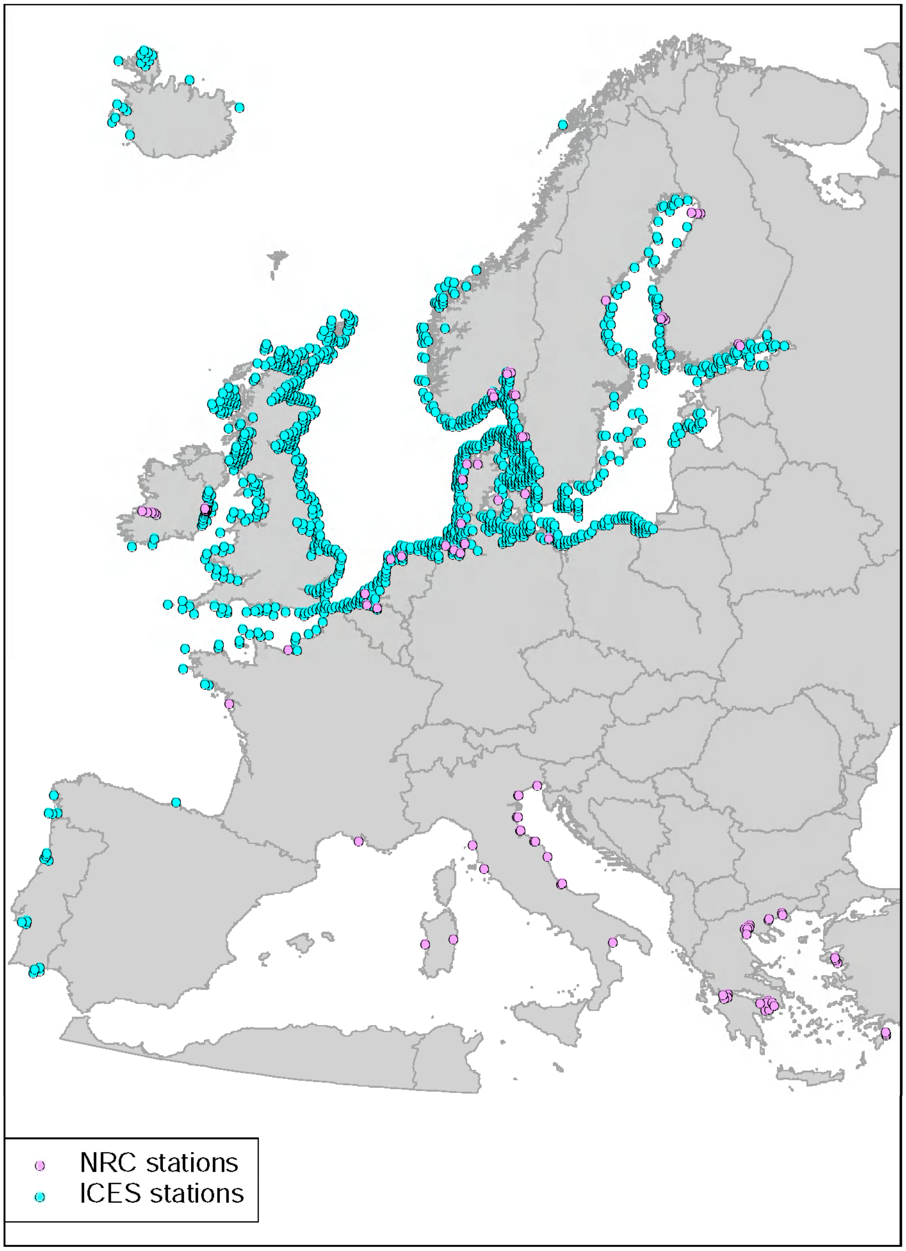
(2) For coastal zones the load is given as total load to the marine area to which the coastal zone belongs.

Table 2 shows how well the different eutrophication variables are covered for the selected estuaries, and Figure 3 shows the location of the selected NRC sites. However, Table 2 does not reflect how many eutrophication variables have been reported within each category, e.g. the nutrient category entails 11 variables which may be partially or completely reported. There are no countries reporting benthic fauna and only two countries have reported benthic vegetation. The dataset is incoherent making an overall comparison between different estuaries difficult. For most estuaries, nutrients and chlorophyll-a levels and to some extent oxygen levels have been reported and only these variables can be used for an overall assessment of the state of eutrophication.

4.1. Spatial coverage: coastal zones

The spatial coverage of data is only analysed for ICES data, as data from the NRCs cannot substantiate such an analysis. Data delivered by ICES have been divided into regions corresponding to the boundaries defined by OSPAR and Helcom. The spatial coverage of each region is assessed by the number of squares covered with monitoring data. Within each region the spatial coverage of the national coastal zones is assessed for each country. Table 3 shows the number of squares (10 x 10 km or 20 x 20 km) in each region listed for the selected eutrophication variables. Figure 3 shows all the squares where information on at least one eutrophication variable was available.

Figure 3. Map showing location of squares where information on eutrophication variables has been obtained from the ICES databank and NRCs



Note: The Italian stations represent the centres of different coastal zones.
Source: Data stored in MARINEBASE (EEA, 2001).

Table 3. Spatial coverage of monitoring data delivered by ICES given by number of squares

Region	O_2	NH_4	NO_2	NO_3	PO_4	SiO_3	Chl-a	TN	TP
Baltic Proper	**106**	**58**	**76**	**77**	**81**	**70**	**42**	**50**	**53**
Denmark	10	6	7	7	7	6	6	6	6
Estonia		1	1	1	1	1		1	1
Finland	3	7	7	7	7	7	2	7	7
Germany	20	6	9	9	9	8	7		1
Latvia		3	4	4	4	4		1	3
Poland	44	14	22	22	23	22	11	12	12
Russia	1	1	1	1	1	1		1	1
Sweden	28	20	25	26	29	21	16	22	22
Bay of Biscay		**1**	**1**	**1**	**1**	**1**	**3**		
France							3		
Spain		1	1	1	1	1			
Belt Sea	**50**	**26**	**36**	**36**	**36**	**34**	**10**	**15**	**22**
Denmark	21	10	13	13	13	13	8	2	9
Germany	29	16	23	23	23	21	2	13	13
Celtic Seas		**26**	**23**	**82**	**84**	**57**	**55**	**16**	
Ireland				15	16	16	5		
United Kingdom		26	23	67	68	41	50	16	
Coast of Iceland	**3**			**15**	**15**	**15**			
Gulf of Bothnia	**41**	**20**	**20**	**22**	**22**	**20**	**23**	**22**	**22**
Finland	20	14	14	15	15	14	4	15	15
Sweden	21	6	6	7	7	6	19	7	7
Gulf of Finland	**19**	**35**	**35**	**35**	**35**	**35**	**26**	**35**	**35**
Estonia	3	7	7	7	7	7	5	7	7
Finland	13	21	21	21	21	21	12	21	21
Russia	3	7	7	7	7	7	9	7	7
Gulf of Riga	**6**	**7**	**7**	**7**	**7**	**7**		**7**	**7**
Estonia	4	4	4	4	4	4		4	4
Latvia	2	3	3	3	3	3		3	3
Iberian coast	**2**	**11**	**11**	**11**	**11**	**11**	**2**		
Portugal		11	11	11	11	11			
Spain	2						2		
Kattegat	**91**	**43**	**49**	**49**	**47**	**43**	**52**	**39**	**46**
Denmark	51	19	22	22	22	19	37	19	22
Sweden	40	24	27	27	25	24	15	20	24
North Atlantic	**1**	**8**	**19**	**22**	**22**	**22**	**46**		**1**
Norway			11	11	11	11	1		
United Kingdom	1	8	8	11	11	11	45		1
North Sea	**81**	**231**	**226**	**324**	**315**	**310**	**211**	**104**	**113**
Belgium	7	8	7	8	7	7	8		2
Denmark	11	21	14	16	16	16	32	14	15
France	1	2	1	2	2	2	4		
Germany	30	61	57	60	61	54	13	58	58
Netherlands	15	57	56	56	56	57	37	31	36
Norway		2	26	28	28	28	7	1	1
United Kingdom	17	80	65	154	145	146	110		1
Skagerrak	**56**	**31**	**38**	**40**	**40**	**39**	**81**	**28**	**28**
Denmark	11	14	14	14	14	14	23	15	15
Norway	34	9	15	17	17	16	42	5	5
Sweden	11	8	9	9	9	9	16	8	8
The Channel	**2**	**7**	**4**	**25**	**19**	**19**	**27**		
France	1	3	3	11	11	11	7		
United Kingdom	1	4	1	14	8	8	20		

The number of stations required for a region depends on the desired accuracy for the assessment and the variability of the measurement variables in that region. There are no stringent guidelines to the spatial coverage required for an assessment, and the spatial coverage is evaluated given the information in Table 3 and Figure 3.

The coastal zones in the North Sea, Skagerrak, Kattegat, Belt Sea, Baltic Proper, Gulf of Riga, Gulf of Finland and Gulf of Bothnia have an adequate spatial coverage for all the listed eutrophication variables. In the Baltic Proper there are no data covering the coastal zone from southern Latvia to Kaliningrad. Large rivers draining parts of Latvia, Lithuania, Russia (Kaliningrad region) and Belarus have their outflow to the Baltic Proper in this zone, which would need monitoring.

The North Atlantic and Celtic Seas have adequate monitoring of dissolved nutrients and chlorophyll-a, while monitoring of oxygen concentrations and total nutrients could be improved. Data from the Channel are scarce, especially in the Brittany coastal zone. Eutrophication in the Channel cannot be sufficiently assessed based on the available data from ICES, and a better spatial coverage and more measurements of oxygen and total nutrients are required for such an assessment. The coast of Iceland has measurements of mainly dissolved nutrients on the western and northern coastlines where the Icelandic population lives. Monitoring could be improved with respect to total nutrients, chlorophyll-a and oxygen concentration and a better spatial coverage.

In the dataset there are almost no measurements on eutrophication variables from the Bay of Biscay, Iberian coast and Mediterranean Sea, except for a few major river estuaries. State and trends of eutrophication in these regions cannot be assessed based on the available data, and if no data exist a much stronger effort in monitoring eutrophication variables is required.

4.2. Temporal coverage

A minimum of five years of data is required before a trend can be statistically detected at a 5 % significance level (using Kendalls τ, Sokal and Rohlf, 1981). Although the spatial coverage in certain regions is sufficient, the lengths of the time series may be too short to allow for trend assessment. Furthermore, climatic variations seriously affect the eutrophication variables, such that short time series result in an uncertain evaluation of the state of eutrophication. Some years have high discharges resulting in above average winter nutrient concentrations, and some years have low discharges resulting in below average winter nutrient concentrations. Climatic variations give rise to significant variations in oxygen levels and chlorophyll-a concentrations as well. In order to reduce the effect of climatic variation, a minimum of five years of data should be required to obtain reliable estimates of the eutrophication variables. In the following, data from ICES and the NRCs are analysed separately.

4.2.1. ICES data: coastal zones

The temporal coverage of data from the coastal zones of Europe is assessed by the lengths of the time series available. Table 4 shows the number of squares with at least five years of monitoring within the years 1985–98.

The following countries have supplied data to ICES extending at least five years:

- Belgium
- Denmark
- Estonia (Gulf of Finland only)
- Finland
- Germany
- The Netherlands
- Norway (North Sea and Skagerrak only)

- Poland
- Sweden
- United Kingdom (North Sea only).

Table 4. Number of squares with at least five years of data from the different countries and regions

Region	O_2	NH_4	NO_2	NO_3	PO_4	SiO_3	Chl-a	TN	TP
Baltic Proper	**19**	**11**	**20**	**20**	**23**	**9**	**3**	**10**	**11**
Denmark	2	3	5	5	5	3	1	4	4
Estonia									
Finland		2	2	2	2	2		2	2
Germany	10	1	7	7	7	1	1		1
Latvia									
Poland	3				3				
Russia									
Sweden	4	5	6	6	6	3	1	4	4
Bay of Biscay	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Belt Sea	30	22	28	28	28	11	8	13	19
Denmark	13	9	12	12	12	7	7	2	9
Germany	17	13	16	16	16	4	1	11	10
Celtic Seas	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Coast of Iceland	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Gulf of Bothnia	**1**	**3**	**3**	**3**	**3**	**3**	**1**	**3**	**3**
Finland		2	2	2	2	2		2	2
Sweden	1	1	1	1	1	1	1	1	1
Gulf of Finland	**0**	**3**	**4**	**4**	**4**	**4**	**2**	**4**	**4**
Estonia			1	1	1	1		1	1
Finland		3	3	3	3	3	2	3	3
Russia									
Gulf of Riga	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Iberian coast	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Kattegat	35	18	22	22	20	21	15	11	16
Denmark	17	9	11	11	10	11	10	5	8
Sweden	18	9	11	11	10	10	5	6	8
North Atlantic	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
North Sea	**4**	**63**	**66**	**73**	**75**	**73**	**21**	**37**	**52**
Belgium		6	6	7	7	7	7		
Denmark		4	4	4	4	4	5		4
France									
Germany	4	19	19	19	21	18		16	16
Netherlands		34	34	35	35	35	7	21	32
Norway			2	2	2	2			
United Kingdom			1	6	6	7	2		
Skagerrak	**29**	**8**	**13**	**13**	**12**	**12**	**25**	**3**	**7**
Denmark	3	6	6	6	6	6	6	2	6
Norway	24	1	4	4	4	3	14		
Sweden	2	1	3	3	2	3	5	1	1
The Channel	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Source: ICES.

In addition, the number of time series (≥ five years) of oxygen and chlorophyll-a concentrations is substantially lower than the number of time series available with nutrient concentrations.

The temporal coverage of data is adequate for the coastal zones of the countries listed above belonging to the North Sea, Skagerrak, Kattegat, Belt Sea, Baltic Proper, Gulf of Finland and Gulf of Bothnia. Although the time series may cover different time periods, averaging over at least five years should produce comparable values. The Celtic Seas and North Atlantic have an adequate spatial coverage, but the data are temporally scattered between 1985 and 1998, which makes a comparison between different coastal reaches dependent on climatic variations.

Inter-annual variations in winter nutrient concentrations are mainly determined by variations in the run-off, and the variations in nutrient concentrations are higher in areas dominated by the outflow from the large European rivers (the Channel, the North Sea, Skagerrak and parts of the Baltic Sea). Thus, longer time series for nutrients are required for areas affected by river discharges. Inter-annual variations in oxygen concentrations are mainly determined by the degree of stratification. Some areas have a natural tendency to become stratified, while other areas with large vertical mixing due to, for example, tides show less variation in oxygen concentration. Thus, longer time series for oxygen are required for areas with stratified waters.

4.2.2. NRC data: estuaries and coastal waters

The temporal coverage of data from the selected estuaries and coastal waters is assessed by the length of time series available (Table 5).

The selected estuaries and coastal waters are subject to large climatic variations in terms of run-off. Longer time series of eutrophication variables will reduce the uncertainty of calculated mean values and enable trend detection. Trend assessment cannot be carried out on the majority of eutrophication variables from Greek, Irish, Italian and Norwegian estuaries and coastal waters, because of too few data. It is observed that none of the selected eutrophication variables are available for all estuaries. The measurement variable, which is most consistent throughout the data, is phosphate. Thus, it is difficult to make comparisons between selected estuaries in Europe based on the present dataset. A thorough analysis of eutrophication in Europe can only be based on a subset of the selected estuaries. A more uniform dataset should be striven for, where data from estuaries and coastal waters are reported, provided that measurements of nutrients, oxygen and chlorophyll concentrations are available for at least five years.

Some NRCs reported eutrophication variables for periods other than those requested, while other NRCs did not inform about the period over which data were extracted. Oxygen measurements in bottom waters were requested, but sampling depths were not specified. However, the data are bottom near measurements, most often about 1 m above the sea floor. Furthermore, minimum, median and maximum values were not specified for all entries, and some data were erroneous. All of the above has complicated the task of assessing eutrophication in European estuaries.

4.3. Conclusions

The data delivered by ICES for the coastal zones of Europe show large variations in spatial and temporal coverage. Table 6 summarises the conclusions of the previous sections. NRCs in Belgium, Iceland, Portugal, Spain and the United Kingdom supplied no data in time for this report on selected estuaries and coastal waters. Too few data were supplied by NRCs in Greece, Ireland, Italy and Norway. In total, 6 out of 15 NRCs provided adequate data for an environmental assessment.

Table 5. Number of years of contributed NRC data for selected estuaries and coastal waters

Estuaries	O_2	NH_4	NO_2	NO_3	PO_4	SiO_3	Chl-a	TN	TP
Denmark									
Skive Fiord	13		13	13	13	10	13	13	13
Limfiord: Nissum	13		12	12	12	9	13	13	13
Odense Fiord	13		12	12	12		13	13	13
Ringkøbing Fiord	12		10	10	10	6	12	12	12
Roskilde Fiord	13		10	10	10	4	13	13	13
Finland									
Kymi	12	12	12	12	12	12	12	13	13
Oulu	13	10	10	10	10	10	13	13	13
Pori	13	11	11	11	11	9	12	13	13
France									
Delta du Rhone			13	13	13				
Est. de la Seine			12	12	12				
Est. de Loire					13				
Germany									
Greifswalder B.	13	10	10	10	10	13	13	13	13
East Frisian coast	13				13	6		13	13
Elbe estuary	13				13	4		13	13
Jade estuary	13				13	6		13	13
Mecklenburg Bucht									
North Sea coast	13				13	8		13	13
Weser estuary	9				9	3		9	9
Greece									
Kavala		3	3	3	3			2	3
Lesvos		3	3	3	3	3	3		
Patraikos			1	3	1				
Rhodos		3	4	4	4	4	4		
Saronikos	5	5	5	5	5	5	11		
Strimonikos		3	3	3	3			1	1
Thermaikos		5	5	5	5		4	5	
Ireland									
Shannon estuary	6	2	2	2	3		4		1
Italy									
Abruzzo & Molise	3	3	2	3	3		3		3
Basilicata	1	1	1	1	1		1		1
East Sardinia	1						1		1
Emilia Romagna N	7	8	8	8	8		8		8
Emilia Romagna S	7	8	8	8	8		8		8
FriuliVeneziaGiulia	2	3	1	3	3		3		3
Marche Nord	3	3	1	3	3		3		3
Marche Sud	3	2	1	2	2		2		2
North Tuscany	1						1		1
South Tuscany	1						1		1
Veneto	2	3	1	3	3		3		1
West Sardinia	1						1		1
Netherlands									
Closed Holland coast	13	13	12	12	13	13	10	10	10
Voordelta	13	13	12	12	13	13	13	13	13
Wadden Sea west	12	13	13	13	13	13	13	13	13
Western Scheldt	13	13	11	12	13	13	13	13	13
Norway									
Frierfiord		3		3	3		4	3	3
Hvaler				5	5	5	4	5	5
Oslofiord							2		
Sweden									
Bay of Sundsvall	10	3	3	3	3		3	10	10
Göta älv mouth	12	12	12	12	12	8	12	9	12

Note: Each estuary/coastal zone may include several sampling stations. For estuaries with more than one station, the maximum length of time series is given.

Table 6. Overview of regions where data availability should be improved

Region	Recommendation
Baltic Proper	Data from the coastal zone reaching from southern Latvia to Kaliningrad and longer time series from Estonia, Latvia, Poland and Russia should be made accessible, if possible.
Bay of Biscay	A better spatial coverage with longer time series for all eutrophication variables is required.
Belt Sea	—
Celtic Seas	Longer time series should be made accessible, if possible. Data on oxygen concentrations are needed.
Coast of Iceland	Longer time series should be made accessible, if possible. Data on chlorophyll and oxygen concentrations are needed.
Gulf of Bothnia	Longer time series for oxygen concentration should be made accessible, if possible.
Gulf of Finland	Longer time series for oxygen concentration should be made accessible, if possible.
Gulf of Riga	Longer time series for oxygen concentration should be made accessible, if possible.
Iberian coast	A better spatial coverage with longer time series for all eutrophication variables is required.
Kattegat	—
North Atlantic	Longer time series should be made accessible, if possible. Data on total nutrients and oxygen concentrations are needed.
North Sea	Longer time series from France and Norway should be made accessible, if possible. Longer time series on oxygen concentration is required.
Skagerrak	—
The Channel	Longer time series should be made accessible, if possible. Data on total nutrients are needed. The spatial coverage of ICES data on the Brittany coast should be improved.
The Mediterranean	Collection of eutrophication data should be initiated and data from all Mediterranean countries should be stored in a central databank.

5. Nutrient loads (pressures)

Time series on nutrient loads covering the period 1990–96 are available for the OSPAR sub-regions (OSPAR 1998a, 1998b). Data on nutrient load to the sub-regions of the Baltic Sea are available for the years 1985, 1990 and 1995 (Helcom 1987, 1993, 1998a), but for most regions they are not comparable due to insufficient reporting in 1985 and 1990. Hence, only the 1995 compilation is referred to below. Concerning the Mediterranean Sea no systematic and comprehensive pollution load compilations have been made. However, scattered information is summarised from the literature.

5.1. Present nutrient load

5.1.1. Arctic waters

The Arctic region (OSPAR Region I) includes the Barents Sea, the Norwegian Sea, the Iceland Sea and shelf and the Greenland Sea.

Land-based load (riverine and direct input) is available only for Norway and ranged during the years 1990–96 from 30 300 to 36 700 t y^{-1} for nitrogen and from 1 400 to 2 300 t y^{-1} for phosphorus (Table 7). Additionally, the aquaculture in the Faeroe Islands and Norway contributes about 10 000 t of nitrogen and 2 000 t of phosphorus annually, the main part from Norwegian salmon farming (OSPAR 1998a, 1998b).

Table 7. Nutrient load from Norway to the Arctic waters in 1000 t y^{-1} 1990–96

	Norwegian Sea		Barents Sea			
Year	Norway TN	Norway TP	Norway TN	Norway TP	Total TN	Total TP
1990	31	1.5	4.5	0.2	35.5	1.7
1991	25	1.2	5.3	0.2	30.3	1.4
1992	30	1.5	6.4	0.3	36.4	1.8
1993	29	1.4	5.5	0.2	34.5	1.6
1994	27	2.0	5.0	0.3	32.0	2.3
1995	31	1.5	5.7	0.2	36.7	1.7
1996	26	1.4	5.4	0.4	31.4	1.8
Mean	28.4	1.5	5.4	0.3	33.8	1.8

Source: OSPAR (1998a) (1998b).

The population density of the region is very low and therefore the inputs of nutrients from land are generally low. Only 1 % of Iceland and 3 % of northern Norway are cultivated land, mainly used for grass and animal husbandry. The same is true for the Faeroe Islands. Fish farming is important in Norway (220 000 t fish in 1997) and the Faeroe Islands (14 000 t in 1996 increasing to 40 000 t in 2000), but not important in Iceland (OSPAR Commission QSR 2000, Region I, 2000).

Transboundary inputs of nutrients via the atmosphere or ocean currents, e.g. from the North Sea, have no important influence on the nutrient concentrations in Region I. It is concluded that eutrophication is not an issue of concern, and that the whole of Region I can be regarded as a non-problem area concerning negative effects of nutrients (OSPAR Commission QSR 2000, Region I, 2000).

5.1.2. Baltic Sea

The Baltic Sea region includes the Gulf of Bothnia, the Gulf of Finland, the Baltic Proper and the Kattegat and Belt Sea area.

About 85 million people live in the Baltic Sea drainage basin. Of these more than 26 million live within 50 km of the Baltic coast and nearly 15 million live within 10 km of the coast (Sweitzer et al., 1996). Forests dominate the land cover (48 %) followed by arable land (20 %) and non-productive open lands (17 %). In the northern part (Gulf of Bothnia and Gulf of Finland drainage area) only 8 % is arable land and pastures. In the rest of the drainage area arable land and pastures cover 46 % (Sweitzer et al., 1996).

