# Invited paper

# The Baltic Sea – an example of how to protect marine coastal ecosystems

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Dietwart Nehring
Baltic Sea Research Institute Warnemünde,
Seestrasse 15, 18112 Rostock, Germany

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**Abstract**

The Baltic Sea covers an area of 415 000 km$^2$. A typical brackish sea, it is very sensitive to anthropogenic activities. Inorganic nutrients, trace metals, chlorinated hydrocarbons and crude oil products are contaminants studied in the Baltic Monitoring Programme of HELCOM. The data collected by the riparian countries forms the basis for the periodic assessments of the state of the marine environment of the Baltic Sea Area produced by HELCOM every five years. Since 1992 marine nature conservation has been part of the HELCOM convention.

According to the third status report issued in 1996, it was the first time that HELCOM could strike a positive balance with regard to the decreasing environmental load. This is also reflected in lower concentrations of harmful substances in fish, marine mammals and seabirds in the Baltic Sea Area. The reasons for this progress are the protective actions initiated by HELCOM and the economic collapse in some of the former East Bloc countries, the latter resulting in an abrupt fall in industrial and agricultural production. Although the restoration of the Baltic ecosystem has only just begun, the protective measures introduced to achieve this aim can serve as an example of how to solve similar problems in other semi-enclosed basins and shelf seas.

## 1. Introduction

The Sea covers 361.2 million km$^2$ (70.8%) of the Earth's surface; of this, the Baltic Sea makes up a bare 0.415 million km$^2$ (0.081%). Still greater are the differences in the volumes: the Sea – 1372.2 million km$^3$; the Baltic Sea – 0.022 million km$^3$. The shelf seas and semi-enclosed basins, which contribute about 10% to the overall sea surface, are especially endangered by the anthropogenic environmental load, since they are directly influenced by the activities of man.

Although only a ‘mini-ocean’, the Baltic Sea is large enough for studies on the consequences of the anthropogenic environmental load as well as on measures for restoring marine ecosystems. Long time-series, some of which stretch back into the 19th century, are of significance in this connection.

The Baltic Sea is a land-locked basin connected with the North Sea only by the three Danish straits (smallest total cross-section 0.4 $km^2$). These sea narrows very considerably restrict horizontal water exchange and are the reason for the long residence time of water in the Baltic Sea, on average 25–35 years (North Sea 2–3 years). The vast catchment area of about 1.7 million $km^2$ is responsible for the positive water balance and the brackish character of the Baltic Sea. Its permanent halocline is a common feature of brackish seas and impedes vertical water exchange. As a result of these restrictions in the horizontal and vertical water exchange, stagnant conditions in Baltic deep waters are produced. Extreme inflow events dependent on certain meteorological and hydrographic conditions occasionally terminate the stagnation periods by the inflow of huge quantities of seawater from the North Sea via the Kattegat – Belt Sea into the central Baltic basins.

Nearly 85 million people live in the Baltic Sea’s catchment area. The southern and eastern parts of this region are highly industrialised and densely populated; agriculture is also intensive there. Apart from being plied by passenger, cargo and fishing vessels, the Baltic Sea also serves as an amenity for tourism, leisure and recreation. Because the restricted horizontal and vertical water exchange results in long residence times, the Baltic Sea is very sensitive to climatic and anthropogenic influences.

## 2. Nutrient load and contamination by harmful substances

The most serious environmental problem caused by man is the increasing fertility or eutrophication of the Baltic Sea. Inorganic nutrients are the driving force behind this process. Although eutrophication has a positive effect on the development of food sources for fish, its impact on the oxygen balance in stagnant deep waters is negative.

Among the substances that are environmentally harmful are synthetic organochlorine compounds, classed as ‘xenobiotics’, as well as trace metals and crude oil products of both natural and anthropogenic origin. The heavy metal and organic contaminant concentrations currently measured in Baltic waters and organisms are not alarming. So far, they have caused no acute damage in the Baltic Sea, except the death of oiled seabirds, which are found from time to time. Analytical problems resulting from low concentrations and contamination during sampling and analysis are the reason why reliable data of harmful substances in seawater has become available only in recent times. According to the assessment criteria of the Oslo–Paris Commission (OSPARCOM), their concentrations in water do not represent an acute risk for the Baltic ecosystem. Along the food web, however, heavy metals and organic contaminants become enriched, and in this way they can damage higher organisms. Disturbances of the immune system as well as eczemas and deformities are under discussion in this connection. Organochlorine compounds are also responsible for the eggshell thinning which has reduced the breeding success of some seabirds.

Since we do not possess detailed knowledge of all the long-term consequences for marine organisms of heavy metals and organic contaminants, the anthropogenic sources of these substances must be eliminated or at least reduced. This also applies to inorganic nutrients, though these substances are not harmful in the true sense of the word. But as the driving force of eutrophication, they play a dominant part in the environmental load of the Baltic ecosystem with respect to its oxygen balance.

Substances of environmental relevance originate from municipal, industrial and agricultural sources or are generated by road traffic. Their input into the Baltic Sea takes place by direct waste-water discharge and by river run-off as well as via the atmosphere. Point sources of waste water and stack gases from large-scale combustion plants can be eliminated relatively simply by treatment plants and stack gas filters. However, eliminating or reducing pollutants is much more difficult in the case of diffuse sources (non-point sources) such as agriculture and road traffic.

The chemical munitions dumped after World War II (Theobald 1996), and artificial radionuclides (HELCOM 1996a), the level of which rose for a short time after the Chernobyl accident in April 1986, at present pose no acute risks for the Baltic ecosystem. They are therefore not covered in this article.

### 2.1. Eutrophication and its consequences

Phosphates and nitrates, both important nutrients for algae, have been identified as the main factors causing eutrophication. Their long-term winter concentrations have increased significantly in the Baltic Sea since the 1960s, although substantial fluctuations have also been recorded during this period. Fig. 1 shows this development for the phosphate concentrations in the Baltic Proper. However, the decreasing trend observed since the late 1980s and early 1990s has levelled out in recent times (Matthäus et al. 1999, 2000). The situation regarding nitrate concentrations is similar (Nehring & Matthäus 1991–92).