In 1995 the Baltic Sea received 761 000 t nitrogen and 38 000 t phosphorus from land (Table 8, Figures 4 and 5). Less than 0.3 % originated from untreated municipal or industrial discharge directly to the Baltic Sea. Of the nitrogen load 90 % entered via rivers and 10 % came from direct point sources (Helcom, 1998a). About one-third of the nitrogen load is estimated to originate from arable land (Elofsson, 1997). Of the phosphorus load 81 % entered via rivers and 19 % came from direct point sources. It should be noted that riverine load includes both point source and diffuse inputs to the river in the whole catchment area.

The load per km^2 and the estimated anthropogenic proportion varies greatly from country to country (Table 8), depending on population density and agricultural intensity. Generally the anthropogenic load is lowest in the sparsely populated and forested northern parts of the drainage area.

Table 8. Nutrient load in 1995 from different countries and the atmosphere to sub-areas of the Baltic Sea

Total nitrogen load

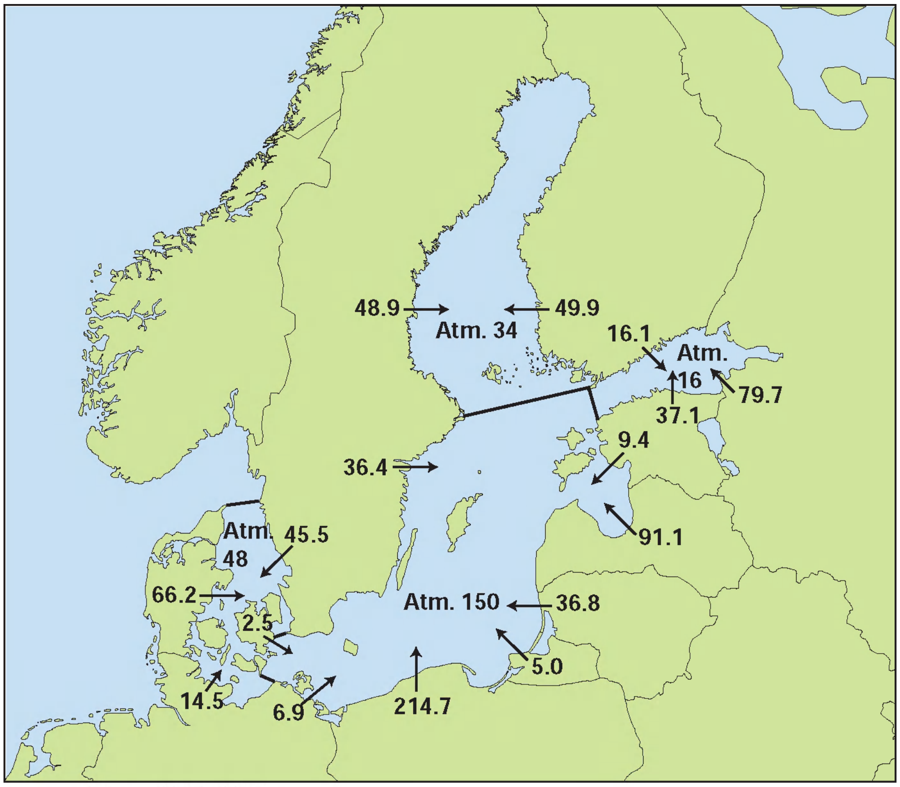
Sea Area	Denmark	Estonia	Finland	Germany	Latvia	Lithuania	Poland	Russia	Sweden	Total	Atmosphere
Gulf of Bothnia			49 933						48 873	98 806	34 000
Gulf of Finland		37 079	16 140					79 680		132 899	16 000
Baltic Proper	2 502	9 389		6 905	91 065	36 824	214 747	4 967	36 421	402 820	150 000
Kattegat/ Belt Sea	66 178			14 466					45 580	126 224	48 000
Total	68 680	46 468	66 073	21 371	91 065	36 824	214 747	84 647	130 874	760 749	248 000
kg/km2	2 208	551	286	747	692	372	688	280	307	460	
Anthropogenic %	88	n.i.	44	79	95	92	81	n.i.	79(*)		

Total phosphorus load

Sea area	Denmark	Estonia	Finland	Germany	Latvia	Lithuania	Poland	Russia	Sweden	Total
Gulf of Bothnia			2 929						2 685	5 614
Gulf of Finland		1 030	632					6 499		8 161
Baltic Proper	89	260		197	2 183	1 405	14 208	609	1 011	19 962
Kattegat/ Belt Sea	2 508			382					1021	3 911
Total	2 597	1 290	3 561	579	2 183	1 405	14 208	7 108	4 717	37 648
kg/km2	84	15	15	20	17	14	43	23	11	23
Anthropogenic %	88	n.i.	55	95	88	48	86	n.i.	n.i.	

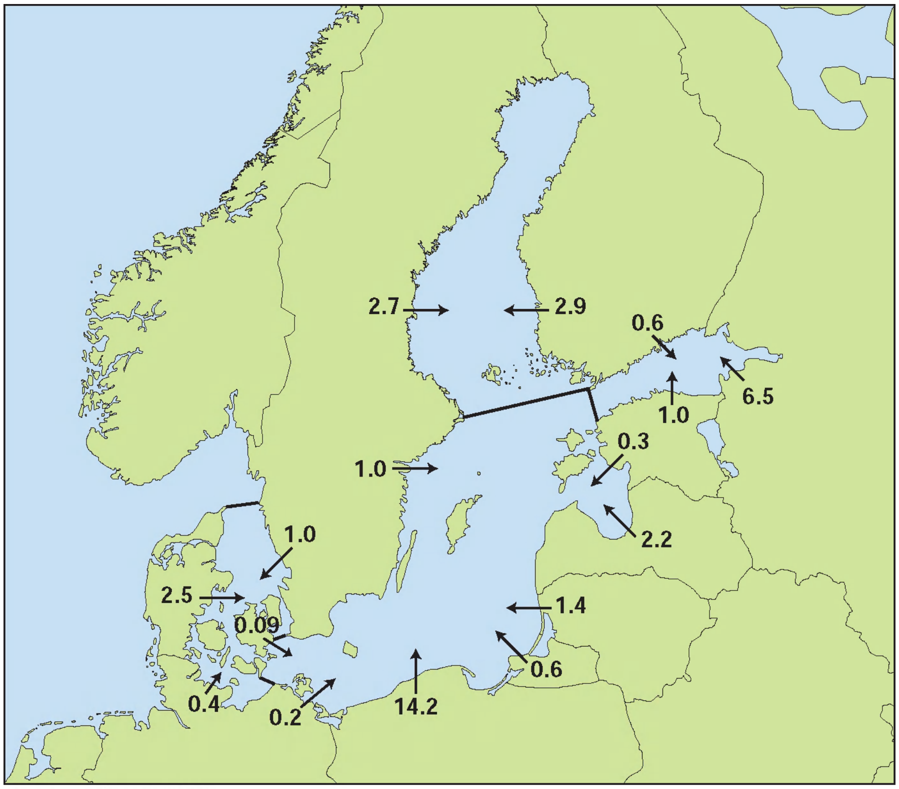
Key: Anthropogenic % = percentage of riverine inputs; n.i. = no information; (*) = southern Sweden only.
Source: Helcom (1997) (1998a).

Figure 4. Nitrogen load to the Baltic Sea area in 1995 in 1 000 t N/year



Source: Helcom (1997) (1998).

Figure 5. Phosphorus load to the Baltic Sea area in 1995 in 1 000 t P/year



Source: Helcom (1998).

Model estimations of total atmospheric deposition of inorganic nitrogen to the Baltic Sea varied between 329 000 t y^{-1} in 1986 and 248 000 t y^{-1} in 1995 (Helcom 1997).

5.1.3. Greater North Sea

The Greater North Sea includes the English Channel, main North Sea, Skagerrak, Kattegat and the northern Atlantic between Norway and Scotland.

Approximately 184 million people live within the catchment area of the Greater North Sea. The number of people in the coastal regions varies substantially due to tourism, mostly with a seasonal character. The Greater North Sea is surrounded by highly developed north-western European countries mostly with a high population density, high industrial production and intensive agriculture.

The total load with nutrients from land to the Greater North Sea including estuaries, fiords, etc. in the period 1990–95 varied between 967 000 and 1 463 000 t y^{-1} for nitrogen and between 73 000 and 89 000 t y^{-1} for phosphorus (OSPAR, 1998a). Model estimations of the atmospheric wet deposition of inorganic nitrogen to the main North Sea varied between 310 000 and 371 000 t y^{-1} in the same period (OSPAR 1998b). The loads in 1995 per country and sub-area are shown in Figures 6 and 7, and for the years 1990–95 in Tables 9 and 10.

Table 9. Nutrient load to the main North Sea in 1000 t y^{-1}, 1990–95/96

TN load

Year	Belgium	Denmark	Germany (1)	Netherlands (1)	Norway	UK	Total	Atmos-phere(*)
1990	54	23	192	345	30	165	809	354
1991	59	19	159	326	25	157	745	310
1992	63	26	230	396	30	199	944	371
1993	55	22	237	366	25	198	903	366
1994	54	28	351	491	25	206	1155	328
1995	60	22	281	577	28	190	1158	327
1996	n.i.	12	197	310	25	151		
Mean	58	22	235	402	27	181	952	343

TP load

Year	Belgium	Denmark	Germany (1)	Netherlands (1)	Norway	UK	Total
1990	5.2	1.0	11	23	1.0	19	60.2
1991	6.3	0.8	12	20	0.8	18	57.9
1992	5.3	0.6	12	20	0.9	18	56.8
1993	4.0	0.5	16	22	0.9	17	60.4
1994	3.1	0.7	13	29	0.9	18	64.7
1995	6.6	0.6	12	34	1.0	18	72.2
1996	n.i.	0.33	9.0	22	0.8	18	
Mean	5.1	0.6	12.1	24.3	0.9	18.0	62.0

(1) The load given for a country might include load from other upstream countries. This is especially the case for the Netherlands and Germany where the rivers Rhine and Elbe discharge into the North Sea.

Where a load interval was given, the mean was used.

n.i.: no information.

(*): wet deposition only.

Source: OSPAR (1998a) (1998).

Table 10. Nutrient load to the Channel, Kattegat and Skagerrak in 1000 t y^{-1} 1990–95/96

TN load	Channel		Kattegat		Skagerrak		
Year	France*	UK	Denmark	Sweden	Denmark	Norway	Sweden
1990	74	22	34	35	3.6	38	3.9
1991	94	33	29	32	2.8	33	3.1
1992	92	31	33	35	2.9	35	2.9
1993	106	35	32	29	2.4	39	3.9
1994	138	36	43	40	3.6	40	3.8
1995	149	38	33	37	2.6	41	2.9
1996	120	28	19	n.i.	1.7	34	n.i.
Mean	110.4	31.9	31.9	34.7	2.8	37.1	3.4

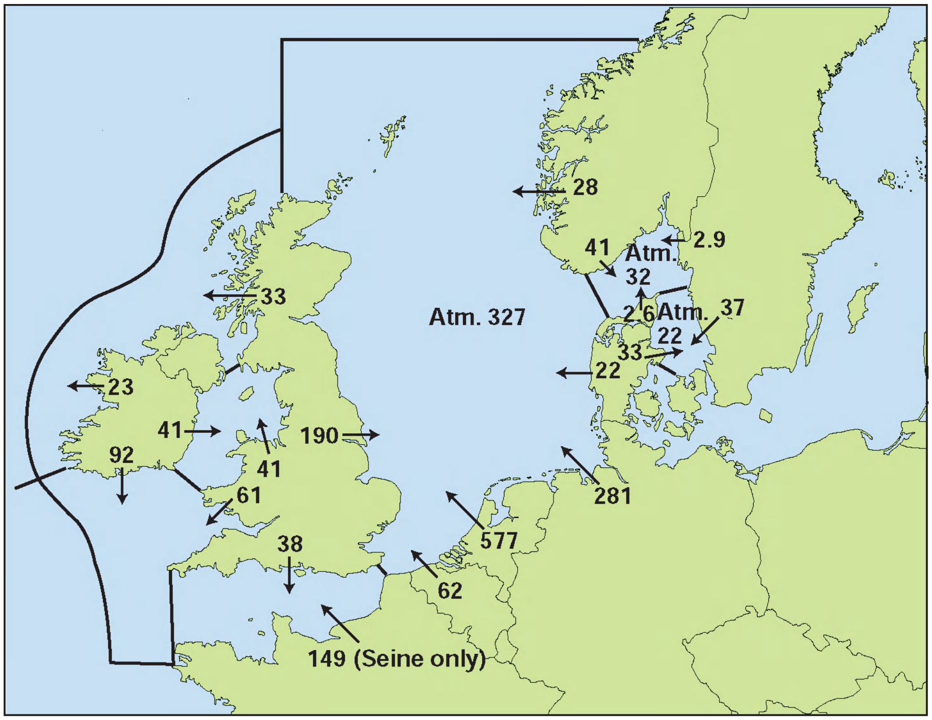
TP load	Channel		Kattegat		Skagerrak		
Year	France*	UK	Denmark	Sweden	Denmark	Norway	Sweden
1990	10	3.5	1.6	1.3	0.3	1.3	0.12
1991	11	3.6	1.1	0.9	0.2	1.1	0.09
1992	11	3.0	0.9	0.7	0.2	1.1	0.09
1993	11	3.1	0.9	0.6	0.1	1.1	0.06
1994	11	2.6	1.3	0.9	0.2	0.9	0.14
1995	10	2.9	0.9	1.2	0.1	1.2	0.12
1996	7.3	2.6	0.6	n.i.	0.07	0.9	n.i.
Mean	10.19	3.04	1.04	0.93	0.17	1.12	0.10

n.i: no information.
(*) River Seine only.
Source: OSPAR (1998a) (1998b).

Most of the sources of nutrients to the North Sea are linked to anthropogenic activities. Nitrogen in rivers originates mainly from the leaching of agricultural soils and from urban wastewater discharge. Phosphorus is mainly linked to urban wastewater and soil erosion. River discharges account for 65 to 80 % of the total nitrogen inputs and for 80 to 85 % of the total phosphorus inputs. Nitrogen in the atmosphere (NO_x and NH_x) originates from domestic and industrial combustion processes and traffic, as well as from agricultural sources such as animal housing and the spreading of manure (OSPAR Commission QSR 2000, Region II, 2000).

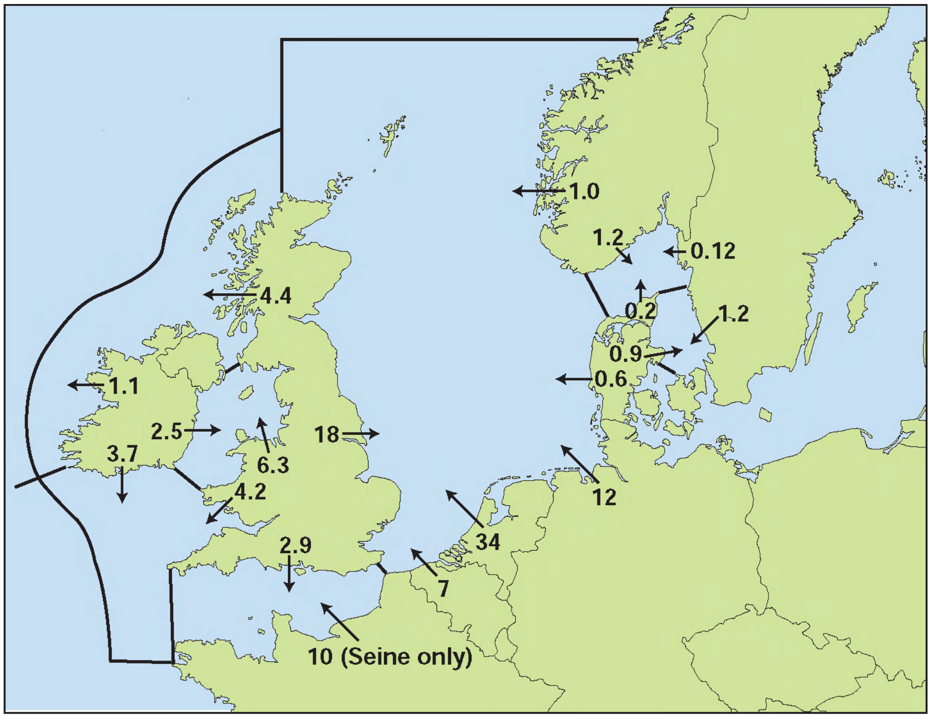
The actual loads to the open coastal areas may be lower than mentioned above due to retention of nutrients in the estuaries and fiords (Nixon et al., 1996). However, after substantial phosphorus load reductions, the Danish estuaries in these years export more phosphorus to the open sea than they receive from land. This is due to the release of phosphate stored in the sediment in earlier times with higher load. It is expected that a new balance will be established between load and sediment pools within 10 to 20 years (Ærtebjerg et al., 1998).

Figure 6. Nitrogen load to the Greater North Sea and Celtic Sea areas in 1995. Maximum estimates in 1 000 t N/year



Source: OSPAR (1998).

Figure 7. Phosphorus load to the Greater North Sea and Celtic Sea areas in 1995. Maximum estimates in 1 000 t P/year



Source: OSPAR (1998).

5.1.4. Celtic Seas

The Celtic Seas include the Irish Sea and Bristol Channel, the Celtic Sea, the Malin Shelf and the continental shelf to the west of Ireland and Scotland.

The total load with nutrients from land to the Celtic Seas in the period 1990–95 varied between 278 000 and 313 000 t y^{-1} for nitrogen and between 21 000 and 26 000 t y^{-1} for phosphorus (OSPAR, 1998a). The loads in 1995 per country and sub-area are shown in Figures 6 and 7, and for the years 1990–95 in Table 11.

Table 11. Nutrient load to the Celtic Seas, Biscay and Iberian coast in 1000 t y^{-1} 1990–95/96

TN load	Atlantic		Irish Sea		Celtic Sea		Biscay and Iberian coast		
Year	Ireland	UK	Ireland	UK	Ireland	UK	France (*)	Portugal	Spain
1990	30	35	41	47	87	39	194	18.0	n.i.
1991	30	35	50	47	93	52	194	18.0	n.i.
1992	29	39	36	60	63	60	194	8.4	n.i.
1993	26	35	52	45	88	52	194	18.0	n.i.
1994	30	28	47	49	103	57	194	16.0	n.i.
1995	23	33	37	41	92	61	194	9.7	n.i.
1996	31	27	46	55	113	46	n.i.	n.i.	n.i.
Mean	28	33	44	49	91	52	194	15	

TP load	Atlantic		Irish Sea		Celtic Sea		Biscay and Iberian coast		
Year	Ireland	UK	Ireland	UK	Ireland	UK	France (*)	Portugal	Spain
1990	0.8	4.7	2.4	8.5	3.6	5.0	9.5	3.1	n.i.
1991	0.9	4.4	2.3	10.0	3.1	3.3	9.5	3.1	n.i.
1992	1.0	2.7	2.1	9.2	3.3	5.0	9.5	3.0	n.i.
1993	1.0	4.6	2.6	4.9	4.2	3.7	9.5	5.8	n.i.
1994	1.2	3.1	2.9	7.7	6.4	4.5	9.5	14.0	n.i.
1995	1.1	4.4	2.5	6.3	3.7	4.2	9.5	3.1	n.i.
1996	1.3	3.6	2.5	6.5	5.9	3.1	n.i.	n.i.	n.i.
Mean	1.0	3.9	2.5	7.6	4.3	4.1	9.5	5.4	

Note: Where a load interval was given, the mean was used.
n.i.: no information.
(*) Only the rivers Loire and Gironde.
Source: OSPAR (1998a) (1998b).

5.1.5. Bay of Biscay and the Iberian coast

Load data for this region are incomplete (Table 11). The total load with nutrients from Portugal and through the French rivers Loire and Gironde in the period 1990–95 varied between 202 000 and 212 000 t y^{-1} for nitrogen and between 13 000 and 24 000 t y^{-1} for phosphorus (OSPAR, 1998a).

5.1.6. Mediterranean Sea

There are no systematic and comprehensive pollution load compilations for the Mediterranean Sea as for the Helcom and OSPAR regions. In UNEP/FAO/WHO (1996) an estimation of the total load is made on the basis of population density, fertiliser use, land use and livestock populations for three different scenarios. The calculations revealed that the most likely actual total nitrogen load from land-based sources would lie within the range of 1.5 to 2.5 million tonnes, and that for phosphorus between 0.15 and 0.25 million tonnes per year.

About 450 million people live in the Mediterranean coastal states, and more than 135 million tourists visit the coastal regions per year. Out of 230 coastal cities, with information available, about 45 % were without sewage treatment plants, and about half of the total volume of sewage is discharged untreated. Where treatment plants were present only 38 % of them had secondary treatment (EEA, 1999c). In

UNEP/WHO (1999) an identification of priority pollution hotspots and sensitive areas in the Mediterranean region is made and the nutrient load mainly from sewage to the areas given (Table 12).