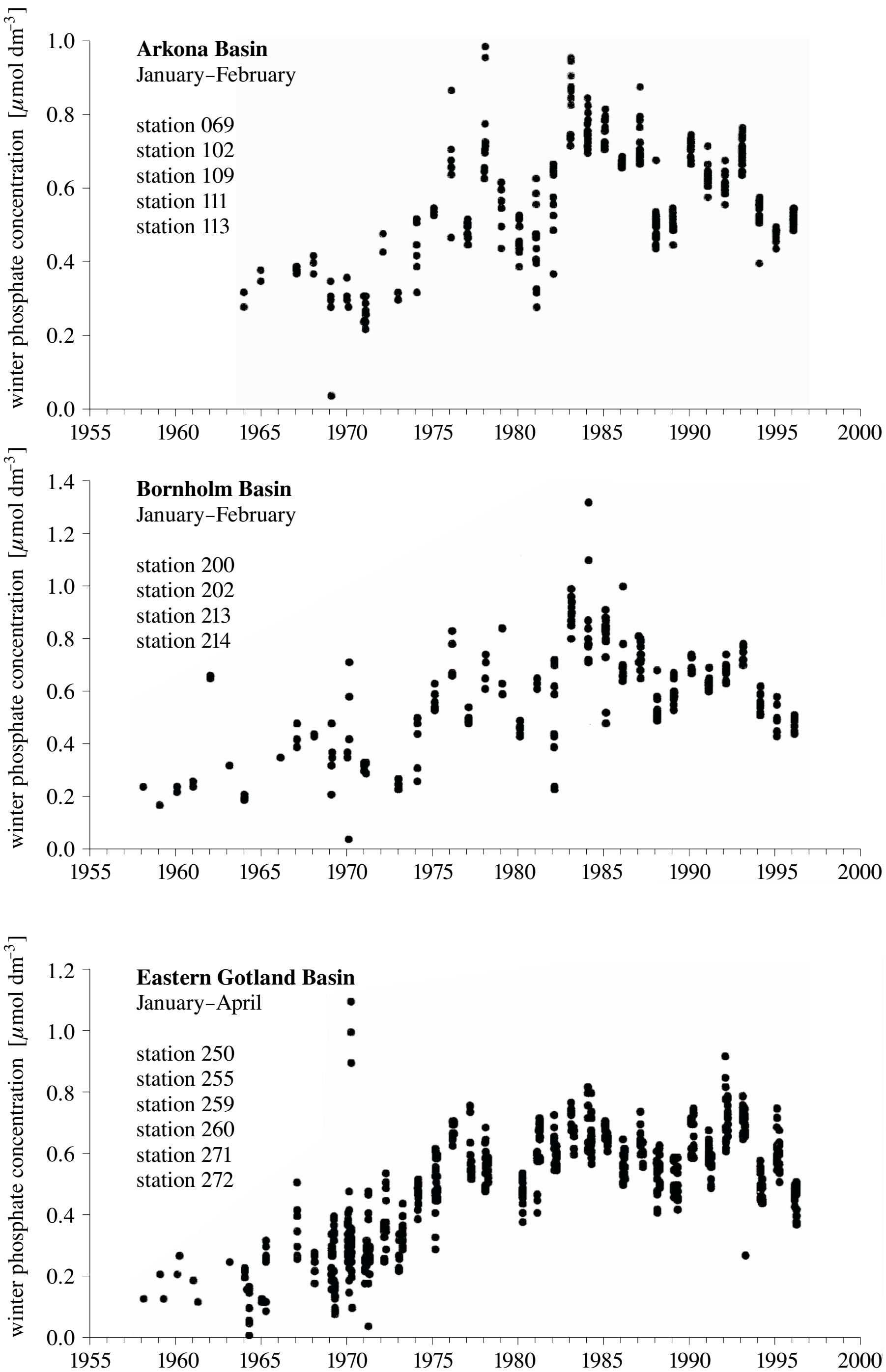


**Fig. 1.** Long-term changes in the winter phosphate concentrations in the surface layer (0–10 m) of different areas of the Baltic Sea

The increasing phosphate and nitrate concentrations in the Baltic Sea are caused mainly by municipal and industrial sewages and stack gases (point sources), along with diffuse inputs from agriculture and road traffic (non-point sources). The nitrate concentrations in Baltic coastal waters sometimes correlate with river run-off (Kornvang et al. 1993, Bachor et al. 1996). Fig. 2 shows an example for Danish coastal waters. According to Table 1, the nutrient inputs are not all compensated by sinks, among which the sediments play a poorly understood role in the immobilisation and remobilisation of nutrients (Nehring & Ærtebjerg 1996).

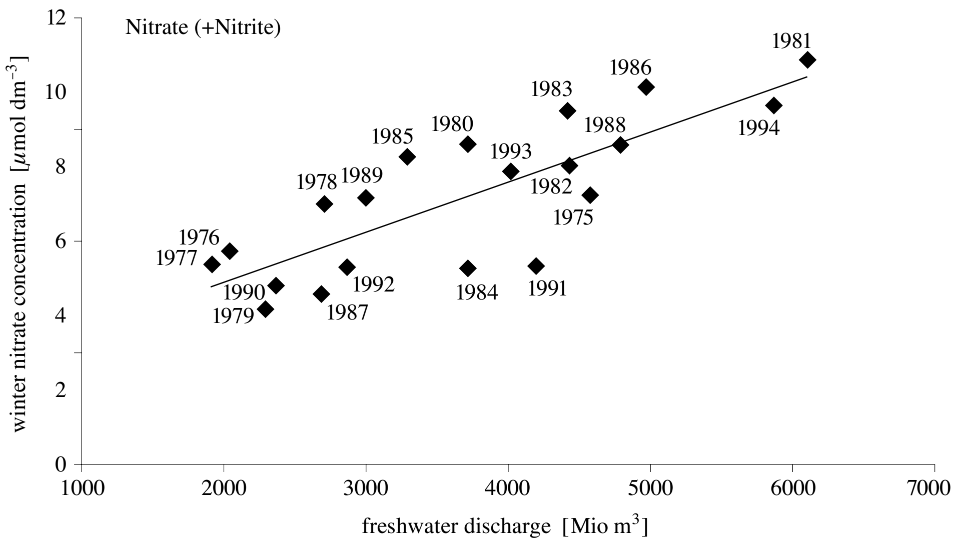


**Fig. 2.** Mean winter nitrate concentrations (December–Febuary) as a function of riverine discharge in Danish coastal waters (October–January; Nehring & Ærtebjerg 1996)

Owing to their strong spatial and temporal variations, changes in the plankton biomass corresponding with the nutrient conditions are often not significant in the Baltic Sea area. But the benthic macrofauna, feeding on the particulate organic material which settles down from the surface layer, has strongly increased in recent decades, indicating a higher biological productivity. Its biomass has grown by a factor of 2–10 since the 1930s, depending on the species and regions under investigation (Cedervall & Elmgren 1980, Gosselck 1985, HELCOM 1996a). Exceptions are areas with anoxic conditions in the bottom water.

The increasing nutrient load intensifies the biochemical cycle of matter, which in turn affects the oxygen demand. The organic matter produced in the well-illuminated surface layer by photosynthesis settles into the stagnant

**Table 1.** Important nutrient sources and sinks of the Baltic Sea (cf. Nehring & Ærtebjerg 1996)

| | | Total-P | Total-N |
|---|---|---|---|
| | | (in kilotons per year) | |
| land-based inputs | (source) | | |
| via water (a) | | 46 | 661 |
| via atmosphere | | (6) | 330 |
| ship-generated sewage | (source) | 0.05 | 0.13 |
| fisheries | (sink) | 4 | 20 |
| denitrification | (sink) | – | 470 |
| $N_2$-fixation | (source) | – | 130 |
| sediment | | | |
| immobilisation (b) | (sink) | 55 | 1060 |
| remobilisation (c) | (source) | 7 (?) | 589 (?) |
| Baltic entrances | | | |
| inflow | (source) | 10 | 100 |
| outflow | (sink) | 10 | 120 |

(a) River inputs and waste-water discharges (municipal and industrial).

(b) Total for the Baltic Proper and the Gulf of Bothnia (Wulff et al. 1990), supplemented for the other regions corresponding to their share of the total area of the Baltic Sea.

(c) Calculated as the difference between sinks and sources.

deep water, where it is decomposed by micro-organisms. The consequence of this process is oxygen depletion followed by the formation of toxic hydrogen sulphide. Inflows of saline waters from the North Sea occasionally replace the stagnant deep waters in the central Baltic basins. These events are accompanied by an oxygen supply to the water below the halocline. Fig. 3 illustrates the variations in the oxygen conditions in central Baltic deep waters as a consequence of stagnation and water renewal.

Fish and other aerobic organisms are unable to survive severe oxygen depletion and the presence of hydrogen sulphide. The fish themselves are able to escape, but their spawn and larvae often perish. The areas where hydrogen sulphide tends to form in their deep waters are shown in Fig. 4. These conditions, characterised by strong interannual variations, currently affect about 20% of the Baltic Sea bed (HELCOM 1990). They are particularly hostile to organisms living on and in the bottom, which

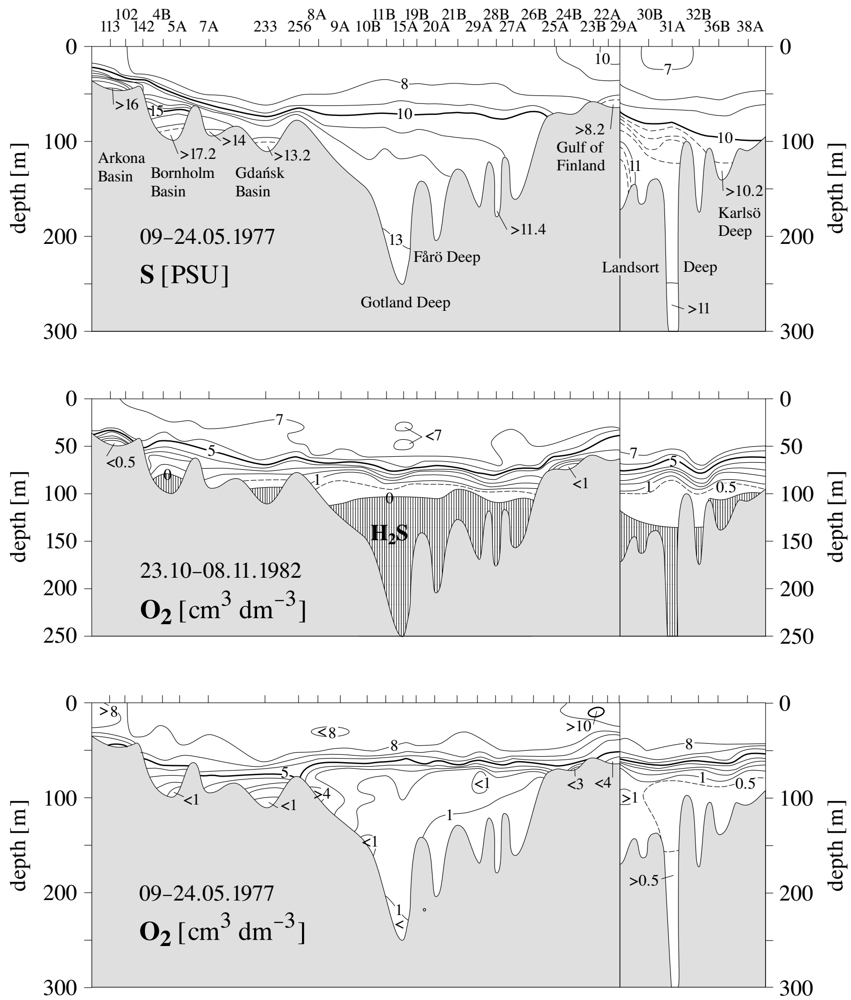


**Fig. 3.** Vertical distribution of salinity and oxygen during and after a stagnation period in the deep basins of the central Baltic Sea. The area of deep water containing hydrogen sulphide is shown hatched