Table 12. Identified priority pollution hotspots and sensitive areas in the Mediterranean region (a few areas without load information have been omitted)

Country	Hotspot	Source	Population	BOD t/y	COD t/y	Total-N t/y	Total-P t/y	TSS t/y
Albania	Durres	d	120 000	2 864		477	96	4 300
	Vlore	d	110 000	2 628		438	88	3 942
Algeria	Oran Ville	m	1 230 000	26 937	44 895	6 734	2 693	40 405
	Rouiba	m	120 000	2 628	4 380	657	262	3 942
	Ghazaouet	m	120 000	2 628	4 380	657	262	3 942
	Alger	m	1 957 334	42 865	71 442	10 716	4 286	64 298
	Mostaganem	m	631 000	13 818	23 031	3 454	1 381	20 728
	Bejaia	m	859 000	18 812	31 353	4 703	1 881	28 218
	Annaba	m	890 000	19 491	32 485	4 872	1 949	29 236
	Skikda	m	747 000	16 359	27 265	4 089	1 635	24 538
Croatia	Kastela Bay + industrial zone	m	See Split	5 006	11 095	594	129	8 481
	Split	m	350 000	1 643	3 286	411	115	1 232
	Sibenik	m	60 000	201	410	89	20	240
	Zadar + indusrial zone	m	85 000	1 056	3 940	154	26	1 410
	Pula	m	63 979	329	513		4	259
	Rijeka + Kvarner Bay	m		32	121			25
	Dubrovnik	d	50 000	160	310	79	19	139
Cyprus	Limassol	m	130 000	1 181	2 185	39	15	336
Egypt	Abu-Qir Bay	m		91 701	575 490	4 966	8 248	120 035
	El-Mex Bay	m		219 498	175 654	2 081	2 628	286 645
	Alexandria	d	4 000 000	1 632		1 520	2 266	8 831
France	Marseille	d	900 000	13 700	24 800	4 700	300	3 100
	Gardanne	i						31 600
	Toulon	d	310 000	1 300	5 000	1 500	150	1 000
	Cannes	d	144 000	1 900	3 800	600	150	1 000
	Frejus	d	175 000	650	1 700	400	40	400
Greece	Thermaikos Gulf	m		297	1 043		15	142
	Inner Saronic Gulf	m	3 345 000	59 386	11 8735			42 815
	Patraikos Gulf	m	155 180	127	473	110	29	110
	Pagasitikos Gulf	m	77 907	657	1 095			
	Heraklio Gulf	m	117 167	84	141			29
	Elefsis Bay	i		61	446			70
	NW Saronic Gulf	i		22	22			5
	Larymna Bay	i			7 516			2 505
	Nea Karvali Bay	i		295	739	625	126	
Israel	Haifa Bay	m		5 300	20 000	11 055	1 272	7 200
	Naharaiya	d	37 500	2 900	6 200	122	86	2 250
	Akko	d	46 000	2 000	4 400	330	53	2 200
	Gush Dan	m	1 100 000			2 900	1 200	44 000
	Ashdod	i		2 630	12 150	600	7	258
Italy	Porto Marghera (VE)	m	309 422	9 988	39 953	3 746	2 497	19 977
	Genova	m	678 771	15 796	63 184	5 923	3 949	31 592
	Augusta-Melilli-Priolo	m	57 311	1 808	7 232	678	452	3 616
	Brindisi	m	95 383	2 077	8 308	779	519	4 154

Country	Hotspot	Source	Population	BOD t/y	COD t/y	Total-N t/y	Total-P t/y	TSS t/y
	Gela	m	72 535	2 144	8 578	804	536	4 289
	La Spezia	m	101 422	3 949	15 796	1 450	940	7 346
	Milazzo	m	31 541	616	2 464	231	154	1 232
	Golfo di Napoli	m	1 540 814	16 251	65 005	6 094	4 063	32 502
	Ravenna	i	135 844	6 363	25 453	2 386	1 591	12 727
	Taranto	m	232 334	2 484	9 937	932	621	4 968
	Rosignano Solvay (Marritimo)	i	30 021	187	747	70	47	373
	Bari-Barletta (Global)	d	1 200 000	7 707	30 827	2 890	1 927	15 413
	Livorno	i	167 512	2 698	10 792	1 012	674	5 396
	Manfredonia	m	58 318	1 272	5 087	477	318	2 543
	Ancona-Falc	i	131 390	2 990	11 959	1 121	747	5 979
Lebanon	Gt Beirut Area	m		29 235				14
	Jounieh	m	200 000	4 280				80
	Saida-Ghaziye	m	205 000	5 134				293
	Tripoli	m	353 000	7 446				
	Batroun Selaata	m	51 000	1 077				
Libya	Tripoli	d	1 200 000	3 100	4 650	740		4 300
	Benghazi	d	750 000	2	2 100	306		1 226
Malta	Weid Ghammieq	m	270 085	10 250	16 021	135 415	12 447	124 538
	Cumnija	m	59 224	2 412	3 599	1 914	1 495	14 240
	Ras il-Hobz	m	25 957	1 273	3 318	1 777	2 233	28 165
Morocco	Tangier	m	526 215	9 401	22 076	928	150	9 651
	Tetouan	m	367 349	6 861	15 304	723	114	7 143
	Nador	m	246 113	1 888	4 435	83	100	1 433
Slovenia	Koper (including rizana river)	m	46 221	485	5 111	76	8	250
	Izola	m	13 770	1 092		90	21	414
	Delamaris	i	(See Izola)					
	Piran Submarine Outfall	d	17 000	125	290	23	26	116
Spain	Barcelona	m	4 680 000					
	Tarragona	m	110 000					
	Valencia	m	2 143 000					
	Cartagena	d	168 000					
	Algeciras	d	85 000					
Syria	Tartous	m	319 152	18.5		74	34.3	
	Lattakia	m	746 851	530				168
	Banias	m	142 564	163	316			
	Jableh	m	166779	542				225
Tunisia	Gabes	m	150 000	1 732		320	724	4 860
	Lake of Tunis	i	400 000	2 243	4 384	300	26	1 210
	Lake of Bizerte	i	250 000	2 687		476	118	2 329
	Sfax-South	i	395 277	843	1 900	100	40	345
Turkey	Icel area	m	897 813	19 659	32 768	4 916	1 967	29 491
	Antalya area	d	707 209	15 487	25 812	3 872	1 549	23 232
	Adana area	m	1 198 285	26 242	43 737	6 561	2 624	39 333
	Antakya area	d	434 084	9 504	15 842	2 376	950	14 258
	Bodrum area	d	65 061	1 424	2 373	356	142	2 136
Total			40 163 694	804 244	1 729 853	259 691	75 234	1 251 423

Note: Pollution source: d = domestic; i = industrial; m = mixed; TSS = total suspended substance.
Source: UNEP/WHO (1999).

Besides urban (and industrial) sewage, agriculture is a major anthropogenic nutrient source to the Mediterranean Sea. Due to the specific morphology of the Mediterranean basin, intense agricultural activity is carried out in the limited coastal plains, often as a result of reclamation of wetlands. The main pressures from agriculture are soil erosion and nutrient surplus from excessive fertilisation. Also large river basins like the Rhone and Po basins are subjected to agricultural pressures. The first six drainage regions, following a tentative ranking of the risk of soil erosion and nutrient losses, are found in peninsula Italy, Sicily, Sardinia, Greece, Turkey and Spain (EEA, 1999c). EEA (1999c) estimated an annual minimum agricultural load (excluding Croatia, Egypt, Libya, Malta and Slovenia) to the Mediterranean Sea of 1.6 million tonnes nitrogen, 0.8 million tonnes phosphorus and 1.7 million tonnes TOC.

Marine aquaculture has shown a large expansion in production in a number of Mediterranean countries over recent decades, and increased from 78 000 t y^{-1} in 1984 to 248 000 t y^{-1} in 1996. Since marine intensive aquaculture is a relatively new sector in the Mediterranean and concerns mainly shellfish and some fish species, the impact is according to EEA (1999c) still rather limited and localised. Nevertheless, if the estimates made by EEA (1999c) are correct the nitrogen load from marine fish farming (1.8 million tonnes) is of the same order of magnitude as the load from agricultural activities and the phosphorus load (0.21 million tonnes) about one-fourth of the agricultural soil erosion. This means that, at least locally, fish farming is a major nutrient source that can cause eutrophication effects.

In EEA (1999c) a list of the 50 largest rivers to the Mediterranean Sea is given with the mean annual water flow and for some of the rivers also the mean concentrations of nitrate (30 rivers), ammonium (28 rivers) and phosphate (23 rivers). For these rivers a mean annual load of 304 000 tonnes inorganic nitrogen and 21 900 tonnes phosphate was estimated.

The nutrient concentrations found in Mediterranean rivers are about four times lower than those in western European rivers. However, depending on the river size and location, the concentration ranges between rivers are enormous, over an order of magnitude for nitrate and more for ammonia and phosphate (EEA, 1999c).

Discharges of nitrogen and phosphorus to the Adriatic region are of the order of 270 000 and 24 000 t y^{-1}, respectively. The north Aegean Sea receives annually 180 000 tonnes nitrogen and 11 000 tonnes phosphorus from the Black Sea, which is comparable to the inputs from land-based sources to the north-east of the Mediterranean Sea (EEA, 1999c).

5.2. Recent trends in land-based loads

5.2.1. Baltic Sea

The nitrogen load to the Baltic Sea since the 1980s displays considerable year-to-year variations, depending on river run-off, and no clear trends have been observed. However, the nitrogen load is assumed to have decreased slightly and the phosphorus load significantly since 1985. This is for nitrogen mainly due to the reduction in fertiliser usage in the countries in transition, and for phosphorus the installation or improvement of sewage treatment plants as well as phosphate-free detergents, which in certain areas has resulted in a 50 % reduction in the phosphorus load (Helcom, 1998b). The eutrophication symptoms have decreased in some coastal areas where the reduction of nutrient inputs has been substantial.

On average about 10 % of the total load with nitrogen and phosphorus (excluding the Belt Sea and Kattegat) leaves the Baltic Sea through the Danish straits (Wulff and Stigebrandt, 1989). The remaining load is removed from the water through denitrification and deposition in the sediment.

5.2.2. *The OSPAR region*

Trend analysis of the annual load to the OSPAR sub-regions in the period 1990–96 was made using the Trend-y-tector method. This is a non-parametric Mann-Kendall test combined with a smoother. The trend analyses were performed on the log-transformed time series using a two-sided test with a significance level of 5 %.

The analysis showed a decrease in nitrogen load to the Kattegat, and a slight decrease to the Atlantic (UK and Portugal). No trend was noticed for the Skagerrak as a whole in spite of decreasing trend in the load from Denmark. Increasing nitrogen load was found to the coastal zone influenced by the Rhine and to the Channel with the main contribution from the river Seine. However, the time series are short and no correction for varying riverine flow rates was possible. Therefore, the detected trends in nitrogen loads mostly reflect the natural variations in freshwater run-off.

A decreasing trend in phosphorus load was found for the Skagerrak and Kattegat, and a minor decrease for the Channel and Irish Sea. A slight increase in phosphorus load to the North Sea, Celtic Sea and Norwegian Sea can be related to higher river flow rates.

Arctic waters

The limited information on riverine and direct inputs to arctic waters reported to OSPAR shows that levels of nutrients are low and stable, and no trends can be perceived (OSPAR Commission QSR 2000, Region I, 2000).

North Sea

Time series of nitrate and phosphorus concentrations in major EU rivers covering the period 1980–95 show that the nitrate concentrations were approximately constant, and that the phosphorus concentrations were about halved since 1985 (EEA, 2000). For example, the TP and phosphate load via the Elbe decreased by 40 % and 60 %, and via Lake Ijsselmeer by 50 % and 80 %, respectively, between 1985 and 1996. However, the ammonium load via Lake Ijsselmeer, Ems and Elbe also decreased in the same period by 55 %, 60 % and 80 %, respectively, mainly due to improved sewage treatment (Wadden Sea QSR, 1999).

In agreement with the general development, since 1985 there has been a significant reduction in the total inputs of phosphorus, but no discernible reduction in inputs of nitrogen to the North Sea. This is primarily due to the poor reduction of the input to the aquatic environment from agriculture. However, over the period 1990–96 the direct inputs of nitrogen to the North Sea decreased by about 30 % and those of phosphorus by about 20 %, which reflects improvement in sewage treatment (OSPAR Commission QSR 2000, Region II, 2000).

5.2.3. *Mediterranean Sea*

In all documented cases concerning rivers to the Mediterranean Sea, nitrate levels are increasing, although the trend for ammonium is variable depending on the method of sewage collection and treatment carried out. Phosphate concentrations may increase dramatically, as in Greece, or steadily as found in France, or decrease when phosphorus restriction measures are imposed, e.g. a phosphorus ban on detergents in Italy (EEA, 1999c).

5.3. Recent trends in atmospheric nitrogen deposition

Model estimations of atmospheric wet and dry deposition of inorganic nitrogen to the Baltic Sea showed that the deposition on the Baltic Sea as a whole decreased by about 25 % from 1986 to 1995, but in the Kattegat and Belt Sea area only by about 14 %. The reduction seems to be roughly the same for both reduced (NH_x) and oxidised (NO_x) nitrogen originating mainly from agriculture and combustion of fossil fuels, respectively. It is believed that the decrease is mainly due to reduced agricultural and industrial productivity in east European countries and partly to changed agricultural praxis in western Europe (Helcom, 1997).

No general trends were noted for atmospheric wet deposition of inorganic nitrogen to the North Sea in the period 1990–96 (OSPAR Commission QSR 2000, Region II, 2000).

5.4. Historic development in nutrient load

The main increase in nutrient load to the coastal areas probably took place from the late 1940s to the late 1970s before most freshwater and atmospheric monitoring programmes were started, and before nutrient load compilations were performed.

Gerlach (1990) analysed data from Bennekom and Salomons (1981) and the Rhine Commission on annual mean concentrations of phosphate, nitrate and ammonium in the Rhine at the border between the Netherlands and Germany during the period 1930–86. He concluded that a sevenfold increase of phosphate concentrations in the water of the Lower Rhine had taken place between 1950 and 1975 (from 0.06 to 0.4 mg P l^{-1}). Dissolved inorganic nitrogen (DIN) concentrations had increased fourfold during the same period (from 1.0 to 4.5 mg N l^{-1}). Until 1986 phosphate concentrations stayed nearly constant, and the rise in DIN concentrations seemed to slow down.

After model removal of the influence of varying freshwater run-off, a significant increase of 3.7 % per year in the export of nitrate during the period 1967–78 was observed in Danish rivers draining mainly agricultural catchment areas. In contrast, no significant trends could be detected for the period 1978–89 (Kronvang et al., 1993).

These estimates are probably indicative for the development in nutrient loads between the 1950s and the 1980s from agricultural and highly developed industrial areas to the EU coastal seas. However, not all drainage areas in the EU are densely populated or have been through intense agricultural and industrial development. Therefore, a conservative estimate of the increase in nitrogen loads to the Helcom and OSPAR regions (excluding the Arctic region) is a doubling from the 1950s to the 1980s (Hansen et al., 1995), and a fourfold increase in the phosphorus load from the 1940s to the 1970s. The historic development in nutrient load to the Mediterranean Sea is unknown, but probably in the same order of magnitude.

Gerlach (1990) also found that a threefold increase from 1950 to 1980 of the airborne nitrogen load was a reasonable estimate for the German coastal waters (from 0.7 t km^{-2} to 2 t km^{-2}). Asmann et al. (1988) estimated nearly a doubling (43 % increase) in the ammonium concentration in rain over Denmark from 1950 to 1980 (from 37 to 53 µM). More conservatively Hansen et al. (1995) estimated an increase from the 1950s to the 1980s in atmospheric nitrogen deposition to the whole North Sea and the Baltic Sea of 40 % and 50 %, respectively.

6. Present state of eutrophication

The dataset mainly covers the coast of Iceland, North Sea, Irish Sea, Channel, Skagerrak and the Baltic area including the Kattegat, Belt Sea, Gulf of Bothnia, Gulf of Finland and Gulf of Riga. For the rest of the Community waters including the coasts of the Mediterranean Sea and the Atlantic coasts of Portugal, Spain and France, very few data are available and do not allow for spatial segregation. In this chapter the analysis is based on ICES data. The maps in Annex 1 show the average winter nutrient and summer chlorophyll-a concentrations in the surface layer and summer bottom oxygen concentrations within the years 1985–98, as determined from the available dataset.

6.1. Nutrients

Eutrophication of marine coastal areas mainly results from input of nutrient with the run-off of freshwater. Within a given area the state of eutrophication depends on the one hand on the amount of the nutrient loads, and on the other hand on the mixing processes within the marine environment. Different areas react differently to the same nutrient load; a closed fiord will be more eutrophic than an open oceanic coastline. The gradual offshore dilution of nutrients can be visualised in plots showing nutrient concentrations versus the salinity. This type of plot provides valuable information also on background nutrient concentrations, the significance of freshwater as a source of nutrient input, freshwater nutrient concentrations and in some cases even on internal processes. This information can be compared with the spatial salinity patterns to give a picture of the area affected by eutrophication. There are, however, some premises for the interpretation of these plots. In the case of a complex hydrography combined with several sources of freshwater load conclusions should be made carefully. In the following the premises are discussed individually for the Community waters. Nutrient concentrations are given as mols per litre (µmol/l = µM).

6.1.1. North-east Atlantic

This dataset covers the coast around Iceland, some data from the Shetland Islands and the Norwegian coast up to 64 degrees latitude. Data from the Spanish and French coast are too scarce for analysis.

Coast around Iceland

This dataset covers only nitrate, phosphate and silicate (Annex 1, Maps 13, 22). As the dataset does not include data on salinity it is not possible to analyse the impact of freshwater run-off on the coastal nutrient levels. However, all nutrients occur in low concentrations, and the concentrations are more or less constant. Thus there is no indication of eutrophication at the coast around Iceland.

Shetland Islands and the Norwegian coast

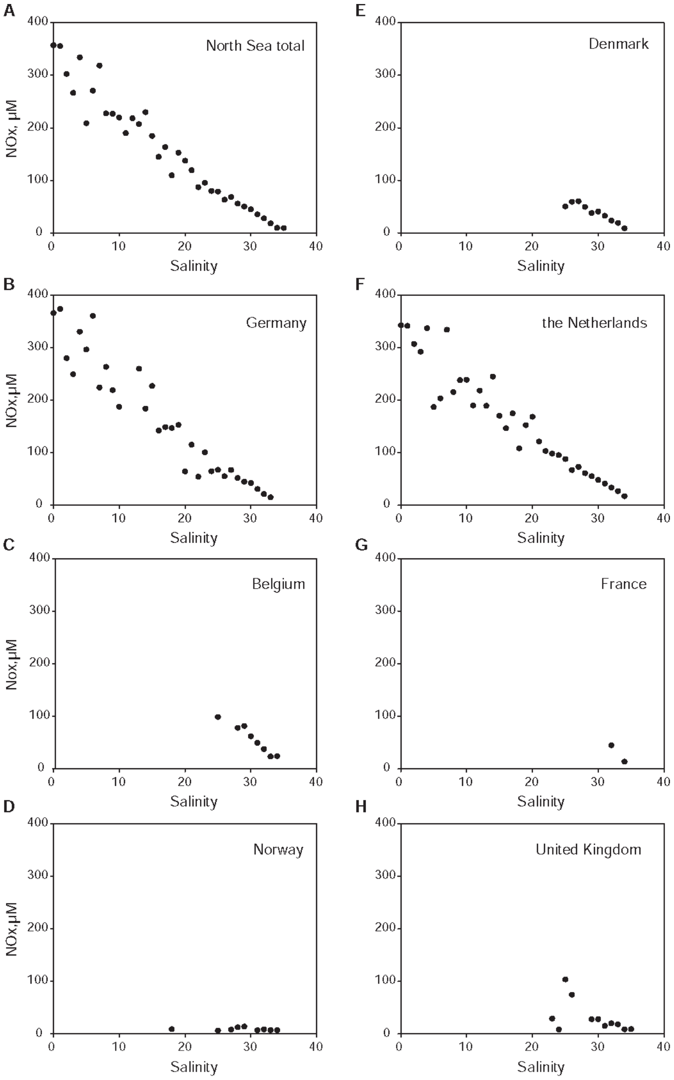
Data cover a range of salinity going from 31 to 34 psu. Nitrate concentrations do not exceed 11 µM in any of the squares either at the Shetland Islands or at the Norwegian coast. Average for the whole region is 7.8 µM and data show only little variation (Annex 1, Maps 10, 12). Average phosphate concentrations are in the range of 0.6–0.7 µM and show little variation across the whole area (Annex 1, Maps 3, 5). The concentration of silicate is also low and constant throughout the area (Annex 1, Maps 19, 21). The coastal water chemistry reflects the general (more pristine) conditions in the open parts of the North Atlantic, which is also evident from the salinity in the depicted areas. In conclusion, the present data from the north Atlantic coasts of the Shetland Islands and Norway show no indication of eutrophication.

6.1.2. Greater North Sea

North Sea

Winter concentrations of nitrate + nitrite, NO_x, show one order of magnitude variation within the coastal areas of the North Sea. Extreme winter concentrations are found in 'hot spots' in the southern part of the North Sea, along the east coast of the UK and along the coastline going from the Channel to the Wadden Sea including the coastline of Belgium, the Netherlands and Germany (Annex 1, Maps 10, 12). The summed concentrations of nitrate + nitrite, NO_x, show medium to high levels in the eastern part along the Danish coastline. The lowest winter concentrations are found along the Norwegian coastline (Figure 8).

Figure 8. Nitrate + nitrite concentrations versus salinity (psu) for (A) the total dataset for the North Sea; (B) Germany; (C) Belgium; (D) Norway; (E) Denmark; (F) the Netherlands; (G) France and (H) United Kingdom

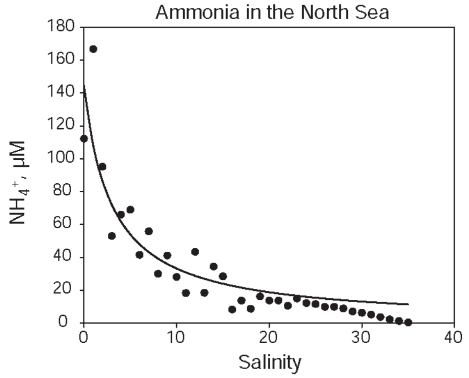


The patterns in winter concentrations of NO_x show a very close relationship with salinity, the more brackish the higher the content of NO_x. For the North Sea as a whole this inverse relationship between inorganic nitrogen concentration and salinity goes from a mean value of 350 µM in freshwater to about 10 µM in water having a salinity of 35 psu. For the individual areas, divided by countries, the same relationship can be reproduced showing that freshwater input to the southern North Sea has more or less the same concentration of nitrate. In terms of load there are considerable differences (Table 9) with the highest values for the Netherlands followed by Germany and the UK. However, it is worth noticing that the order of the countries only reflects the locations of the river mouths with highest impact on the load.

In the northern part of the North Sea at the Norwegian coastline the concentration of inorganic nitrogen is low in a range of salinity going from 18 to 35 psu. Thus, nutrient load from freshwater seems to be insignificant in Norwegian waters because the freshwater comes mainly from non-agriculture catchments. Brackish water in this region may originate both from the Baltic area and as a result of local run-off from Norway. The salinity–nutrient relationship for the UK is based on data from both the Scottish and English coastline (Annex 1, Map 12). In the plot, two outliners having low nutrient and salt concentrations represent data from the northern part of the UK.

Ammonium concentrations vary more than two orders of magnitude from less than 1 µM in 34 psu water and up to 100 µM in freshwater flowing into the southern North Sea. Ammonium comes from the same sources as NO_x; run-off from agricultural and urban areas. Thus, the patterns of ammonium concentrations show hot spots located at the mouth of the Dutch and German rivers as well as the river Thames. The dynamics of ammonium are different from that of nitrate. The relation between ammonium and salinity follows a hyperbolic function rather than a linear one (Figure 9). This kind of relationship clearly shows that two processes (at least) lower the ammonium concentration: mixing and consumption within the system. During winter, oxidation to nitrite and nitrate is the most important process. Eventually freshwater input of ammonium will contribute to the pool of nitrate at more offshore locations.

Figure 9. Ammonium concentrations versus salinity (psu) in the North Sea



Overall, the phosphate concentrations show the same pattern as the inorganic nitrogen compounds: highest concentrations in the freshwater and a linear decrease along the mixing gradient with seawater. The highest concentrations are found in the southern North Sea. German, Dutch and English rivers contribute approximately 90 % of the total phosphate load to the North Sea (Annex 1, Maps 1, 5). The salinity–phosphate relationship shows considerable more scatter than that of NO_x (Figure 10). For the different countries the slope of this relationship is markedly different suggesting that freshwater run-off from Denmark and Belgium has the highest phosphate concentrations. There are relatively few data from Norwegian waters, but they show no relationship between phosphate and salinity which indicates that Norwegian freshwater has an insignificant effect on the state of eutrophication. For phosphate point sources are relatively more important and traditionally urban areas were the main sources of phosphate. However, during the last decade more sewage plants have significantly improved phosphate removal. Estuaries in the transition zone between rivers and the marine systems may export phosphate from hypoxic/anoxic sediments and contribute to the marine pools.

Silicate concentrations follow exactly the same salinity pattern as nitrate concentrations (Figure 11). Highest concentrations are found in the southern part of the North Sea (Annex 1, Maps 19, 21), where the main sources of silicate are also located, namely the German, Dutch and English rivers.

Figure 10. Phosphate concentrations versus salinity (psu) for (A) the total dataset for the North Sea; (B) Belgium; (C) Denmark; (D) Germany; (E) the Netherlands; (F) Norway and (G) United Kingdom (note: different scales)

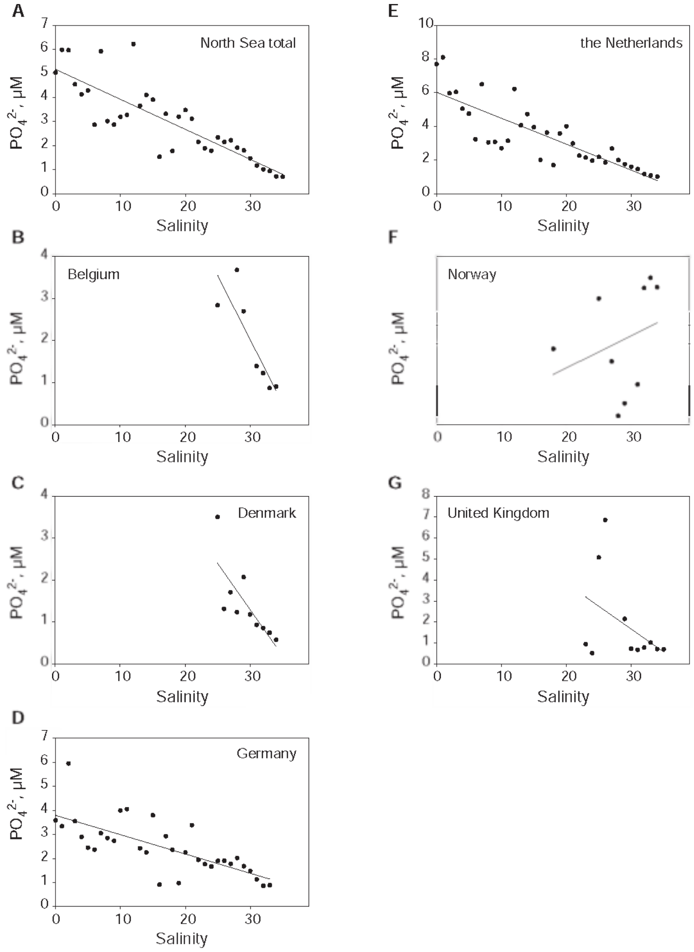
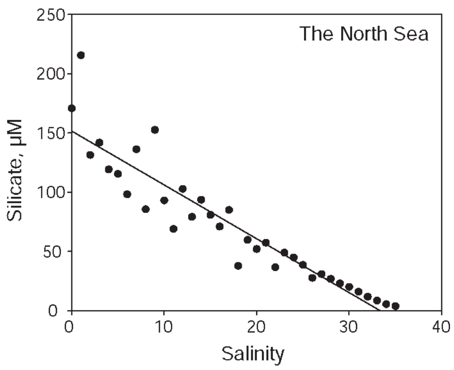


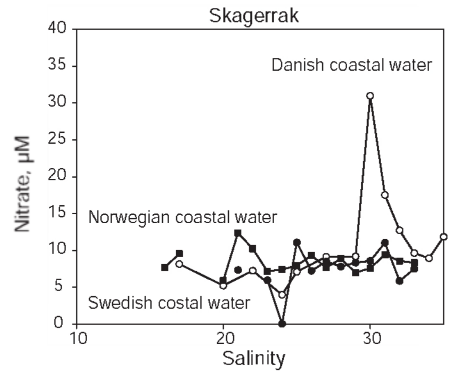
Figure 11. Silicate concentrations versus salinity (psu) in the North Sea



Skagerrak

The dataset covers the Danish, Norwegian and Swedish coasts with a salinity range going from 16 to 35 psu (Annex 1, Maps 3, 10, 15, 19). Nitrate concentrations are highest along the Danish coast with an average value of 12 µM whereas the level is about 8 µM at the Swedish and Norwegian coasts. The higher average concentration in the Danish waters is due to peak concentrations in water of 30–32 psu (Figure 12). Water in the range of 16–29 and 33–35 psu show the same nitrate levels as in the Norwegian and Swedish coastal regions.

Figure 12. Nitrate concentrations versus salinity (psu) in the Skagerrak for Danish coastal water (open circles), Swedish coastal waters (closed circles) and Norwegian coastal water (filled squares)

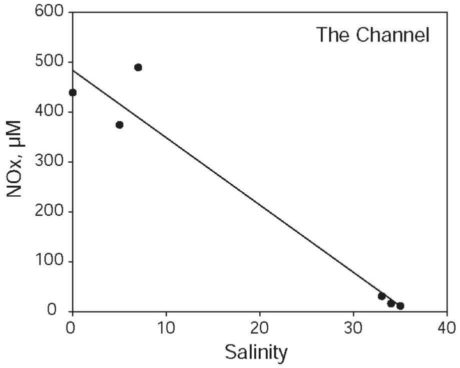


Danish coastal water originates from the southern part of the North Sea transported northward with the Jutland coastal current. Swedish and Norwegian coastal surface waters result from mixing of water from the central Skagerrak with outflowing water from the Kattegat and with local freshwater output. Water from the Jutland coastal current is characterised by 30–32 psu salinity and the high nutrient load in the southern North Sea likely affects the nitrate concentration in coastal areas as far north as the Danish Skagerrak coast. In the rest of the data there is no clear correlation between nitrate and salinity. Thus from these data it is not possible to identify local sources of nitrate. Phosphate concentration also peaks in 30 psu water at the Danish coast. However, the peak is not as pronounced as for nitrate concentrations.

Channel

In the Northern part of the Channel following the English coast NO_x concentrations are low (Annex 1, Map 12) which agrees with the fact that water originates from the Atlantic and there is no significant input of freshwater. At the French coast nutrient concentrations show a hot spot at the mouth of the river Seine with nitrate concentrations exceeding 400 µM. Although data are few, salinity and nutrient again show a linear relationship and indicate freshwater nutrient concentrations of about 500 µM (Figure 13). The concentration of ammonium is also low along the English coastline with concentrations ranging between 0 and 4 µM. At the French coast there is only data from the mouth of the river Seine, where the concentration of ammonium reaches 89 µM (Annex 1, Map 17).

Figure 13. Nitrate + nitrite versus salinity (psu)



The concentrations of phosphate and silicate (Annex 1, Maps 5, 21) follow exactly the same pattern as NO_x with one important hot spot at the mouth of the river Seine, higher concentrations at the French coast and low concentrations along the English coast.

Celtic Seas

Data include the Irish Sea, Bristol Channel and a few data from Lands End (Annex 1, Maps 5, 12, 17, 21). In the Bristol Channel most of the data show nitrate levels less than 20 µM, except in the innermost part. In the outer part of the Bristol Channel, water chemistry is dominated by inflow of oceanic water, and eutrophication, assessed in terms of nutrients, is relatively low.

Irish Sea

Nitrate + nitrite levels remain low to medium high throughout the Irish Sea, with the exception of two points. All the depicted data show mean winter concentrations less than 20 µM nitrate (quantitatively nitrite is unimportant). In the present dataset there is no clear relationship between salinity and NO_x suggesting that freshwater run-off has a limited effect on nitrogen pools in the Irish Sea (Figure 14). However, this is in contrast to earlier reports (OSPAR Commission QSR 2000, Region III, 2000) showing a close relationship between salinity and winter nitrate concentration. In the estuaries, Mersey, Ribble, and Wyre, salinity–nutrient relationships show freshwater nitrate concentrations of 250 up to 500 µM. In terms of load, freshwater input directly into the Irish Sea is limited.

Figure 14. Nitrate + nitrite versus salinity (psu) in the Irish Sea for data from the United Kingdom (open symbols) and Ireland (filled symbols)

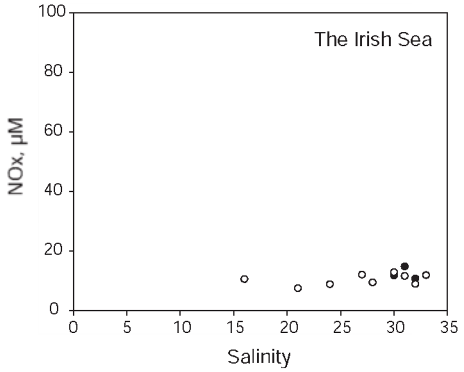
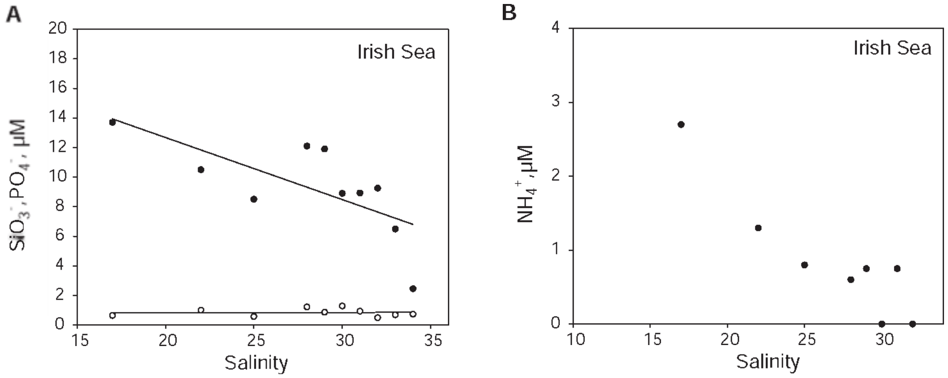


Figure 15. (A) Silicate concentrations (filled symbols) and phosphate concentrations (open symbols) versus salinity (psu) and (B) ammonium concentrations versus salinity (psu)



The highest concentration of ammonium is 2.7 µM (Annex 1, Map 17). Ammonium concentrations decline with the salinity but there are too few data to decide on the exact shape of the relationship (Figure 15B). These low concentrations could be due to the fact that there are no records in water of less than 17 psu (compared with the shape of the salinity–nutrient relationship in the North Sea). Thus, it cannot be decided if input of ammonium is important for the nitrogen pool in the Irish Sea.

Phosphate data depicted ranges between 0.4 and 4 µM (Annex 1, Map 5) with the highest values in Liverpool Bay and in the inner part of the Bristol Channel. From these data there is no clear relationship between salinity and phosphate concentrations (Figure 15A).

Silicate (SiO_3), concentrations range between 2 and 13 µM (Annex 1, Map 21). The relationship between salinity and silicate suggests that silicate concentration in freshwater run-off ranges between 20 and 30 µM, which are low values compared with the North Sea (Figure 15A). Silica is not of anthropogenic origin and is not a problem in terms of eutrophication. In the case of the Irish Sea the relationship between silica and salinity shows that the freshwater input of nutrient can be traced if occurring. Turning back to phosphate, this means that if freshwater was a source of phosphate it should be evident in Figure 15.

6.1.3. Baltic Sea

Data were supplied by the Helcom Commission and include the Gulf of Bothnia, Gulf of Finland, Gulf of Riga, Baltic Proper, Belt Sea and Kattegat.

The surface salinity of the Baltic Sea describes a gradient going from about 1 psu in the inner parts of the Gulf of Bothnia and Gulf of Finland, to 8 psu at the entrance to the Belt Sea and finally to about 25 psu in the northern Kattegat. In spite of the low salinity nitrate concentrations are low to medium high at the stations depicted (*Annex 1, Map 11).* Considering data from the entire Baltic Sea there is no linear relationship between salinity and nitrate concentrations (Figure 16B).

The relative low nitrate concentrations in the low saline Baltic water may result both from low concentration in freshwater, which comes from relatively low populated areas dominated by forests in the northern part. In the southern part of the Baltic Proper sedimentation of organic bound nitrogen and subsequent removal by denitrification is another significant process keeping nitrate concentrations low.

The levels of phosphate range between 0.3 and 3 µM (Annex 1, Map 4). There is no correlation between salinity and the concentrations of phosphate (Figure 17A). Spatial and temporal variations are closely linked to the varying concentrations of oxygen in the bottom water. Phosphate is released from anoxic sediments while a net sedimentation takes place during well-oxygenated periods. Long-time variation in bottom water oxygen concentration is determined by the episodic inflows of saltwater to the deep basins, probably overriding patterns of load.

Silicate shows medium levels (10–20 µM) in most areas (Annex 1, Map 20). A few observations of concentrations of up to 60 µM are located at the German and Polish coasts influenced by the Vistula, Odra and Nemunas rivers. Overall there is no distinct pattern of silicate in relation to salinity (Figure 18).

Figure 16. Nitrate + nitrite concentrations versus salinity (psu). (A) Gulf of Bothnia (open symbols) and Gulf of Finland (closed symbols); (B) Baltic area in total (closed symbols), German part of the Baltic Proper (open symbols) and Polish part of the Baltic Proper (triangles); (C) Belt Sea (closed symbols) and Kattegat (open symbols)

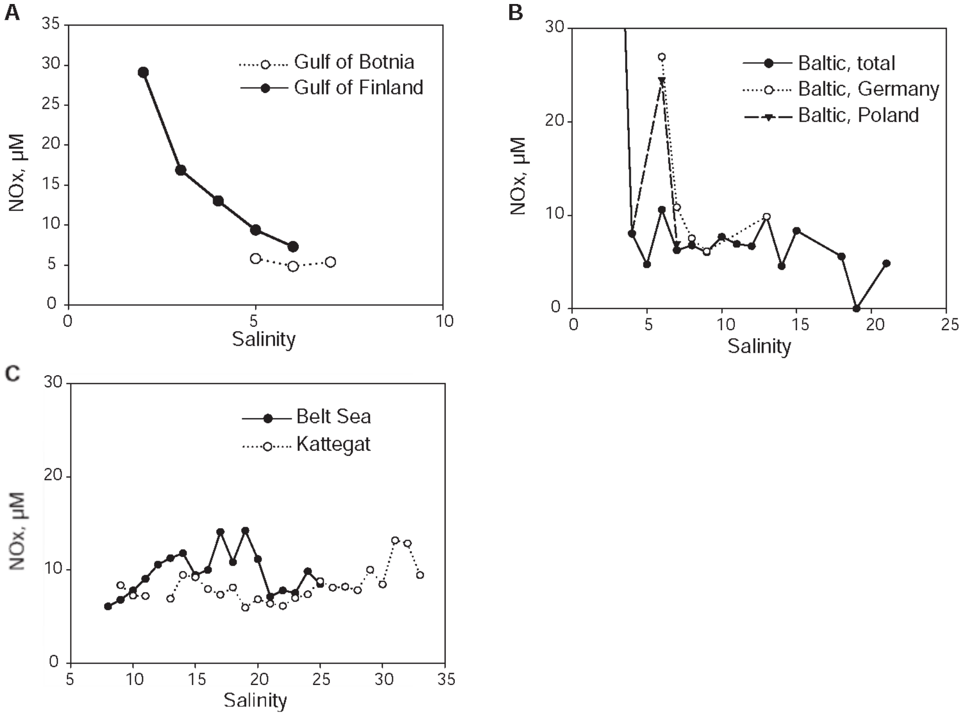


Figure 17. Phosphate concentrations versus salinity (psu). (A) Baltic Sea; (B) Gulf of Finland

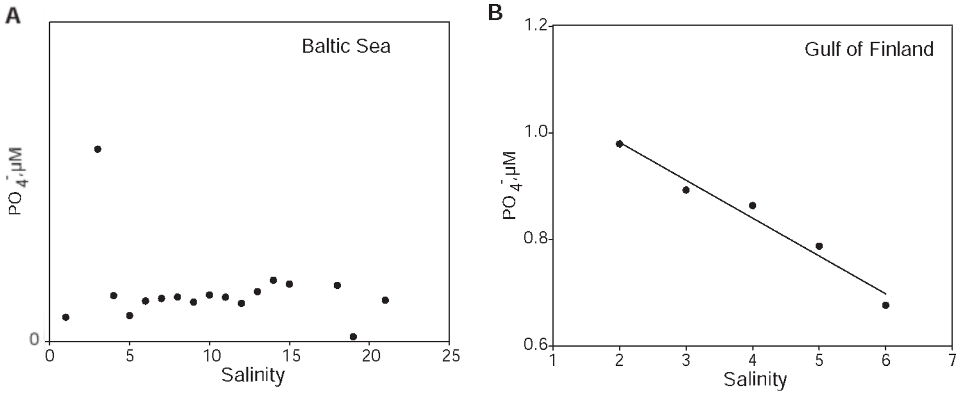
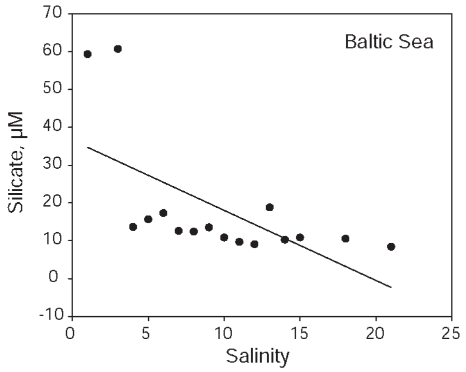


Figure 18. Silicate concentrations versus salinity (psu) in the Baltic Sea



Gulf of Bothnia

Nitrate + nitrite concentration does not exceed 9 µM in any of the squares (Figure 16A) and the pattern in concentrations is not related to the salinity. There is no data from water of less than 5 psu making it difficult to analyse the salinity–nitrate relationship. According to Helcom (1996) the Gulf of Bothnia receives 98 800 tonnes of nitrogen and 192 km^3 freshwater per year. These numbers correspond to an average freshwater nitrate concentration of 34 µM. Thus, low values of nitrate throughout the entire Gulf may to some extent be due to the lack of data of less than 5 psu. Phosphate concentrations are low throughout the entire Gulf of Bothnia (Annex 1, Map 4) ranging between 0.27 and 0.57 µM. These low phosphate values agree with the well-oxygenated conditions of the Gulf. This relationship suggests that freshwater input of phosphate to the Gulf is low. However there are significant inputs from several large rivers. The low concentrations of phosphate in surface water are due to effective chemical precipitation of phosphate with iron compounds in the Bothnian Bay.

Gulf of Finland

In the Gulf of Finland the highest nitrate concentrations are found in the inner parts of the Gulf (Annex 1, Map 11). Freshwater input to the Gulf mainly comes from the river Neva, which upstream passes through the city of St. Petersburg. Nitrate increases with decreasing salinity from 7 µM in 6 psu water and up to 29 in 2 psu water. Interpolation of the relationship to 0 psu gives a freshwater concentration of about 50 µM, which is lower than the 66 µM calculated from the Helcom (1996) nitrate load. The salinity–nitrate relationship follows a slightly hyperbolic line rather than a straight line, which indicates that processes other than mixing remove nitrate — most likely denitrification (Figure 16A). This is in agreement with data from Helcom (1996) showing that denitrification can remove about 64 % of the river input of nitrogen. Nitrification adds less than half the amount of nitrogen to the Gulf as is removed by denitrification. In total, 35 % of the nitrogen input to the Gulf is removed by processes other than mixing and give rise to the hyperbolic shape of the salt-nutrient relationship.

Phosphate concentrations are generally two to three times higher compared with levels in the Gulf of Bothnia (Annex 1, Map 4). Highest concentrations are found in the inner parts of the Gulf. Phosphate concentrations increase with decreasing salinity (Figure 17B), which agrees with the fact that the Gulf receives 11 700 t of phosphorus from rivers, industry and urban sewage. Due to the relatively good oxygen conditions in the recent years, there is a net sedimentation of phosphorus in the Gulf.

Baltic Proper and Gulf of Riga

No data are present from the inner part of the Gulf of Riga and those data from the outer part are assessed together with data from the Baltic Proper (Annex 1, Maps 4, 11, 16, 20). Nitrate concentrations are generally lower than 10 µM. Data higher than 10 µM are all located in the southern part of the Baltic Proper at the Polish and German coastline with values of 56 and 27 µM, respectively. These high values are all in areas influenced by river outflow. Freshwater mainly comes from the Vistula, Odra and Nemunas rivers, which have catchments that are strongly influenced by human activity, e.g. agricultural and urban areas. Similarly to the Gulf of Finland the relation between salinity and nitrate presents a hyperbolic curve. This shows that nitrogen is removed within the system, likely by sedimentation and denitrification. Ammonium concentrations reach 4 and 12 µM at the German and Polish coasts in areas affected by the three rivers mentioned above. Phosphorus varies between 0.3 and 3 µM. The highest values are found in the southern part along the coasts of Germany and Poland. As described above bottom oxygen conditions are an important determining factor for the phosphate concentrations in the Baltic Proper, which may be why there is no clear pattern related to salinity (Figure 17A).

Belt Sea and Kattegat

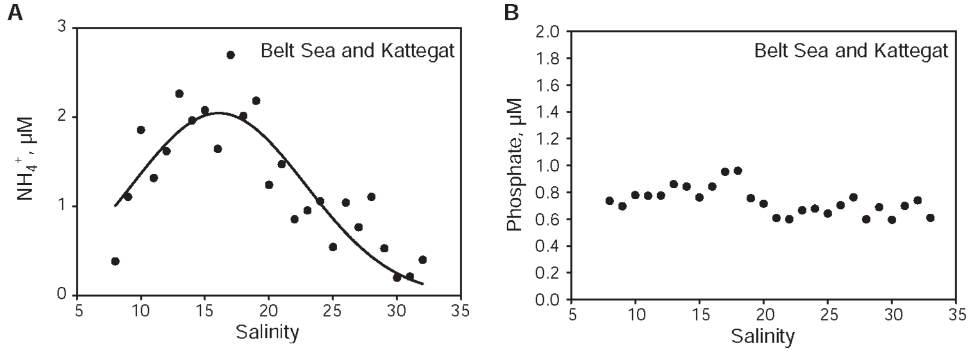
Nitrate concentrations vary between 5 to 15 µM (Annex 1, Map 10). In the Belt Sea and Kattegat Baltic low saline water mixes with high saline water from the Skagerrak. The salinity–nitrate relationship shows a peak in the Belt Sea corresponding to salinities of 15 to 20 psu. Because the nitrate concentration is higher than in both water masses under mixing, elevated nitrate concentrations result from local input. Freshwater input to the Belt Sea from Germany and Denmark comes from areas of intensive agriculture and relatively densely populated areas. Both regions are characterised by a dynamic hydrography. Year-to-year variations are closely linked to variations in precipitation. Parts of the freshwater pass through smaller estuaries before entering the Belt Sea and Kattegat, where a fraction of the nitrogen is retained. In the open areas of the Belt Sea and Kattegat internal processes like nitrification and denitrification are of minor importance.

Average concentrations of ammonium range between 0.2 and 4 µM (Annex 1, Map 15). Ammonium concentrations versus salinity show exactly the same picture as that of nitrate: a distinct peak at 17 psu salinity (the Belt Sea) (Figure 19A). Due to nitrification, ammonium is relatively short lived in the marine systems. Thus, the peak concentrations in the Belt Sea indicate a local input.

Phosphate concentrations are 0.9 and 0.6 µM on average in the Belt Sea and in the Kattegat, respectively (Annex 1, Map 3). There is no distinct peak along the salt gradient (Figure 19B), which suggests that there is no important local net input of phosphate. During the last decade phosphate loads have decreased markedly as a result of improved sewage treatment. In coastal areas there is a clear declining trend in winter phosphate concentrations (Ærtebjerg et al., 1998).

Average silicate concentrations vary from 18 µM in the Belt Sea to 9 µM in the Kattegat (Annex 1, Map 19). This difference can be explained by the fact that the Belt Sea is closer to the main input sources of silicate.

Figure 19. (A) Ammonium concentrations versus salinity in the Belt Sea and Kattegat; (B) Phosphate concentrations versus salinity in the Belt Sea and Kattegat



6.2. Open sea background nutrient concentrations

A linear relationship between nutrient concentrations and salinity indicate that mixing is the dominant process that transports nutrients away from the coastal regions. Thus, from the relationship between winter nutrient concentrations and salinity it is possible to predict background nutrient concentrations at open sea, even if there are no data of nutrients at oceanic salinities. Predicted values of nutrient concentrations at open sea are listed in Table 13. In those cases where there is no significant relationship the predicted value is similar to the nutrient concentration found at the highest salinity in the dataset. The dynamics of nutrient in the central Baltic Sea are dominated by internal processes, rather than mixing with other open oceans. Thus, to calculate a background nutrient concentration for the Baltic Proper at a salinity of 7 is also meaningful.

However, it should be noted that the background concentrations at least in the open Baltic Proper and Irish Sea are not pristine concentrations but have increased since the 1960s as shown in Chapter 7.