are doomed under these conditions. Such conditions are also becoming common in the shallower parts of the Baltic Sea and its internal coastal waters, the boddens and haffs (lagoons), where the nutrient load together with organic matter in river discharge accelerates eutrophication. In these areas, however, the formation of hydrogen sulphide under stagnant conditions is only a transient process. As a result of wind-induced mixing, the water column is soon replenished with oxygen (Nehring et al. 1995a). Nevertheless, the subsequent recolonisation of the sea bed is a very slow process, initially characterised by a low diversity of benthic species.

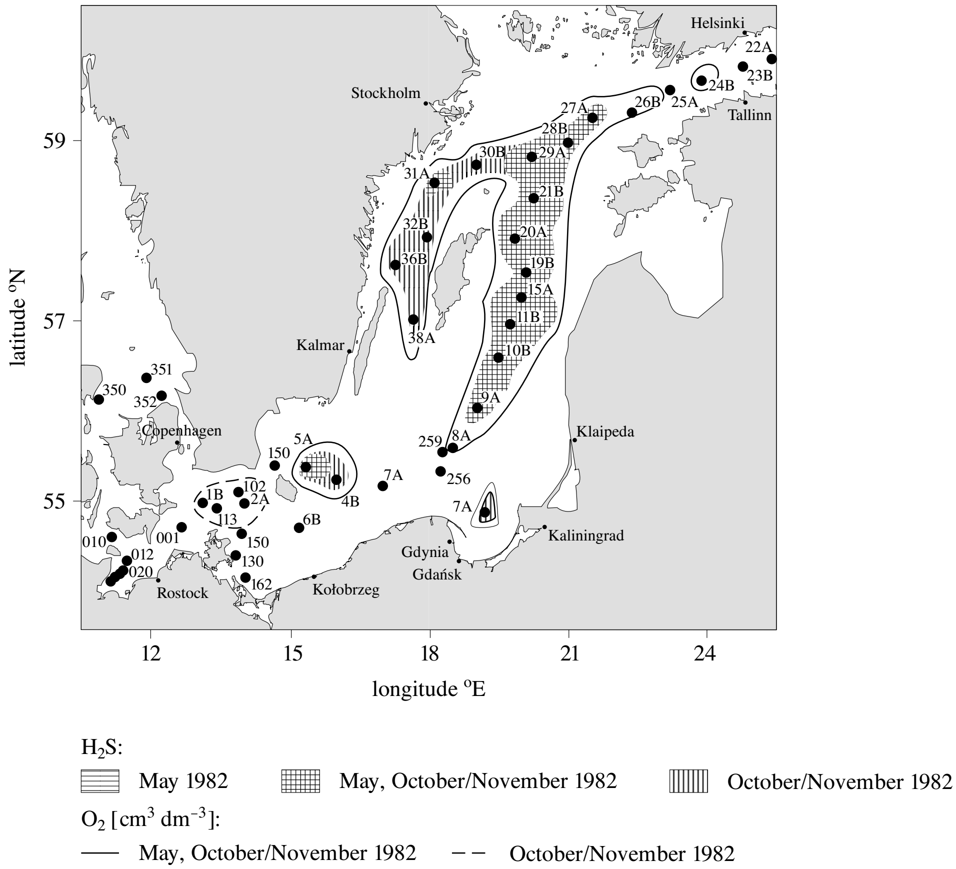


**Fig. 4.** Station map and areas in the central Baltic Sea endangered by oxygen deficiency and hydrogen sulphide (hatched). The extreme situation in the bottom water layer in 1982

The increasing turbidity of the water due to the high phytoplankton density is a further negative consequence of eutrophication and is particularly evident in the shallow internal and external coastal waters. Since the depth to which light can penetrate is thereby reduced, photosynthesis is prevented and the algae growing on the bottom are killed; fish are thus deprived of their spawning substrate, and fish larvae and juveniles of their nursery.