Table 13. Background nitrate and phosphate concentrations at oceanic salinities (34.5 psu) and predicted average freshwater nutrient concentrations estimated from linear regression of salt/nutrient relationships

Nitrate

Sea	Freshwater, µM	R^2	Oceanic background, µM	R^2
Iberian coast	90.7	0.71	3.68	0.87
North Sea	335	0.94	9.22	0.98
North Atlantic	—	—	8.12	0.68
Skagerrak	—	—	9.02	(*)
The Channel	483	0.95	16.77	0.94
Irish Sea	—	—	10.63	(*)
Baltic Sea	—	—	4.61	(**)

Phosphate

Sea	Freshwater, µM	R^2	Oceanic background, µM	R^2
Iberian coast	—	—	—	—
North Sea	5.11	0.94	1.28	0.62
North Atlantic	—	—	0.62	(*)
Skagerrak	—	—	0.88	(*)
The Channel	18.45	0.95	1.67	0.96
Irish Sea	—	—	1.18	(*)
Baltic Sea	—	—	0.68	(**)

(*) The relationship between salt and nutrient was not significantly different from zero and background concentration estimated as average of all nitrate data at salinities higher than 30.

(**) Average predicted nutrient concentrations at 7 psu estimated from three different regression analyses of the Baltic Sea, Gulf of Finland and Gulf of Bothnia.

6.3. Chlorophyll concentrations

The plant pigment, chlorophyll-a, is present in all photosynthesising algae in the marine environment. It is relatively simple to measure the concentrations of chlorophyll in water samples, and therefore chlorophyll-a concentrations are very often used as a measure of the phytoplankton biomass in the aquatic science. Often chlorophyll concentrations represent the only quantitative measurement of the phytoplankton biomass. The content of chlorophyll in marine phytoplankton typically accounts for about 1/40–60 of the total carbon biomass in the algae, but this ratio varies considerably depending on the species composition of the plankton, and on the physiological state of the algae. Thus, comparisons of chlorophyll concentrations in space and time should be done with caution. Even though the chlorophyll-a concentration is not a very precise measure of phytoplankton biomass, the parameter is still useful in assessing the state of eutrophication, e.g. high chlorophyll-a concentrations indicate eutrophic conditions.

The concentration of nutrients is often the limiting factor for the build-up of phytoplankton biomass and, consequently, those areas with high nutrient concentrations in the winter are also expected to show high levels of chlorophyll in the algal growth season. However, there is no close relationship between the winter nutrient concentration and the concentration of chlorophyll in the water column in the summer because the dynamics of these two parameters are completely different. During the spring and summer most of the nutrient pool is taken up by the algae and converted into phytoplankton biomass. However, as the phytoplankton biomass is processed continuously in the pelagic food web and is lost from the water column by sedimentation, only a fraction of the produced biomass is present in the water column at a certain time.

The nutrient pool sets the theoretical maximum for phytoplankton biomass although this level may never be reached. The maximum chlorophyll concentrations occur typically during short bloom periods. The pattern of fluctuations in the chlorophyll-a concentrations may indicate eutrophic conditions if many successive blooms occur, but blooms may be overlooked in many monitoring programmes due to low resolution in time. Thus, average winter nutrient concentrations and average summer chlorophyll concentrations are two different measurements of eutrophication, which in many cases may lead to different conclusions.

In the data material, high chlorophyll concentrations are found scattered in the southern part of the North Sea, in the southern part of the Baltic Proper and in the Gulf of Finland (Annex 1, Maps 24, 25, 26). However, the relationship between winter concentrations of NO_x and summer concentrations of chlorophyll-a shows only a weak positive correlation, even in the low range of NO_x concentrations between 0 and 50 µM.

6.4. Oxygen in bottom water

Sedimentation and subsequent degradation of autoand allochthonous organic material result in consumption of oxygen in the bottom water. At water depths below the euphotic zone the supply of oxygen depends entirely on physical transport with water masses. This means, in short, that the input of organic matter determines the bottom oxygen demand while the hydrography determines if the oxygen supply can meet the demand. The amount of organic matter sedimenting to the bottom in an area depends on the state of eutrophication whereas the hydrography in general is not modified by eutrophication but varies with the climate. Thus, some areas are more susceptible to oxygen deficiency than others due to differences in the hydrography, and it is not possible to judge the state of eutrophication from the oxygen saturation alone. Bottom water oxygen deficiency typically follows long periods of stratification in the water column. Estuaries with a permanent halocline are very susceptible to oxygen deficiency and are the most heavily impacted by eutrophication.

In this assessment hypoxia/anoxia is common only in the Baltic area including the Belt Sea and the Kattegat (Annex 1, Maps 27, 28). In this area, the presence of hypoxia/anoxia may in all cases be explained by a combination of frequent or permanent stratification and high sedimentation rates. In the rest of the areas hypoxia/anoxia is not a common phenomenon as judged from the aggregated data. Although nutrient and chlorophyll concentrations are higher in the southern North Sea compared to the Baltic area, tides and wind stress ensure well oxygenated conditions at the sea bed. Overall the bottom oxygen concentrations are not correlated with either chlorophyll concentrations or with nutrient concentrations.

7. Impact of eutrophication and responses

The statements below on present eutrophication impacts in the European seas are taken from assessments made by the international sea conventions and information in the literature. The recent trends of eutrophication variables are analysed from the limited dataset available. Simple trend analysis has been made using the non-parametric Kendall's τ method. The trend analyses were performed on non-transformed time series using a two-sided test with a significance level of 5 %. Only time series including at least five years within the period 1985–98 were analysed. The main increase in eutrophication impacts in the coastal areas of Europe took place before most marine monitoring programmes were started. Therefore the historic development of eutrophication is evaluated based on literature studies.

7.1. Impacts of eutrophication

7.1.1. Arctic waters

No serious impacts of eutrophication are recognised in the Arctic waters with very sparsely populated drainage areas. Eutrophication from fish farming in sill fiords is the major threat. However, the aquaculture production is spread along the coastline, and due to extensive water exchange the nutrient input constitutes an insignificant part (less than 1 %) of the nutrient budgets in fiords and coastal waters. In fiords with shallow sills and restricted water exchange, the discharges of nutrients and organic material from feeds and faeces may cause local problems (OSPAR Commission QSR 2000, Region I, 2000).

7.1.2. Baltic Sea

All areas of the Baltic Sea are affected by eutrophication with increased nutrient concentrations, least in the Gulf of Bothnia. Generally, in coastal areas the depth distribution of perennial macrophytes has decreased, and short-lived filamentous epiphytic or drifting algae have become increasingly prevalent. The frequency and spatial coverage of phytoplankton blooms, especially cyanobacteria (Figure 20), has increased due to the increase in nutrient concentrations, but also to changes in the seasonal availability and relative proportions of nutrients (Helcom, 1996, 1998b).

Figure 20. Cyanobacteria bloom (*Nodularia spumigena*) in the western Baltic 1997

Photo courtesy of L. Angantyr.

Since harmful/toxic species are natural constituents of the phytoplankton, the blooms of harmful algae have also increased. The blooms have caused losses to fish farming, deaths of fish, sea birds, dogs and cattle, and also caused some damage to human health. The zooplankton biomass has increased, especially in the northern parts, and periods of oxygen depletion have increased, especially in the south-western parts (Helcom, 1996, 1998b).

7.1.3. Greater North Sea

The anthropogenic input of nutrients from land and changed nutrient ratios primarily affect the coastal zone. In particular in estuaries and fiords, the Wadden Sea, the southern and German Bights, the Kattegat and the eastern Skagerrak, nutrient related problems are widespread. Negative impacts include periodic disturbances of the ecosystem such as oxygen depletion and the subsequent mortality of benthic organisms, as well as changes in abundance and diversity of the different animal and plant communities, e.g. increased phytoplankton blooms (Figure 21) including harmful species and drifting algal mats. As a result of periodic oxygen depletion in the southern Kattegat bottom water in 1985–88, the fishery for Norwegian lobster had almost ceased in this area until 1999 (OSPAR Commission QSR 2000, Region II, 2000, P. Nielsen personal communication).

Figure 21. *Noctiluca miliaris* bloom in the German Bight, 13 August 2000

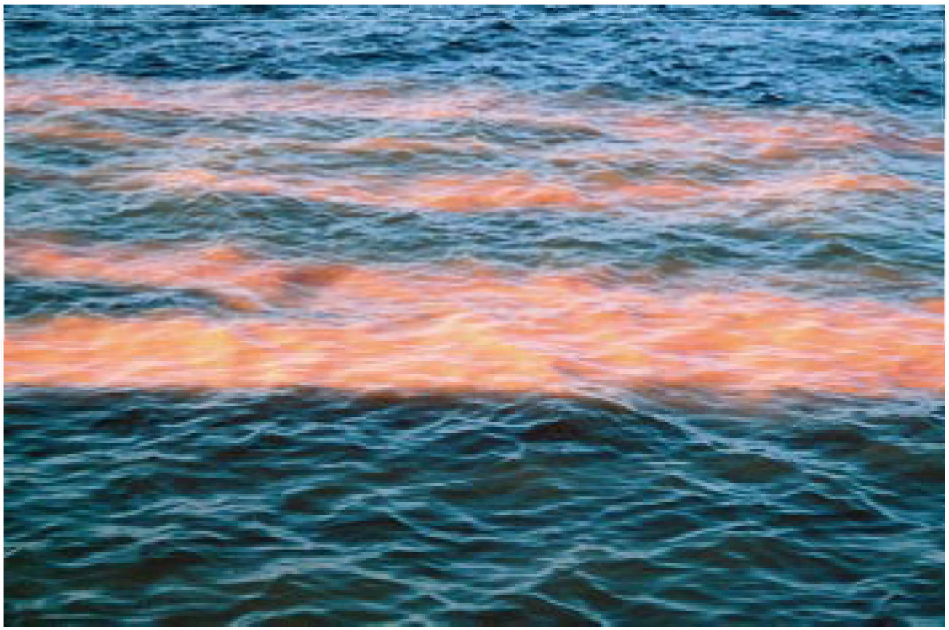


Photo courtesy of G. Ærtebjerg.

7.1.4. Celtic Seas

In the Irish Sea and many estuaries, concentrations of both nitrate and phosphate have been anthropogenically enhanced. In spite of this OSPAR Commission QSR 2000, Region III (2000) states that very few areas are considered to be eutrophic with 'undesirable' biological changes associated with increased nutrient concentrations. In UK waters the Mersey estuary/Liverpool Bay area and Belfast Lough are considered to be showing signs of eutrophication. In Ireland the inner Cork Harbour is considered eutrophic together with parts of Dublin Bay, and a few estuaries to the north of Dublin Bay being affected for limited periods (OSPAR Commission QSR 2000, Region III, 2000).

Decreases in oxygen concentration exist in a number of Irish estuaries, in the heavily urbanised Mersey estuary and in Belfast Lough and occasionally, at times of stratification, in Liverpool Bay. In addition a limited area of seabed around the Garroch Head sewage sludge disposal ground is affected.

7.1.5. *Bay of Biscay and Iberian coast*

The few available data on nutrients, dissolved oxygen, phytoplankton composition and abundance of benthic fauna reveal that there is no evidence of eutrophication of coastal zones in this region (OSPAR Commission QSR 2000, Region IV, 2000), although toxic phytoplankton blooms have occurred (EEA, 1999b).

In some estuaries and coastal lagoons large cover of green seaweed occurs (Douarnenez, Concarneau, Arcachon) (EEA, 1999b), and events of oxygen depletion have been recorded (Bay of Vilaine, Arcachon and Ria Formosa) as the combined result of high organic load, weak local circulation, high primary productivity and temperature. Only in the Bay of Vilaine does deoxygenation of bottom waters take place each summer following the phytoplankton blooms (OSPAR Commission QSR 2000, Region IV, 2000).

7.1.6. *Mediterranean Sea*

Mediterranean surface waters in the open sea are classified among the poorest in nutrients (oligotrophic) of the world oceans. However, in the deep water in the western deep basin the concentrations of phosphate and nitrate were in 1994 as high as 0.4 µM and 8.7 µM, respectively (Béthoux et al., 1998).

The absence of significant upwelling generally keeps the nutrients in the deep water out of the biological recycling process, and eutrophication appears to be limited mainly to specific coastal and adjacent offshore areas. Several and sometimes severe cases of eutrophication are evident, especially in enclosed coastal bays which receive elevated nutrient loads from rivers, together with direct discharges of untreated or poorly treated domestic and industrial wastewater (EEA, 1999c).

Algal blooms, diversity reduction of marine species and depletion of oxygen as well as potential human health risks related to the ingestion of seafood contaminated by pathogens or toxic algal blooms are some of the problems associated with Mediterranean eutrophication. Side effects (e.g. hypoxia/anoxia, algal blooms) have been reported in several coastal areas of the Mediterranean Sea, but they are confined to limited areas rather than being widespread phenomena (EEA, 1999c).

The Adriatic, the Gulf of Lion and the northern Aegean Sea are areas with relatively higher mean nutrient concentrations, higher primary and secondary production and, sometimes, local algal blooms related sporadically to hypoxic or anoxic conditions and rarely to toxic algal blooms (EEA, 1999c).

7.2. Recent trends in eutrophication

7.2.1. *Baltic Sea*

Very few stations in the Baltic Sea show significant trends, and no general development is seen within the period 1985–97/98, except may be a tendency to decreasing phosphorus concentrations in certain areas (Table 14). Along the open Baltic coasts 7 ICES squares out of 58 showed decreasing trends in either phosphate or TP concentrations, while increasing trend was observed in one square in the Gulf of Finland.

Table 14. Number of ICES squares in the Baltic Sea showing: — = no trend, ↑ = increasing trend, ↓ = decreasing trend in eutrophication variables within the period 1985–97

	Gulf of Bothnia			Gulf of Finland			Baltic Proper			Belt Sea		
	—	↑	↓	—	↑	↓	—	↑	↓	—	↑	↓
PO_4	2		1	3	1		20		3	28		
TP	3			4			9		2	16		3
NO_3	3			4			19	1		26		2
NO_{3+} NO2	3			4			19	1		27		1
NO_2	3			4			19	1		28		
NH_4	3			3			10		1	22		
TN	3			4			10			13		
SiO_3	3			4			9			11		
Chl-a	1			1	1		3			8		
O_2	1						17	2		30		
O_2-sat.	1						19			30		

In the Baltic estuaries (Denmark, Finland, Germany, Sweden) the reduction in phosphorus concentrations is more pronounced than along the open Baltic coasts as 9 stations out of 15 showed decreasing trends in either winter phosphate, winter TP or year-round TP, while two Finnish stations showed an increase (Table 16). In the estuaries a tendency to reduced TN concentrations were also observed as 5 out of the 15 stations showed decreasing trends and only one showed an increase. The main reason might be improved treatment of domestic and industrial effluents, reduced phosphorus content in detergents, but also variations in run-off and water exchange.

7.2.2. Greater North Sea

In the Greater North Sea including the Kattegat and Skagerrak the only general tendency in the development of eutrophication variables in the period 1985–97 is a decrease in phosphorus concentrations in Kattegat, Skagerrak and the south-eastern North Sea including the Wadden Sea (Table 15). Out of 106 ICES squares, 39 showed a decreasing trend in winter-phosphate concentrations, and 29 out of 75 squares showed a decrease in TP. The same tendency is seen in the North Sea estuaries (Germany, France, the Netherlands and Sweden), where 8 out of 17 stations showed a decreasing trend in winter phosphate or TP, but no trends were seen in the Norwegian estuaries (Table 16).

Table 15. Number of ICES squares in the Greater North Sea showing: — = no trend, ↑ = increasing trend, ↓ = decreasing trend in eutrophication variables within the period 1985–97

	Kattegat			Skagerrak			North Sea		
	—	↑	↓	—	↑	↓	—	↑	↓
PO_4	15		5	10		2	42		33
TP	8		8	5		2	33		19
NO_3	22			12		1	71	2	
NO_3+NO_2	22			12		1	70	2	1
NO_2	22			13			57	5	4
NH_4	17		1	7		1	52	4	7
TN	8	1	2	2		1	34		3
SiO_3	20		1	12			68	3	2
Chl-a	13		2	24	1		20	1	
O_2	34	1		29			4		
O_2-sat.	27	4		28		1	3		1

Table 16. Number of stations in European estuaries and coastal zones showing: — = no trend, ↑ = increasing trend, ↓ = decreasing trend in eutrophication variables within the period 1985–97

	Denmark			Finland			France			Germany			Greece			Italy			The Netherlands			Norway			Sweden		
	-	↑	↓	-	↑	↓	-	↑	↓	-	↑	↓	-	↑	↓	-	↑	↓	-	↑	↓	-	↑	↓	-	↑	↓
PO_4	1/1		3/	5	2		1		2	1/4		/1	11	1		4					5	3			2		1
TP	/1		4/	4	1	3				/5		1/				4					5	3			2		2
NO_3+ NO_2	4/1			7			2												4						3		
NH_4				4	2	1						1/	7			4			4		1				3		
TN	3/1		1/	5	1	2				/4		1/1	1						3		1	3			3		1
SiO_3	1/1		1/	5		1				1/3			5						3		2	3			3		
O_2	4/1									1/2	/3		5		1	4			4	1					1		
Chl-a	3/1		1/	6	1	1				1/			4			4			5						3		
Secchi	4/	/1																									
Sea-grass	3/																										
Sea-weed	1/																										

Note: Denmark and Germany: Baltic Sea/North Sea estuaries.

Source: National reference centres.

7.2.3. Mediterranean Sea

The only trends seen in the data from the Mediterranean coasts and estuaries (France, Greece, Italy) are decreasing phosphate concentration at one station in the Rhone Delta/Gulf of Fos, increasing phosphate at one out of six stations at Saronikos, Greece, and decreasing oxygen concentration at one of the stations at Saronikos (Table 22).

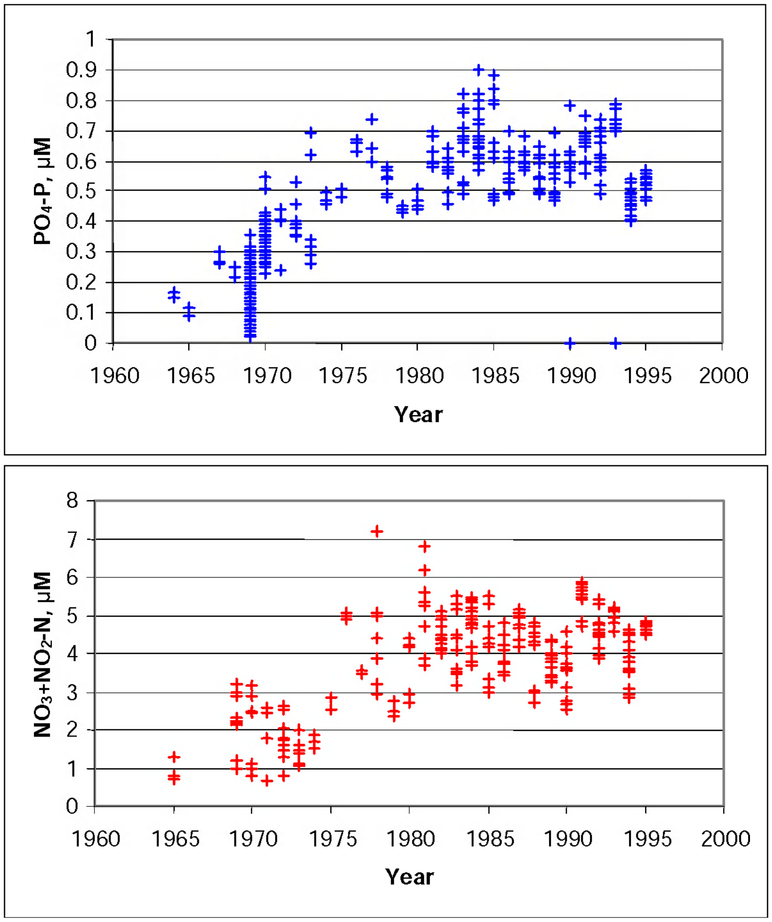
7.3. Historic development of eutrophication

7.3.1. Baltic Sea

Wulff et al. (1994) estimated the total amounts of nutrients in the entire Baltic Sea for four five-year periods from 1971 to 1991. The amounts of nitrate and TN had increased during the whole period in the entire Baltic Sea. The increase in phosphorus that occurred during the 1970s had ceased in the Gulf of Bothnia but continued elsewhere. Total amounts of silicate had decreased in the entire area during the whole period. But the regional and seasonal distributions of nutrients had not been altered.

Analyses of winter concentrations of phosphate and nitrate in the surface layer (0–10 m) of the open Baltic Proper (Figure 22) showed an increase of 2.1 to 2.6 times in the phosphate concentrations and an increase of 1.8 to 2.1 times in the nitrate concentrations from the period 1969–73 to the period 1984–88. A few measurements from the period 1958–68 indicate that the increase started in the late 1960s. In the period 1989–93 the concentrations stayed about the same high level as in 1984–88 (Nausch et al., 1999). By comparing the development in nutrient concentrations with the use of synthetic phosphorus and nitrogen fertilisers in the drainage area of the Baltic Sea Nausch et al. (1999) concluded that the response time of the open Baltic Sea to changed nutrient loads is of the order of five to ten years.

Figure 22. Long-term development (1964–95) of winter concentrations (mid-January to mid-April) of phosphate and nitrate + nitrite in the surface layer (0–10 m) of the open Baltic Proper (East-Gotland basin)



Source: ICES and Helcom.

Even silicate input is assumed not to be significantly influenced by human activity. The dissolved silicate concentrations (DSi) in the Baltic Sea surface layer (0–10 m) have decreased by 0.19–0.85 µM y^{-1} in the period 1968–86, except in the south-western Baltic Proper (Sandén et al., 1991). Also the DSi:DIN ratio significantly decreased from 1970 to 1990. This can be explained by an increased net sedimentation of biogenic silica due to increased production of diatoms attributable to the increased nutrient loading and concentrations (Rahm et al., 1996).

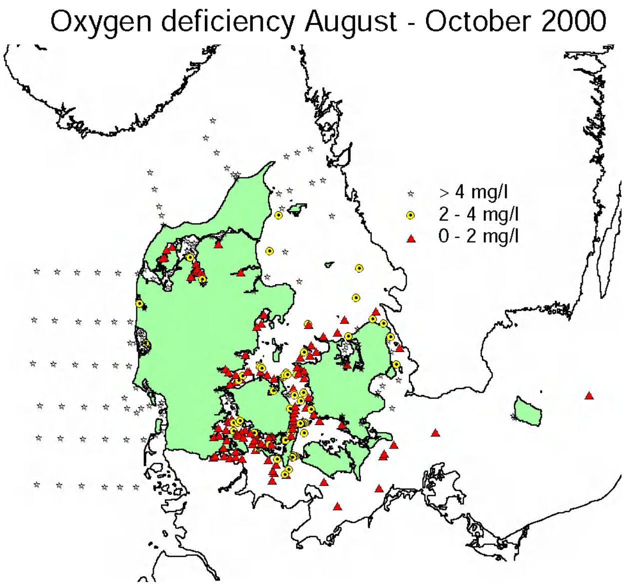
In addition, the Secchi depth has decreased in the Baltic Sea. Between the periods 1919–39 and 1969–91 the median Secchi depth in the Baltic Proper decreased by 1.1 m in the April–June season and by 3.0 m in the July–September season. During the later period 1969–91 a trend slope for the April–September season of about 0.05 m y^{-1} corresponding to 1.2 m in all was estimated (Sandén and Håkansson, 1996).

Long time series on phytoplankton primary production exist only from the Kattegat and Belt Sea. These data show approximately a doubling from the middle of the 1960s to the late 1970s (Nielsen et al., 1981; Kronvang et al., 1993).

Deduced from the development in nutrient load, nutrient concentrations and Secchi depth, a corresponding development in primary production in the Baltic Sea must have taken place.

The oxygen consumption in the Baltic Sea has increased parallel to the primary production. However, the overall oxygen conditions in the deep Baltic basins are governed by the irregular inflows of saline and oxygen-rich water from the Kattegat and the length of the stagnation periods of the bottom water in the basins. In the shallow but stratified Belt Sea, Babenerd (1991) estimated the mean subpycnocline oxygen concentration in July–September to have decreased by 0.136–0.153 mg l^{1} (0.01–0.11 ml l^{1}) per year during the period 1957–86. Agger and Ærtebjerg (1996) estimated significant decreasing bottom oxygen concentrations in the Belt Sea and southern Kattegat during the period 1975–92, and in the northern Kattegat in the period 1975–88. In some years oxygen depletion is widespread in Danish waters (Figure 23).

Figure 23. Oxygen depletion in Danish waters, late summer–autumn 2000



Source: NERI.

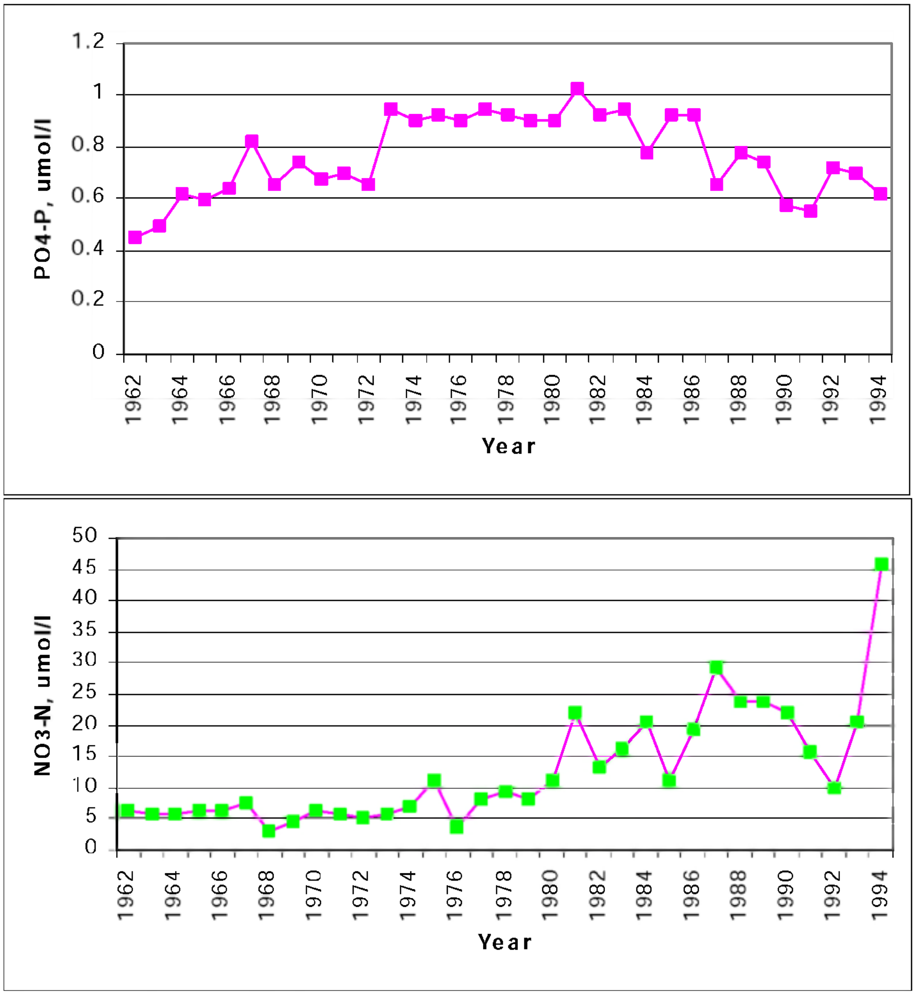
7.3.2. Greater North Sea

In the Kattegat the concentrations of TN, TP and DIN increased in the period 1971–82 both in the surface water during winter and in the deep water during summer. Local supply dominated the change in DIN. In the same period the oxygen concentrations in the deep water decreased indicating a 50 % increase in oxygen consumption (Andersson and Rydberg, 1988). Andersson (1996) also showed a significant increase in winter concentrations of DIN, TN, DIP and TP in the Kattagat surface water over the 20-year period 1971–90. Declines in silicate concentrations have also been reported (Conley et al., 1993). The primary production approximately doubled from the middle of the 1960s to the late 1970s (Nielsen et al., 1981; Kronvang et al., 1993) or late 1980s (Richardson and Christoffersen, 1991).

In fiords and estuaries along the Norwegian Skagerrak coast oxygen has been measured annually since 1927. The general trend in the bottom water oxygen saturation was characterised by a slow, gradual decrease until the beginning of the 1970s, followed by a sudden drop to a significantly lower level, and then stabilising at this low level after the middle of the 1970s. At intermediate depths, 10 and 30 m, there was no trend in oxygen saturation until the middle of the 1960s, followed by an almost linear decrease up to the 1990s (Johannessen and Dahl, 1996).

Increased sedimentation of phytoplankton and phytodetritus due to a combination of enhanced phytoplankton biomass and lower herbivore grazing may explain the increased oxygen consumption in the bottom water. Increased energy flow through the microbial loop might be the reason for the oxygen trends found at the intermediate depths (Johannessen and Dahl, 1996).

Figure 24. Long-term development (1962–94) of mean annual concentrations of phosphate and nitrate in the surface of the German Bight (Helgoland Reede)



Source: Umweltbundesamt, 1997.

In the German Bight, Weichart (1986) showed an at least two-fold increase in the winter phosphate concentration at 30 psu from 1936 to 1978. Measurements at Helgoland since 1962 (Figure 24) show nearly a doubling in annual median concentrations of phosphate up to the middle of the 1970s, and more than a doubling in winter nitrate concentrations at 32 psu from the 1970s to the late 1980s (Hickel et al., 1994; Radach et al., 1990).

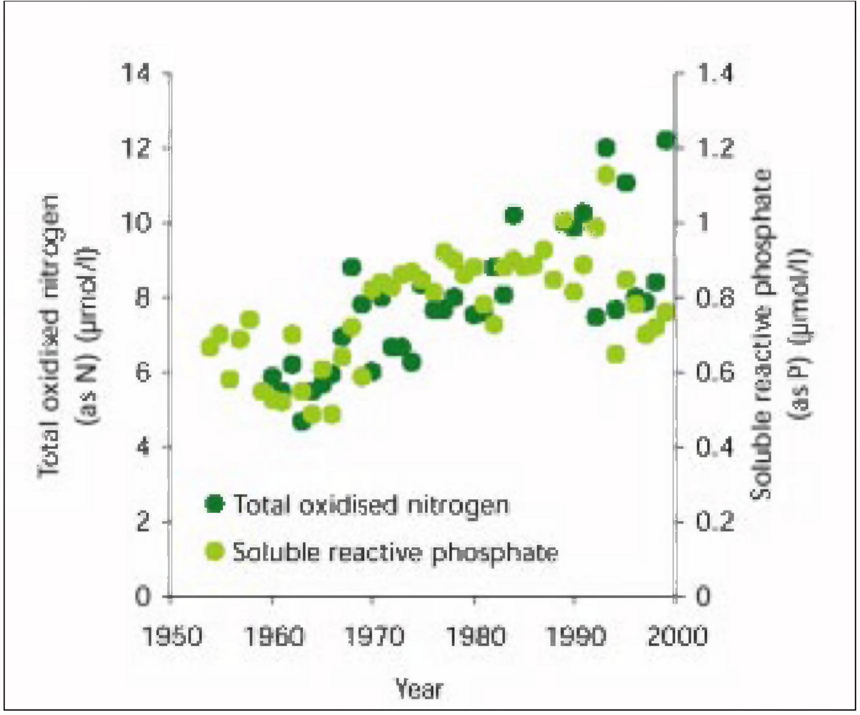
Silicate concentrations in the German Bight decreased dramatically from 1966 to 1984 with seasonal low concentrations observed for longer time periods (Radach et al., 1990). The out-of-phase increase in phosphorus and nitrogen nutrients and the decrease in silicate changed the DIN:DIP, DSi:DIN and DSi:DIP ratios dramatically. This might have changed diatom growth and biomass, species composition, food web dynamics and nutrient-recycling processes (Conley et al., 1993).

The biomass of benthic fauna in areas without hypoxia has increased in recent decades, e.g. in the Wadden Sea (Beukema and Cadee, 1986), in the deep Skagerrak (Rosenberg et al., 1987; Josefson, 1990) and in the northern Kattegat (Josefson, 1990; Jensen and Josefson, 1990). In contrast, decreased biomass has been reported from areas experiencing increasing hypoxia (Diaz and Rosenberg, 1995) such as the southern Kattegat (Josefson and Jensen, 1992) and in some Danish estuaries (Sørensen and Fallesen, 1998).

7.3.3. Irish Sea

Even eutrophication problems in the Irish Sea are regarded as being restricted to certain coastal areas and estuaries. The open Irish Sea is also affected by eutrophication with increased nutrient concentrations (Figure 25).

Figure 25. Long-term development (1954–99) of nutrient concentrations in the central Irish Sea. Total oxidised nitrogen = nitrate + nitrite



Source: http://www.environment-agency.gov.uk/yourenv/ Environment 2000 and beyond.

At a station in the central part Allen et al. (1998) have shown a significant increase in surface phosphate in the period 1954–91 with the biggest increase occurring from the mid-1960s to the mid-1970s. The phosphate concentration increased from 0.5–0.6 µM before 1965 to 0.8–0.9 µM by the late 1970s. Nitrate + nitrite concentrations underwent a steadier rise with levels increasing from approximately 5 µM to 8 µM between 1960 and 1984. Also the chlorophyll-a concentrations in May–June showed a gradual rise over the years of sampling (1966–91). Contrary to continental eutrofied coastal areas the silicate concentrations in the Irish Sea showed increasing tendencies. However, the Si:N ratio at the winter maximum was clearly declining, which can lead to a shift away from diatom-dominated phytoplankton populations, with a possible increase in the abundance of toxic or nuisance species (Conley et al. 1993).

As no significant trend in salinity was recorded for any season, it is unlikely that major trends in nutrients are caused by changes in the relative influence of coastal and Atlantic waters (Allen et al., 1998).

7.3.4. Mediterranean Sea

The historic development of eutrophication in the Mediterranean Sea is not known. In the deep water of the western basin an annual increase in the phosphate concentration of 0.0015 µM and in nitrate of 0.0923 µM has been observed in the periods 1962–94 and 1969–94, respectively. The trends are related to increased terrestrial and atmospheric inputs and not to influx from the Atlantic (Béthoux et al., 1998).

The historic development of nutrient concentrations in European seas is summarised in Table 17.

Table 17. Factors of increase in concentrations of nitrate and phosphate in surface waters of different open European seas and Mediterranean deep water in the period 1960/70s to 1980/90s

Sea area	Nitrate		Phosphate		References
	Period	Factor	Period	Factor	
Bothnian Bay	1972/76 –1987/91	1.6	1972/76 –1987/91	0.7	Wulff et al., 1994
Bothnian Sea	1972/76 –1987/91	1.8	1972/76 –1987/91	1.3	Wulff et al., 1994
Baltic Proper	1969/73 –1984/88	1.8–2.1	1969/73 –1984/88	2.1–2.6	Nausch et al., 1999
Kattegat	1971–90	1.4	1971–90	1.14–1.4	Andersson 1996
German Bight	1970–89	> 2	1962–75	~ 2	Hickel et al., 1994;
Irish Sea	1960–84	1.6	1954–91	1.3–1.8	Allen et al., 1998
Western Mediterranean deep water	1969–94	1.36	1962–94	1.14	Béthoux et al., 1998

7.4. Responses (regulations to minimise eutrophication)

Besides national action plans and regulations to reduce local nutrient load and eutrophication, a number of actions have been taken at international level to reduce eutrophication in the coastal areas of the European regional seas.

All Baltic Sea sub-areas are more or less affected by eutrophication, and at the ministerial meeting of the Helsinki Commission in 1988 the ministers agreed to aim at a 50 % reduction in nutrient load. The ministers reaffirmed their commitment in 1998 and defined specific targets to be realised before 2005. At the

Second North Sea Ministerial Conference in 1987 the ministers agreed to aim at a 50 % reduction in nutrient load to areas affected by or likely to be affected by eutrophication. The commitment was reaffirmed in 1990 and 1995. Thus the Baltic Sea states and the North Sea states have decided to aim at a 50 % reduction of the nitrogen and phosphorus load from land compared to the level in the middle of the 1980s.

In 1997 OSPAR adopted the 'Common procedure for the identification of the eutrophication status of the maritime area' of the OSPAR Convention. This procedure comprises two steps. The first step is a screening procedure to identify areas which in practical terms are likely to be non-problem areas with regard to eutrophication. The second step is the comprehensive procedure, which should enable the classification of the maritime area in terms of problem areas, potential problem areas and non-problem areas with regard to eutrophication. OSPAR has identified a set of eutrophication variables, which shall be included in the comprehensive procedure.

OSPAR countries have now accomplished the first step and designated the problem areas or potentially problem areas to which the comprehensive procedure should be applied. Belgium, Denmark, Germany, the Netherlands and Sweden have designated all their OSPAR waters and Norway has designated the Skagerrak coast as problem areas or potential problem areas with regard to eutrophication. France, Ireland and the United Kingdom have designated a large number of coastal areas and estuaries as problem areas or potential problem areas, while Iceland, Portugal and Spain regard all their OSPAR waters as non-problem areas.

In addition the EU has decided on measures which are likely to reduce eutrophication in European waters, e.g. the urban wastewater treatment Directive (91/271/EEC) and the nitrate Directive (91/676/EEC). In relation to these directives the Member States of the EU should have monitored, identified and designated their estuarine, coastal and marine eutrophicated waters, or waters threatened by eutrophication, not later than 1993. Insufficient monitoring and incomplete designation of eutrophication sensitive areas afterwards forced the European Commission to launch several legal procedures against Member States. However, it is expected that the directives and especially the recently decided water framework Directive (2000/60/EC) will reduce the nutrient loads to the European coastal areas and the eutrophication impacts to an acceptable level.

In Ireland, France and the UK, the European Commission has identified additional potential sensitive areas compared to the OSPAR common procedure. In Portugal and Spain the Commission has identified a number of potential eutrophication sensitive areas. It is recognised that these 'local areas of concern' should be studied more precisely by the concerned Member States, and it is decided to apply the OSPAR comprehensive procedure to the areas (OSPAR, 2000).

7.5. Future development

By 2000, only the reduction in phosphorus load has been partly successful, while nitrogen load is generally decreasing only very slowly. As nitrogen supply is the main agent governing the eutrophication state in most marine systems, few reductions in the eutrophication impact have been observed until now. However, a few model estimations have been conducted to evaluate the effects of the implementation of a 50 % reduction in the nutrient load to the Baltic Sea and North Sea regions.

Model calculations concerning the Greater North Sea suggest that 50 % input reduction of both nitrogen and phosphorus may yield 30 to 45 % reduction of eutrophication variables. Coastal regions will benefit more than the central and northern North Sea. The merit of a 50 % reduction in inputs has been illustrated in Danish waters where, in a two-year period of low rainfall (1996–97), the ecosystem responded positively to very low riverine inputs of nitrogen (OSPAR Commission QSR 2000, Region II, 2000).

Hansen et al. (1995) estimated among other scenarios the effect of a 50 % reduction in nitrogen load to the North Sea and Baltic Sea on the oxygen conditions in the Kattegat and Belt Sea, including also a likely reduction in the atmospheric nitrogen deposition. This would lower the nitrogen concentrations and raise the minimum oxygen levels in autumn significantly, especially in the southern Belt Sea. However, hypoxia would not be eliminated in unfavourable years, but be less severe, and the minimum oxygen level would still be lower than in the 1950s. To reach the 1950s level further reductions in the nitrogen load, especially from atmospheric deposition, were needed.

A marked improvement in deep water oxygen concentrations following a 50 % reduction in the external nitrogen supply has also been estimated for the Laholm Bay and south-eastern Kattegat by Rydberg et al. (1990). Møhlenberg (1999) calculated that a 25 % reduction in nitrogen loading would reduce the number of days with severe oxygen depletion (<15 % saturation) by more than 50 % in a shallow Danish estuary.

The OSPAR Eutrophication Committee (OSPAR, 2000) carried out late 2000 a draft evaluation of the expected situation for the eutrophication status in the maritime area following the 50 % reduction target for nutrient input, based on several studies (e.g. model calculations, mesocosm studies) and ongoing work by the contracting parties. Positive effects are expected from a 50 % reduction in both nitrogen and phosphorus input for French estuaries/Atlantic coast, the French and UK Channel, Belgian, Dutch, German and Danish waters, Norwegian Skagerrak, Irish estuaries and the Tagus estuary in Portugal.

A reduction of up to 25–30 % in primary production, nitrogen, phosphorus and chlorophyll concentrations in coastal waters is expected. The current increased N/P ratio will move towards normal ratios. Phaeocystis bloom levels and duration will be reduced, as will the risks of toxic blooms, and an improvement in shallow waters in the occurrence and depth limits for long-lived macrophytes is foreseen.

No pronounced oxygen depletion in normal climatic years and decreased risk of oxygen depletion in stratified coastal waters as well as in stratified offshore waters and sedimentation areas is expected. Hence, the risk for benthic life will decrease. Further, it is anticipated that the food supply is still sufficient for higher trophic levels, that the quality of the food supply is improved due to lower risk of nuisance and toxic algal blooms and oxygen deficiency, and that the ecological efficiency will increase.

8. Trophical index for marine systems (TRIX)

8.1. Background

Trophic conditions of European marine areas vary considerably from region to region and within regions. However, the widely accepted trophic reference system proposed by Nixon (1995) and presented in Chapter 2 is not very operational in evaluating the state and development of eutrophication in European coastal waters. It defines 4 trophic classes based on one variable, phytoplankton primary production, which is rarely included in marine monitoring programmes and suffers from low reproducibility (ICES 1990).

In the paper by Vollenweider et al. (1998) the authors propose a new trophic index (TRIX) based on chlorophyll-a, oxygen saturation, total nitrogen and total phosphorus to characterise the trophic state of coastal marine waters. In developing the TRIX the following principles were observed:

- the component variables of the index should be meaningful in terms of both production and production dynamics;
- they should encompass major causal factors;
- and, very importantly, they should be routine measurements in most marine surveys.

The trophic state depends on the availability of nitrogen and phosphorus for the primary production, which in terms determines the phytoplankton biomass and oxygen saturation. In TRIX the nutrients are represented by total nitrogen and total phosphorus; chlorophyll-a is a substitute parameter for phytoplankton biomass, as production is not routinely measured; and the deviation of oxygen saturation from 100 % in the productive layer indicates the production intensity of the system. This encompasses both phases of active photosynthesis and phases of prevailing respiration.

The index derived from the four chosen variables is:

$$X_c = k/n \, \Sigma^{i=n} \left((M-L)/(U-L)\right)_i$$

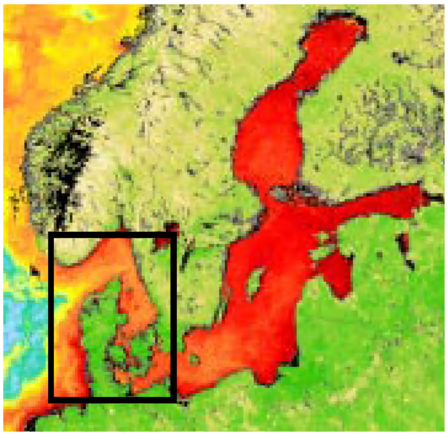
n = number of the variables (in our case four),
M = measured value of the variable,
U = upper limit,
L = lower limit.

This simple index permits one to synthesise key eutrophication variables into a simple numeric expression to make information comparable over a wide range of trophic situations, while avoiding the subjectivity in the usage of traditional trophic terminology. TRIX in itself is an expression for the trophic condition in an area, which independently of the level might be natural, meaning no eutrophication occurs or anthropogenically enhanced, meaning eutrophication occurs However, TRIX combines four eutrophication indicators into one index, and a temporal description of the development of the TRIX should allow a better monitoring and assessment of eutrophication trends.

TRIX is developed by Vollenweider et al. (1998) for Mediterranean waters, and is used by the Italian authorities on a routine basis to monitor the trophic state of the Adriatic Sea. However, the applicability of TRIX in other regions as well as the possibility of developing a general TRIX for all European coastal and marine areas has to be evaluated.

Within the institutional project COAST of the Space Applications Institute (SAI) of the EC Joint Research Centre (JRC) methods are developed for monitoring and assessing the state of coastal and marine waters. In agreement with the ETC/MCE partners, the JRC selected the North Sea/Skagerrak/Kattegat area (Figure 26) as a test area for the evaluation of TRIX.

Figure 26. A SeaWiFS image of June 1999 (the study area is pictured within the frame)



The first step in this exercise is to evaluate the applicability of TRIX for northern coastal areas, based on a large number of relevant Danish, Swedish and Norwegian *in situ* measurements. The test area includes all coastal areas around Denmark from 4° to 14° east and from 53° to 60° north. However, the results presented in the following have to be considered as preliminary. A more detailed evaluation and interpretation is required taking into account the specific hydrodynamic and biological characteristics of the water bodies.

8.2. First TRIX calculation

For the calculation of the trophic index two large datasets with Danish, Swedish and Norwegian data collected from shared stations in 1998 have been made available through ETC/MCE partners. These data are point measurements with a good vertical resolution of the relevant variables, but not all stations support all the required variables with a sufficiently good temporal resolution.

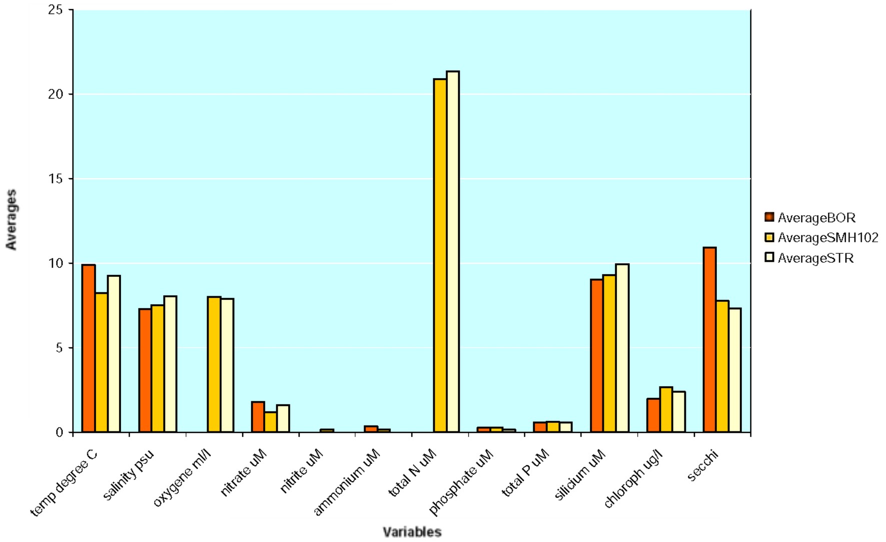
As a first approach only the stations which provide data with a monthly resolution have been taken into consideration. In order to achieve this temporal resolution, the 'window' area has been divided into five sub-areas each of them monitored by two, three or four fixed stations, which provide quite homogeneous data (see example in Figure 27). These sub-areas are:

- North Sea,
- Skagerrak,
- Kattegat and Belt Sea,
- The Sound,
- Western Baltic.

Vollenweider et al. (1998) recommend, for the definition of the upper and lower limits of the variables, excluding extreme values that rarely occur. Otherwise there is the risk that the ranges become too large to permit discrimination between different TRIX.

Some statistics have been performed on the five sub-areas (two cases: grouping the stations that belong to the same area and using the data of each station individually). For each variable a normal distribution of the logarithms of the values has been evidenced. A simple log transformation has been considered adequate to normalise data distribution of individual variable series.

Figure 27. Average values for the different variables at the three measurement stations (BOR, SMH102, STR) located in the Western Baltic are quite homogeneous



Using logarithms rather than non-transformed values for the TRIX elements, the TRIX reads:

$$\text{TRIX} = (k/n)\sum^{i=n}((\log M - \log L)/(\log U - \log L))_i$$

For each sub-area the upper and lower limits (minimum value and maximum value) have been defined as MEAN ± 2 STD (Standard Deviation)and a first seasonal TRIX has been calculated (see example in Table 18).

Table 18. Example from the North Sea on calculation of the TRIX index in the different sub-areas

Limits and ranges	Minimum log units	Maximum log units	Range log units
Chlorophyll-a µg/l	– 0.3	1.16	1.46
Oxygen abs (100–%O)	1.17	0.6	– 2.17
Total nitrogen µM	0.9115	1.73	0.82
Total phosphorus µM	– 0.818	0.41	1.23
Trophic index	{((log C – log min. C)/ Range C) + ((log O – log min. O)/ Range O) + ((log N – log min. N)/ Range N) + ((log P – log min. P)/ Range P)}*{10/4} =		
Winter	(0.48 + 0.1 + 0.84 + 0.9) * 2.5 = 5.81		
Spring	(0.82 + 0.86 + 0.8 + 0.73) * 2.5 = 8		
Summer	(0.69 + 0.15 + 0.54 + 0.67) * 2.5 = 5.13		
Autumn	(0.58 + 0.22 + 0.57 + 0.8) * 2.5 = 5.42		

These first TRIX indexes present one significant problem. Each measured value has been divided by a number (range), which has a well-defined local meaning. In this way it is not possible to compare the obtained results and it is difficult to give an interpretation of the TRIX values obtained for the relevant region or sub-region.

8.3. Second TRIX calculation

For this reason the statistics have been re-performed using all the values of the different stations together in order to determine a mean and an STD that allow to calculate general minimum value, maximum value and range which can be found in the northern seas. Subsequently, for each sub-area and for each season a second TRIX value has been calculated. In this case always the same minimum, maximum and range values determined for each variable have been used (Table 19).

Now the TRIX values obtained with the revised procedure for the various sub-regions can be compared with each other. The North Sea area shows significantly higher values compared to the other sub-regions. Probably this is due to the higher level of nutrients in this area. Inter-seasonal variability is small for some areas (e.g. Western Baltic).

A problem that comes to surface in the calculation of this second TRIX is the comparison of the results of different years. In case the minimum, maximum and range values have to be recalculated according to the distribution of the data collected in the following years the obtained TRIX will be difficult to compare and a trend in eutrophication will be hard to discriminate.

In order to avoid this problem and to make a determination of a general TRIX possible, valid through the years and comparable for all European seas, a further generalisation of the upper and lower limits is needed. Those should cover a wide spectrum of possible situations without being too narrow or too wide.

Table 19. General limits and ranges, and seasonal TRIX values for the different sub-areas of the North Sea/Skagerrak/Kattegat area

Limits and ranges	Minimum log units	Maximum log units	Range log max. – log min.
Chlorophyll-a µg/l	– 0.3	1.12581	1.425
Oxygen abs (100–%O)	– 1	1.509	2.509
Total nitrogen µM	0.904	1.51	0.608
Total phosphorus µM	– 0.65	0.1307	0.78665
Trophic index	{((log C – log min. C)/ Range C) + ((log O – log min. O)/ Range O) + ((log N – log min. N)/ Range N) + ((log P – log min. P)/ Range P)}*{10/4}=		

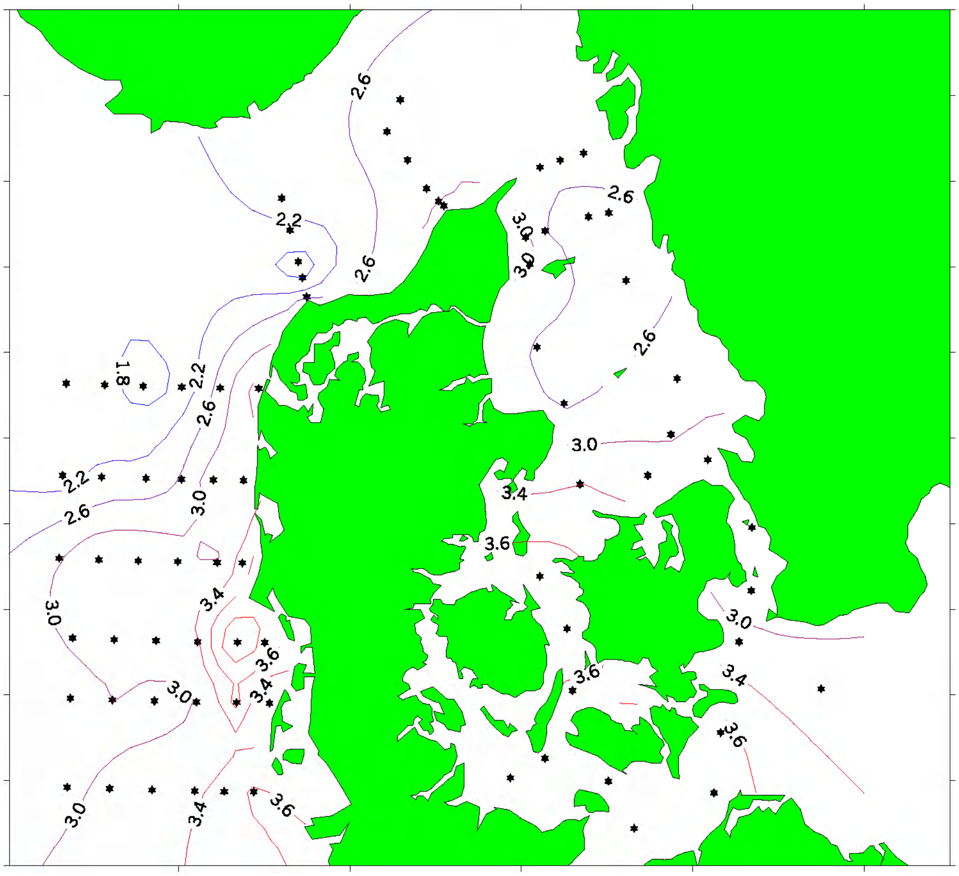
Sub-area	TRIX winter	TRIX spring	TRIX summer	TRIX autumn
Western Baltic	6.12	5.43	6.09	6.2
Kattegat and Belt Sea	7.09	6.15	4.85	6.04
North Sea	9.04	7.47	8.125	7.71
The Sound	5.83	5.1	5.27	6.205
Skagerrak	6.565	7.51	5.55	6.1

8.4. Final TRIX calculation

After some reflections about intercomparison of European waters it has been decided to adopt here the limits used by Vollenweider et al. (1998) in their work. The original datasets have been reprocessed taking into account the measurements made at all stations that do provide the variables without making any temporal resolution requirements. A TRIX value was then calculated for each station and season.

The summer season is the best represented in the dataset, and the geographical distribution of TRIX in August 1998 is shown in Figure 28. The distribution is in general agreement with the expectations, showing the highest TRIX values in the German Bight (due to high nutrient and chlorophyll concentrations), and the Belt Sea (due to relatively high chlorophyll concentrations), and the lowest at the border between the North Sea and Skagerrak where nutrient and chlorophyll concentrations are low.

Figure 28. Geographical distribution of the trophic index TRIX in August 1998 based on one cruise in Danish waters



Discussion and conclusion

Applying the minimum and maximum values used by Vollenweider et al. (1998) for the four variables seem to smooth and lower the TRIX values compared to the TRIX calculations described before. In principle, this procedure makes TRIX values obtained for different geographical regions comparable. However, large ranges between upper and lower limits make the TRIX more insensitive with the risk that the possibility to discriminate between different TRIX values becomes too low. It has to be verified and discussed in the framework of the EEA activities if the limits proposed and used by Vollenweider et al. (1998) are an acceptable assumption for monitoring and assessing the trophic state of all European coastal and marine waters. Perhaps the ranges have to be defined for different regions or areas in order to increase the sensitivity of TRIX. It also has to be decided which data should be used for the TRIX calculation (annual medians, seasonal medians, seasonal medians over several years), in order to make the index less sensitive to natural meteorologically forced variations.

Despite these questions the general approach of the TRIX has a high potential. After further development it could be a practicable and comparable method for monitoring and assessing the trophic state, determining eutrophication trends of European marine and coastal waters.

For the calculation of TRIX, *in situ* measurements have been used. The long-term objective in COAST was to use remote sensed data (in first place chlorophyll data derived from SeaWiFS) together with *in situ* data for the derivation of a 'spatial' TRIX. A spatial and temporal description of the trophic state should allow a better monitoring and assessment of trends, impact of river inputs and hot spots as related to eutrophication. Unfortunately, *in situ* data on nutrients and oxygen seems in general too few to allow spatial interpolation to be used together with remote sensed chlorophyll data. However, the use of TRIX on *in situ* data from, for example, representative stations is still highly relevant.

8.5. Eutrophication risk index (Eutrisk)

A eutrophication risk index (Eutrisk) is under development by the JRC. The objective is to establish an indicator on eutrophication sensitive areas in European coastal seas. Eutrisk is based on observations of high and frequent phytoplankton biomass in the top layer determined as chlorophyll from remote sensing. This is combined with another indicator based on physical climatology and called the physically sensitive areas (PSA) index, which will help to separate regions with high physical resistance to eutrophication and oxygen depletion (high hydrodynamics and deep waters) from regions with low physical resistance (low hydrodynamics and shallow waters). The bottom physics included in the PSA index influences the Eutrisk index to take into account the physical ability of coastal ecosystems to resist oxygen depletion. Eutrisk should be able to separate strongly sensitive ecosystems (hypoxy events) from less sensitive ecosystems (biological stress by oxygen depletion), and from non-sensitive ecosystems. Eutrisk should be able to show trends on yearly timescales.

9. Contribution from remote sensing to support the evaluation of eutrophication in marine and coastal waters

9.1. Introduction

The application of remote sensing techniques in monitoring marine and coastal waters has shown potential to provide synoptic data/information for a number of physical and bio-geochemical parameters. Although the remote sensing technique is limited to the surface layer of the water column, it is considered to give useful additional or complementary information to traditional *in situ* measurements to assess the state of the marine environment. Remote sensing should have the potential to support the evaluation of eutrophication in marine and coastal waters. In this context the possibility of measuring the biomass of phytoplankton as 'chlorophyll-a-like pigments' would be promising.

9.2. Satellite derived estimates of chlorophyll in European seas

As a first approach to identify European coastal areas with enhanced chlorophyll levels compared to neighbouring seas, maps were produced from satellite (SeaWiFS) images showing the spring–summer mean concentrations of chlorophyll-like pigments in the Baltic, western European and Mediterranean seas. The six-month spring–summer mean (April–September) was chosen rather than the annual mean because of (a) the spring–summer period covers the main growing season of the phytoplankton, and (b) the relatively low frequency of satellite observation during autumn and winter. Figure 29 shows the number of SeaWiFS valid observations for the six months of winter–autumn (January–March and October–December) and spring–summer (April–September) 1998 for the Baltic Sea. The winter-autumn case shows a decreasing south-north gradient and a mean number of data below 10 that would certainly affect the reliability of an annual mean. The spring–summer scene shows a much higher mean number of data but also regional variations. The reliability of a six-month chlorophyll-a mean is directly linked to the number of observations. However, the time distribution of observations in the spring–summer period can be considered as quasi-homogeneous. The six-month mean of SeaWiFS chlorophyll estimations were built with monthly mean data files, which means giving the same weight to each month. The description of SeaWiFS data processed by JRC/SAI is detailed in Mélin et al. (2000).

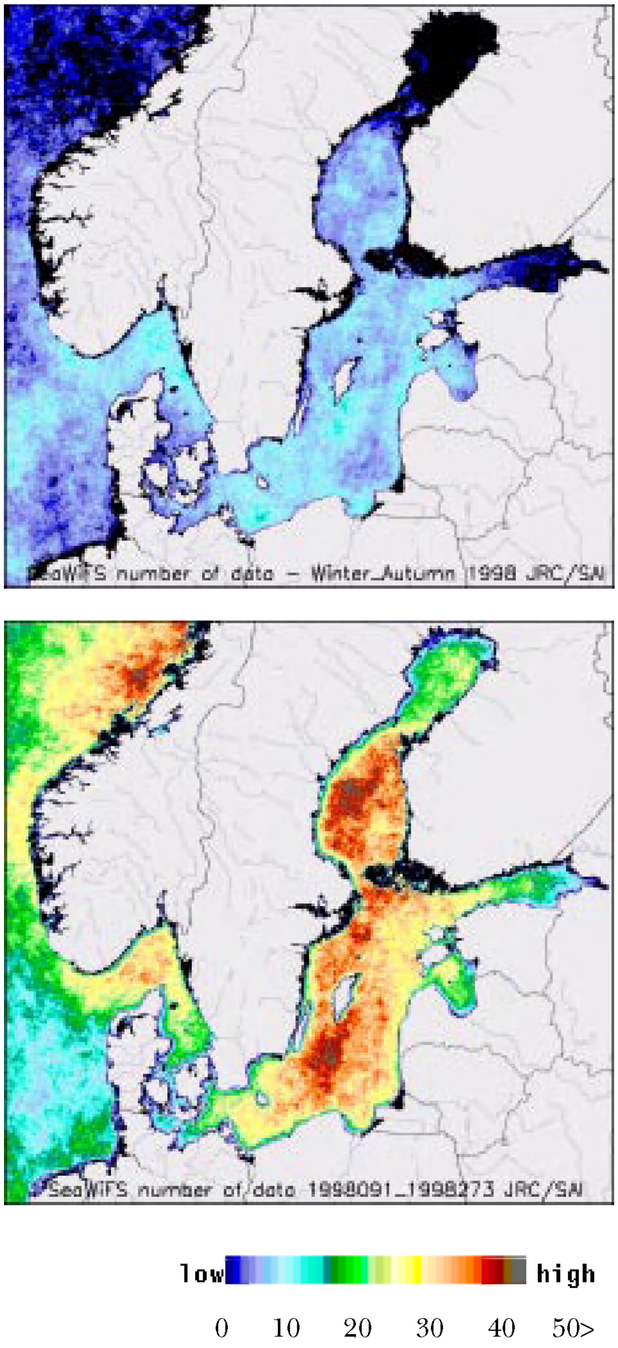
The relatively low numbers of data in the main gulfs of the Baltic Sea and in the eastern North Sea, as well as in the most coastal areas, archipelagos and the Wadden Sea, leads one to interpret the mean chlorophyll values in these areas with more caution. Chlorophyll concentrations in most estuaries and fiords cannot be seen from the satellite.

The characteristics of the images are:

- dataset: SeaWiFS;
- projection: cylindrical;
- resolution: 2 km (at the centre);
- atmospheric corrections: JRC/SAI/ME;
- chlorophyll empirical algorithm: ocean colour 2 (OC2, O'Reilly et al., 1998);

- spring–summer mean from filtered monthly mean (the filter is used to remove non-reliable values due to too low number of data and defined as: for chl-a >10 mg m^{-3}, the value is removed if $\text{chl-a}_{(\text{pixel})} > 1.2 * \text{mean}_{(8\text{pixels})}$, where $\text{mean}_{(8\text{pixels})}$ is the mean of the eight values around the considered pixel);
- log colour scale between 0.2 and 25 mg m^{-3};
- NASA efficiently corrects the decrease of the sensor sensitivity with time.

Figure 29. Number of SeaWiFS valid observations for the six months of winter–autumn (January–March and October–December) and spring–summer (April–September) 1998 for the Baltic Sea



Spring–summer chlorophyll means were prepared for each of the years 1998, 1999 and 2000 for the Baltic, the western European and the Mediterranean satellite windows. Composite pictures for each year are presented in Figure 30, and enlarged 2000 pictures for each window in Figures 31a to c.

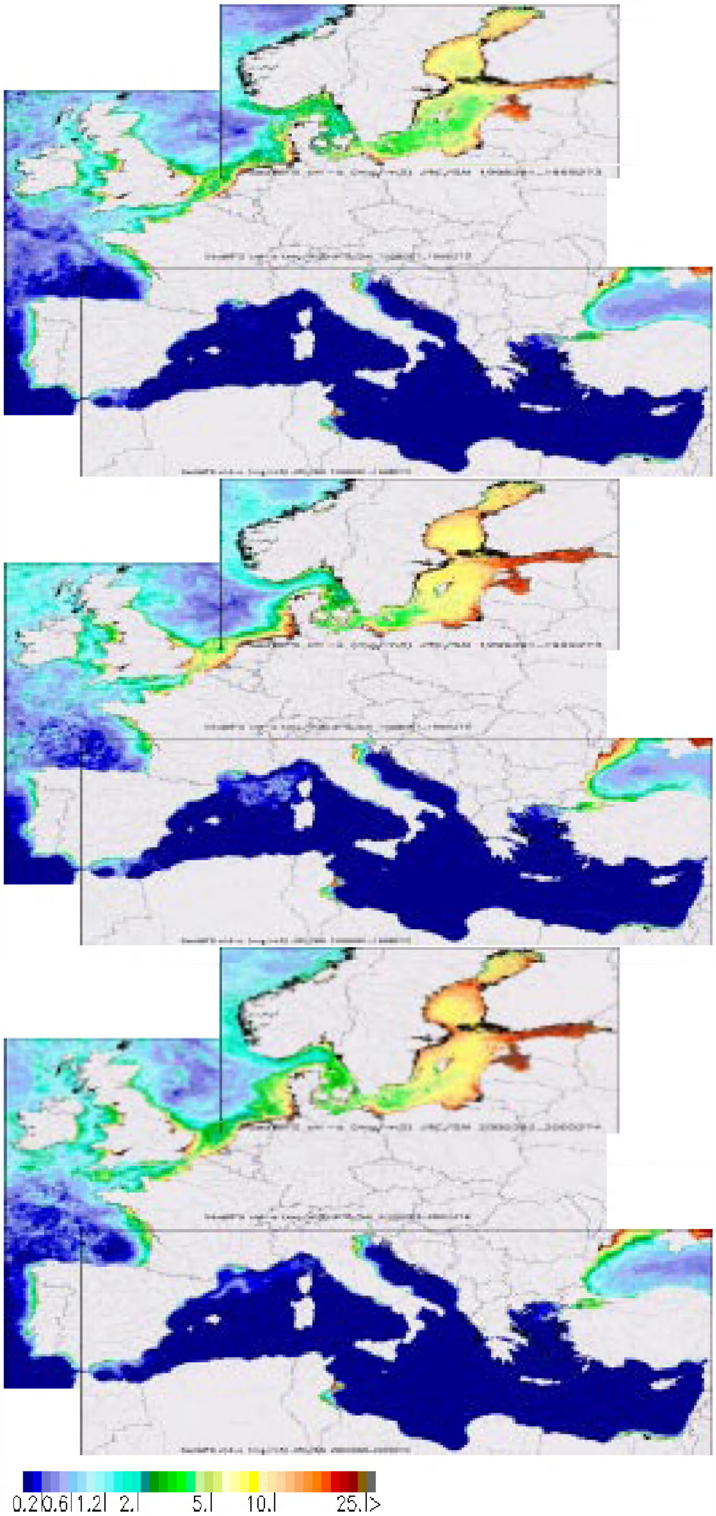
The absolute values of surface chlorophyll mean for coastal areas derived from the OC2 algorithm must be taken with caution and regarded as relative only, as the OC2 algorithm used is designed for oceanic waters. The OC2 algorithm overestimates the chlorophyll content in coastal waters, at least by a factor of two, with variations depending on the concentrations of the water components: chlorophyll, total suspended matter and yellow substances. At the European scale, the main valid information is therefore contained in the observed gradients in space. However, concentrations of yellow substance are high in river influenced areas, especially the Baltic Sea and the German Bight. Likewise, concentrations of suspended matter are high in river influenced areas, shallow tidal areas and the eastern North Sea. Therefore even the spatial gradients should be interpreted with caution. Taking this into account a number of areas (Table 20) with apparently enhanced chlorophyll levels were identified.

Table 20. Coastal areas with apparently enhanced chlorophyll levels compared to neighbouring seas as deemed from the SeaWIFS spring–summer mean chlorophyll images

Baltic Sea: North-eastern part and eastern coast of Bothnian Bay; the Quark area; coastal areas of Bothnian Sea; Gulf of Finland; Gulf of Riga; coastal areas off Kaliningrad and Lithuania; Gulf of Gdansk; Pomeranian Bight; Swedish Baltic Proper coast;
Belt Sea and Kattegat: Especially coastal and shallow areas of the Belt Sea and Kattegat.
Skagerrak: North-eastern and south-western parts and coastal areas of Skagerrak.
North Sea: Eastern North Sea; German Bight; Wadden Sea; southern Bight; UK coast and estuaries.
The Channel: Coastal areas, especially Baie de Somme, Baie de Seine and Baie du Mont St. Michel.
Celtic Seas: Bristol Channel; Liverpool Bay with associated estuaries; Solway Firth; Firth of Clide; Ireland's coast to the Irish Sea.
Bay of Biscay and Iberian coast: French coastal areas and estuaries in Bay of Biscay, especially in the vicinity of the Loire and Gironde estuaries; Spanish and Portuguese Atlantic coasts.
Mediterranean Sea: Costa del Sol; vicinity of the Ebro delta; Gulf of Lyon; Italian west coast, especially Gulf of Gaeta, Napoli Bay and in the vicinity of the rivers Tiber and Arno; northern Adriatic Sea, especially Gulf of Venice and the areas influenced by the river Po; northern Aegean Sea, especially Bights of Thessaloniki and Thermaikos and in the Limnos area with inflow from the Black Sea through the Marmara Sea. Outside EU countries enhanced chlorophyll concentrations are found along the south-east coast of Tunisia and the Egyptian coast from Alexandria to Gaza.

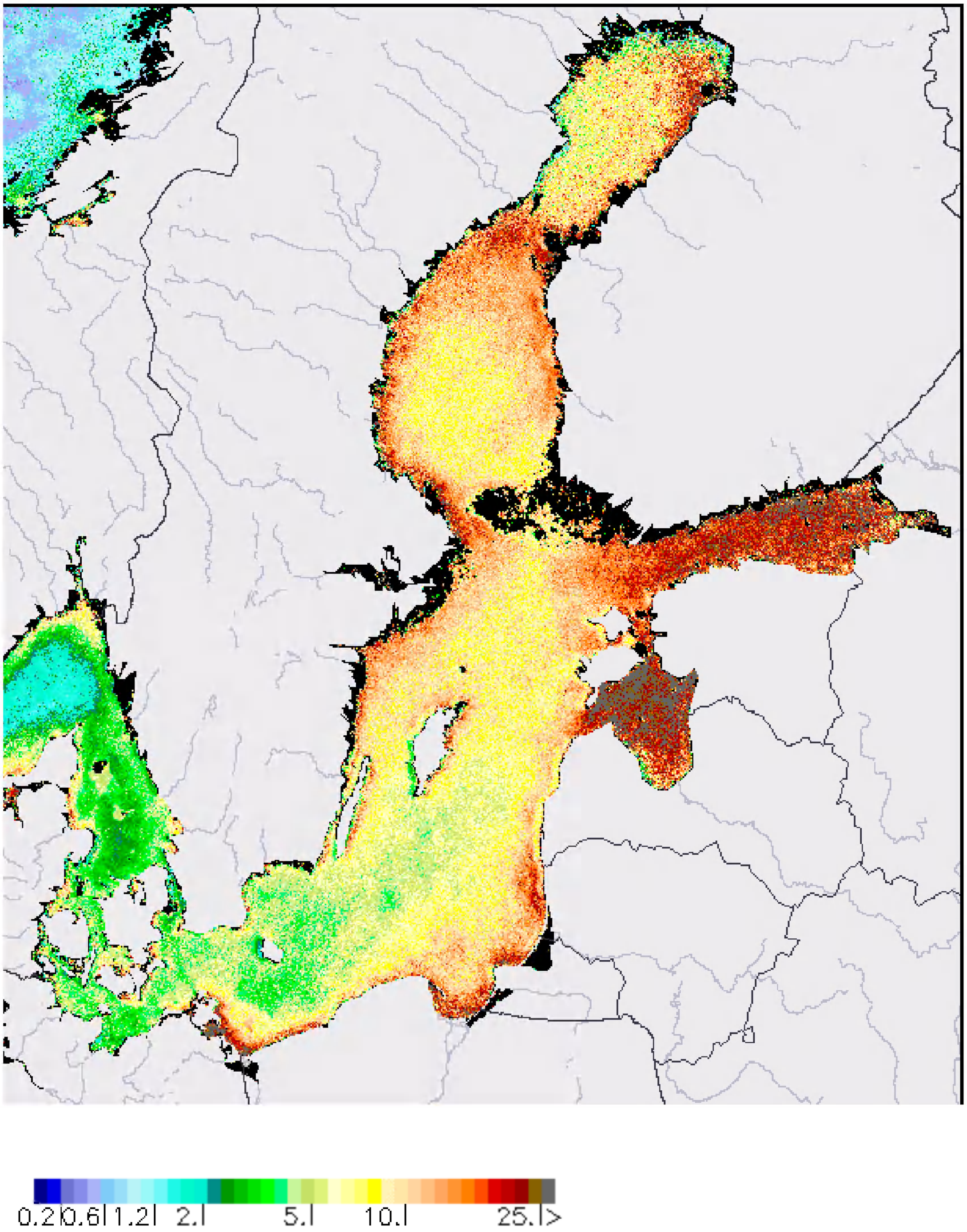
In Figure 30 differences between years are seen in both geographical distribution and in concentration levels of chlorophyll-like pigments, especially in the eastern and southern North Sea and in the Baltic Sea. In the latter case the concentration generally seems to increase over the three years. However, these inter-annual differences are not only due to varying distribution and concentration of phytoplankton blooms related to variations in meteorology and hydrography including run-off, wind direction and wind force, but also to varying distribution of yellow substance and suspended matter. The cyanobacteria bloom in 2000 in the Gulf of Finland was lower than in previous years; even the satellite image indicates a higher concentration of chlorophyll-like pigments.

Figure 30. **Mean spring–summer (April–September) concentrations of chlorophyll-like pigments in European seas as determined from SeaWiFS satellite observations in 1998, 1999 and 2000, respectively**



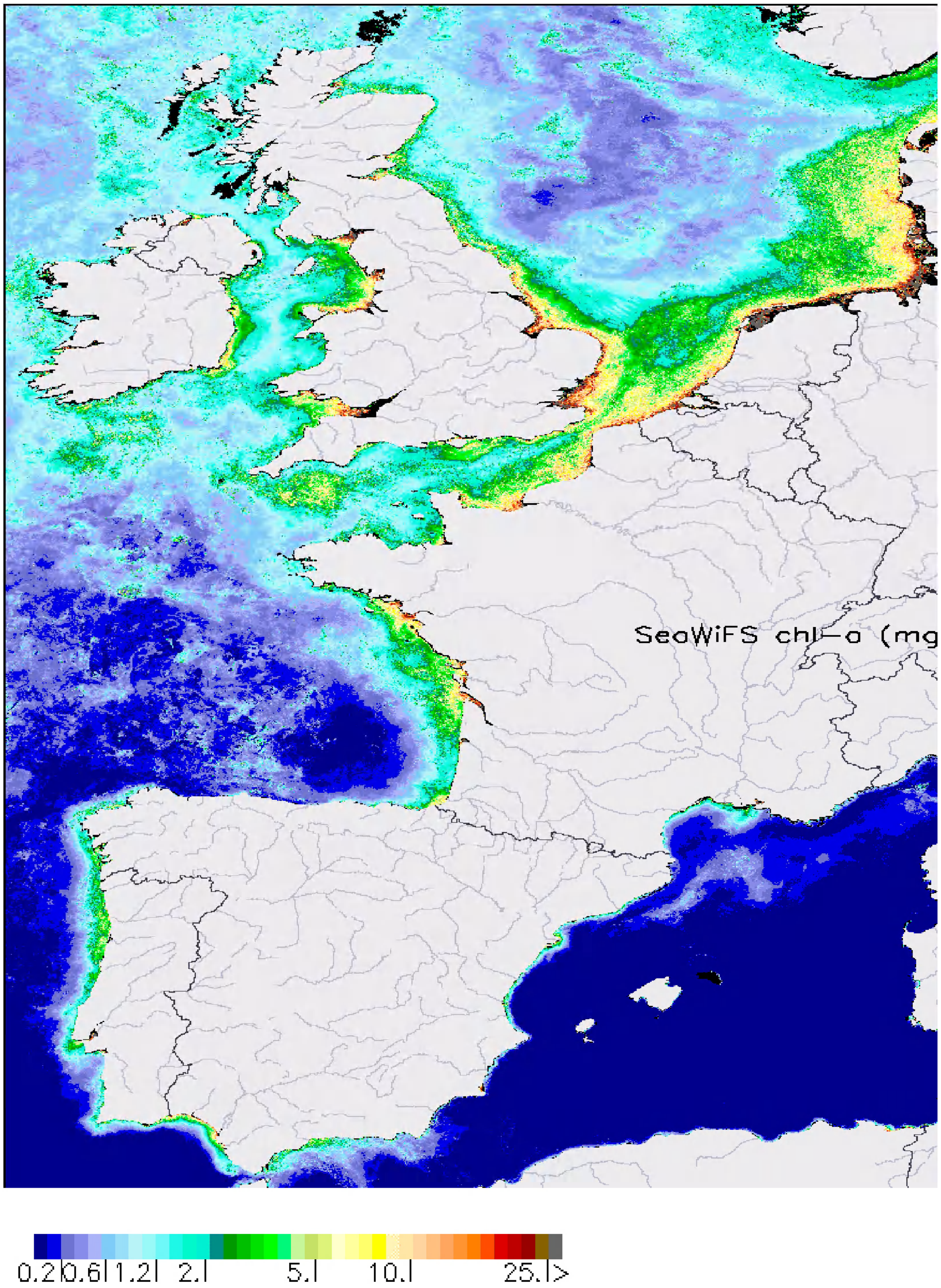
Note: The concentration scale (µg/l) is valid only for oceanic waters and overestimates to a large and variable degree the chlorophyll concentrations in coastal seas

Figure 31a. **Mean spring–summer (April–September) concentrations of chlorophyll-like pigments in 2000 in the Baltic Sea as determined from SeaWiFS satellite observations**



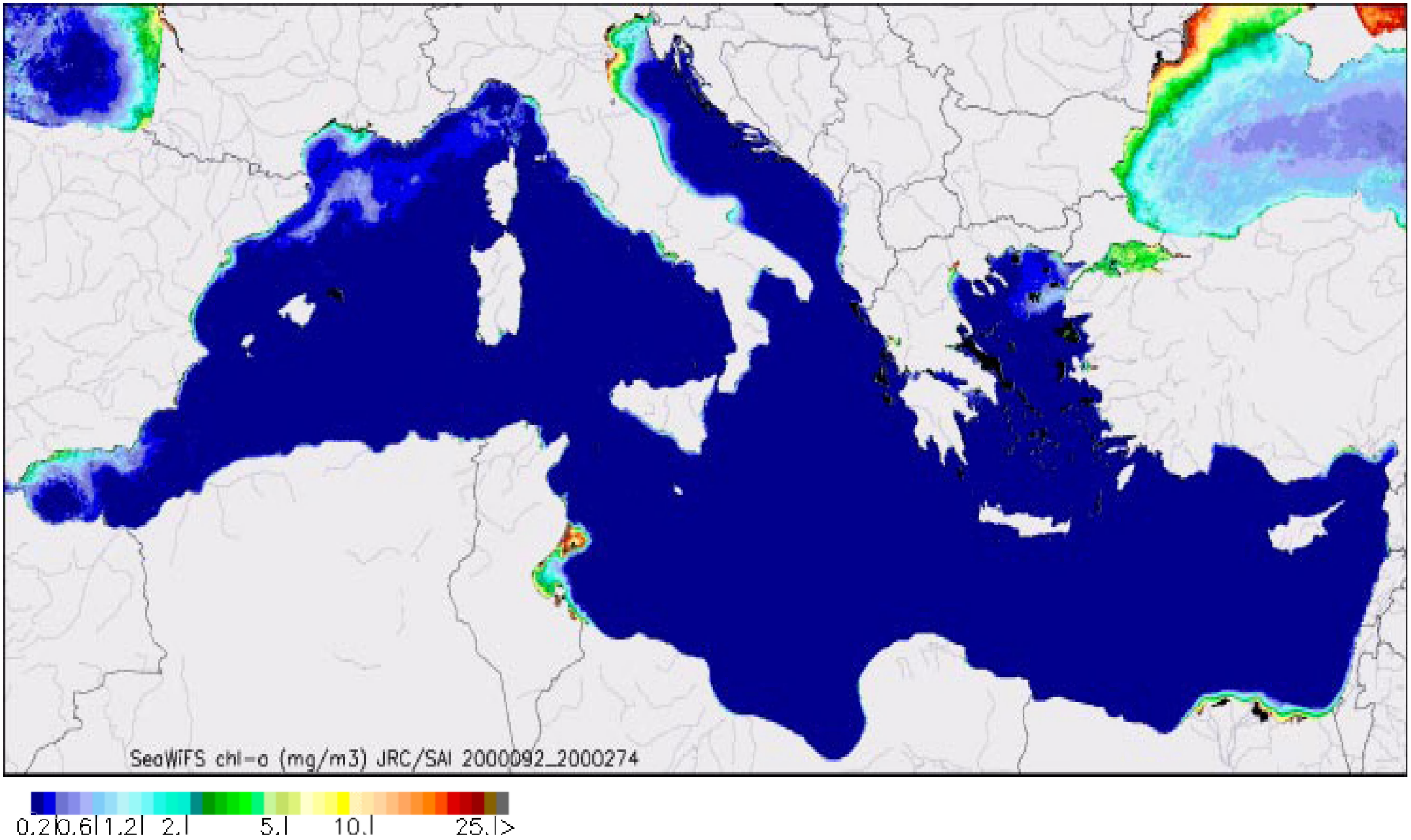
Note: The concentration scale (µg/l) is valid only for oceanic waters and overestimates to a large and variable degree the chlorophyll concentrations in coastal seas.

Figure 31b. Mean spring–summer (April–September) concentrations of chlorophyll-like pigments in 2000 in Western European Seas as determined from SeaWiFS satellite observations



Note: The concentration scale (µg/l) is valid only for oceanic waters and overestimates to a large and variable degree the chlorophyll concentrations in coastal seas.

Figure 31c. Mean spring–summer (April–September) concentrations of chlorophyll-like pigments in 2000 in the Mediterranean Sea as determined from SeaWiFS satellite observations



Note: The concentration scale (µg/l) is valid only for oceanic waters and overestimates to a large and variable degree the chlorophyll concentrations in coastal seas.

9.3. Comparison of satellite derived chlorophyll estimates to chlorophyll concentrations measured *in situ*

So far it has been difficult from satellite observations to determine the chlorophyll concentrations in coastal waters due to the influence of other optical constituents, such as yellow substance and particles. New development of algorithms and new sensors will hopefully in the future improve the use of such data in coastal areas. The possible use of satellite derived chlorophyll estimates for a chlorophyll indicator has been tested. *In situ* measurements have been compared with estimates of 'chlorophyll-a-like pigments' from satellite data to evaluate their use in supporting the monitoring and further evaluation of eutrophication in European marine and coastal waters.

Data and image production

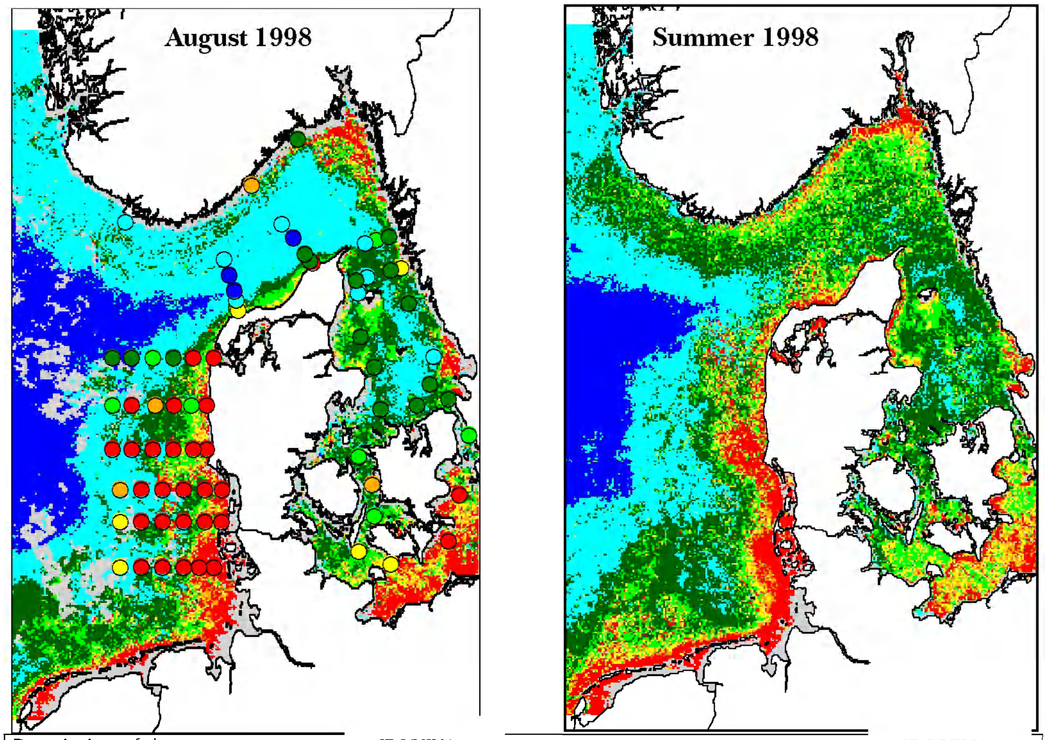
The northern European region has been chosen due to a better coverage of in situ measurements. The in situ data are from Danish, Norwegian and Swedish waters and include data from NERI, NIVA, the Norwegian Institute of Marine Research and the Swedish Meteorological and Hydrological Institute. The satellite data are processed at the Joint Research Centre/SAI and further enhanced at NIVA. Some preliminary examples of images from the SeaWiFS data will be presented here. The images are produced at NIVA as follows.

1. The satellite data were transferred as generic binary data from ftp site me-ftp.jrc.it.
2. The data were imported to an image with ERDAS version 8.4 for Windows NT. Each image contains 391 rows and 277 lines and each pixel value was represented as 16 bit signed values. The bytes were swapped.
3. The SeaWiFS data were processed using algorithms developed by the JRC. This processing code is known under the synonym Rembrandt version 1.0. Chlorophyll-a-like pigments were calculated as $Chla_{SeaWiFS} = pixelvalue \cdot 0.001 + 32$, where the pixel value represents water leaving radiance corrected for atmospheric disturbance.
4. $Chla_{SeaWiFS}$ from 26 August 1998 was compared with field data from 25 and 26 August 1998. A modified equation was then used for calculation of chlorophyll-a-like pigments. $Chla_{\text{mod}ified} = 0.4 \cdot Chla_{SeaWiFS} + 0.2$.
5. The values for chlorophyll-a-like pigments were divided into eight classes.
6. The images were combined with maps in ArcView GIS version 3.1 for Windows NT. The image 'August 1998' includes in situ chlorophyll-a values from surface samples taken in August 1998.

Results

The maps (Figure 32) show the monthly mean chlorophyll-a-like pigments for August 1998 and the summer mean values based on monthly mean values from May to September 1998. In the Kattegat region the satellite data are in agreement with the field data. In the small part of the western Baltic Sea the satellite derived concentrations are higher but in agreement with the *in situ* data. At the west coast of Denmark the satellite derived chlorophyll-a-like pigments are lower than the *in situ* data. This is probably mainly due to the fact that the *in situ* data are from one cruise and the satellite data represent a mean value of several datasets. Anyhow, the *in situ* and satellite data supplement each other and are in agreement near the coast.

Figure 32. Modified mean chlorophyll-a-like pigments from SeaWiFS data for August 1998 compared with *in situ* chlorophyll-a measurements (coloured circles) (left), and modified mean chlorophyll-a-like pigments from SeaWiFS data for summer (May–Sept.) 1998 (right)



JRC/NIVA

JRC/NIVA

Description of dataset

Sensor: Sea-viewing wide field-of view sensor
Dataset: North Sea/Skagerrak/Kattegat
Summer image: Mean of May to September
Projection: Rectangular = cylindrical equidistant
Resolution: 2 km (at centre)
Latitude min./max.: 53.0N/60.0N
Longitude min./max.: 4.0E/13.0E
Image size (pixel/line): 277/391
Processed: JRC/SAI and NIVA

Chlorophyll-a-like pigments

- 🟦 < 0.5 mg/m^3
- 🟦 0.5–1 mg/m^3
- 🟩 1–1.5 mg/m^3
- 🟩 1.5–2 mg/m^3
- 🟨 2–2.5 mg/m^3
- 🟧 2.5–3 mg/m^3
- 🟥 > 3 mg/m^3
- ⬜ Cloud and flagged value

At the Norwegian coast the summer mean values are in good agreement with observations and the general knowledge of the phytoplankton concentrations in the area. At the monitoring station at this coast of Norway the concentration of chlorophyll-a is in the range of 2–3 mg/m^3 80 % of the time, which is in agreement with the summer image.

9.4. Further work

In the examples used the rescaling of the data with *in situ* data seems to give reasonable overall concentrations of chlorophyll-a-like pigments. Different empirical methods (multiband projection, neural network) are now being developed to improve the chlorophyll-like pigment concentration in coastal waters under the mean error level of 100 %. This information can be used to improve the present algorithms or be used in later work with new sensors, such as MERIS on Envisat. MERIS will have improved spectral capability to handle difficulties in the coastal areas.

10. Conclusions and recommendations

Conclusions

- Eutrophication of marine waters caused by excess load with nitrogen and phosphorus nutrients from human activities is a major problem in many European coastal areas. The main source of nitrogen is run-off from agricultural land brought to the sea via rivers. Atmospheric deposition of nitrogen may also contribute significantly to the nitrogen load. This nitrogen originates partly from ammonia evaporation from animal husbandry and partly from combustion of fossil fuels in traffic, industry and households. Most of the phosphorus comes from households and industry discharging treated or untreated wastewater to freshwater or directly to the sea, and from soil erosion. Locally, fish farming may also cause eutrophication problems.

- Eutrophication is not an issue of concern in European Arctic waters. The whole Baltic Sea area is affected by eutrophication, least in the Gulf of Bothnia. In the Greater North Sea eutrophication primarily affects the coastal zone. In particular, nutrient related problems are widespread in estuaries and fiords, the Wadden Sea, German Bight, Kattegat and eastern Skagerrak. In the Celtic Seas, Bay of Biscay and Iberian coast areas eutrophication is restricted to the Irish Sea, estuaries and coastal lagoons. In the Mediterranean eutrophication is limited to specific coastal and adjacent offshore areas. Especially affected are estuaries, bays and coastal lagoons as well as the Adriatic, Gulf of Lion and northern Aegean Sea. Discharge of raw or poorly treated wastewater is a major problem in the Mediterranean Sea, in addition to nutrient loads from agriculture and aquaculture.

- The main increase in nutrient load took place before monitoring programmes and pollution load compilations were started. Derived from information in the literature a conservative estimate of the increase in nitrogen loads from land and atmosphere to the Baltic and North Sea regions is a doubling from the 1950s to the 1980s, and a fourfold increase in the phosphorus load from the 1940s to the 1970s. The development in nutrient load to the Mediterranean Sea is unknown, but probably of the same magnitude.

- In accordance with this, nitrogen and phosphorus concentrations in the Baltic Sea area and German Bight generally more or less doubled from the late 1960s to the middle of the 1980s. Phytoplankton production and blooms increased, and consequently the silicate concentrations decreased, as did the Secchi depth and, in stratified areas, the bottom oxygen concentrations.

- Trend analyses of land-based load data from 1990 to 1995/96 for the Greater North Sea generally showed a recent decrease in phosphorus load due to improved sewage treatment and phosphate free detergents, but there is no discernible reduction in the nitrogen load, even though the load from point sources is reduced. The phosphorus load to the Baltic Sea has also decreased, and the nitrogen load is assumed to have decreased slightly due to the reduction in fertiliser usage in the countries in transition.

- Atmospheric nitrogen deposition to the Baltic Sea area decreased by about 25 % from 1986 to 1995, probably due to reduced production in eastern Europe and changed agricultural practice in western Europe. No changes have been seen in recent years in the wet deposition of nitrogen to the North Sea.

- Analyses of time series of nutrient concentrations from 1985 to 1997/98 showed that phosphorus concentrations also decreased in many estuaries and coastal areas, especially in the Baltic Sea and North Sea areas. However, nitrogen and chlorophyll-a concentrations remained fairly constant. General improvements in biological eutrophication variables were nearly absent or local.

Recommendations

1. Nitrogen and phosphorus nutrients, chlorophyll-a and oxygen concentrations are the most general and widely used eutrophication variables. It is therefore recommended as a first step to focus on these 'best available' variables only in assessing the state and development of eutrophication in coastal waters at European level.
2. However, we recommend that all European national monitoring programmes also include the other 'best needed' eutrophication variables included in the OSPAR comprehensive procedure in all eutrophication sensitive areas in the European coastal waters, such as those appointed in the OSPAR common procedure, and by the European Commission concerning eutrophication sensitive areas in the framework of the urban wastewater treatment directive and the nitrate directive as well as the water framework directive. Hence monitoring should include at least measurements of phytoplankton species composition, macrophyte biomass, species composition and depth distribution, and macrozoobenthos biomass and species composition.
3. In general, the data available for this report were scarce and with the exception of a few regions inadequate for fully assessing the state and trends of eutrophication. It is strongly recommended that the EEA national reference centres should strive to report more data to international databases (OSPAR, Helcom, ICES, Medpol or EEA) to allow for a more coherent analysis of eutrophication in the coastal zones of Europe.
4. It is also recommended that measures be taken to initiate the collection of eutrophication data in the Mediterranean Sea and to store these data in one database for the area. It is hoped that Medpol will take on this obligation in the near future.
5. National reference centres should strive to report on estuaries and coastal areas with as complete datasets as possible. It is recommended that only areas with regular monitoring should be reported, as time series of five years or more are needed for trend analysis.
6. All marine eutrophication data, including reporting under the EU directives, should be reported to the databases of the marine conventions (Helcom, OSPAR, Medpol) and/or to EEA. This would facilitate the development of eutrophication indicators and assessment of eutrophication in European coastal zones. Finally, it is important that routines to assure the quality and completeness of contributed data are developed.
7. Aquaculture is expanding in many European countries. In the Arctic waters eutrophication from fish farming is the major threat, and in the Mediterranean the nutrient load from aquaculture is comparable to the load from agriculture. Therefore, it is further recommended that nutrients and organic matter load from aquaculture be included in future pollution load compilations.
8. We also recommend a further evaluation of the general applicability of the trophical index TRIX, and the use of remote sensing as a eutrophication monitoring tool.

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