## 2.2. Heavy metals

Effluents from heavy-metal industries, exhaust gases from motor vehicles, and stack gases from large-scale combustion plants are the main sources loading the marine environment with trace elements, especially heavy metals like lead, mercury, cadmium, copper and zinc. Owing to their fungicidal properties, mercury compounds have been used in the paper and wood pulp industries and for treating seed grain, and have accordingly contributed to the mercury load in the Baltic Sea.

Reliable long-term series for offshore Baltic waters exist only for cadmium and copper (Schneider 1995). The investigations show a significant decrease in the cadmium concentrations in the surface layer of the central Baltic Sea (Fig. 5), whereas no changes have been recorded below the halocline. Similar results were found for copper.

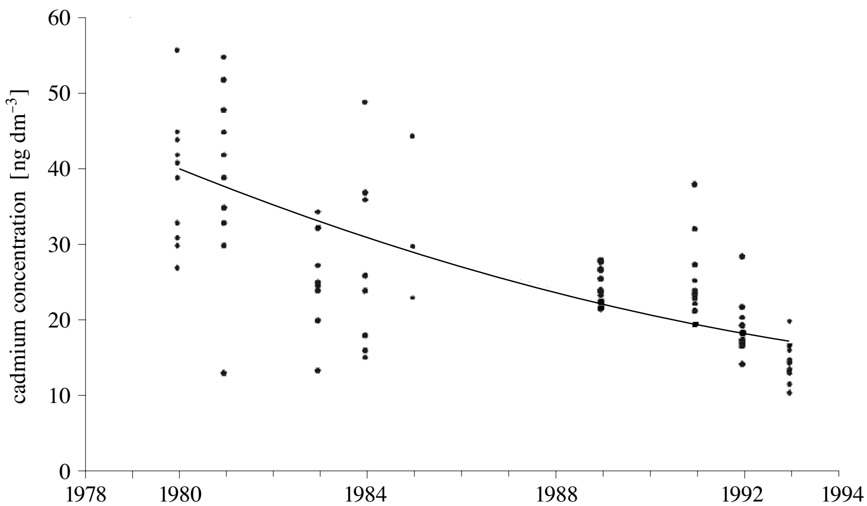


**Fig. 5.** Temporal decrease in cadmium concentrations in the surface layer of the central Baltic Sea (after Schneider 1995)

Despite the major reduction of mercury inputs to less than 50 tons per year, the tissues of fish caught in the Baltic Sea Area still show no sign of a definite reduction in mercury load (HELCOM 1996a). In contrast, lead loads in fish and mussels are decreasing. Although the cadmium and copper concentrations are decreasing in Baltic surface waters, this is not reflected by analogous changes in fish tissues. In some areas of the Baltic Sea, cadmium concentrations even increased annually by 5–8% in herring liver between 1981 and 1995 (HELCOM 1996a).

## 2.3. Chlorinated hydrocarbons

Water, organisms and sediment samples are analysed under the Baltic Sea Monitoring Programme for various chlorinated hydrocarbons. These include DDT and its metabolites (DDTs), lindane and other hexachlorocyclohexane isomers (HCHs), hexachlorobenzene (HCB) and polychlorinated biphenyls (PCBs), a theoretical total of 209 isomers of varying toxicity. Organochlorines are used as insecticides (DDT, $\gamma$-HCH), as coolants in transformers or condensers, and as softening agents in the production of plastics (BCPs). Other organochlorine compounds formed by using chlorine to bleach paper and wood pulp have not been studied in detail. Nevertheless, the waste products of these industries are also of considerable relevance in the Baltic Sea. Since all xenobiotics are synthetic products, their degradation rates are often very low. Thus, chlorinated hydrocarbons are also known as persistent organic pollutants. Because of their lipophilic properties, xenobiotics are accumulated in the fatty tissues of organisms.

As the solubility of chlorinated hydrocarbons in seawater is extremely low, their concentrations lie near the detection limit. The routine analysis of these compounds is thus mostly restricted to sediments and higher organisms like fish, seals and seabirds. Exceptions are lindane and other HCH-isomers. Since they are better soluble and are thus present in higher concentrations, reliable data from these compounds have been available for seawater for more than 20 years (Dannenberger & Lerz 1995). Technical lindane contained up to 80% of the less effective $\alpha$-compound as an impurity. The increasing application of pure lindane is reflected in the continuously decreasing $\alpha$-HCH concentrations in the surface water of the Baltic Sea since about 1976, as shown in Fig. 6.

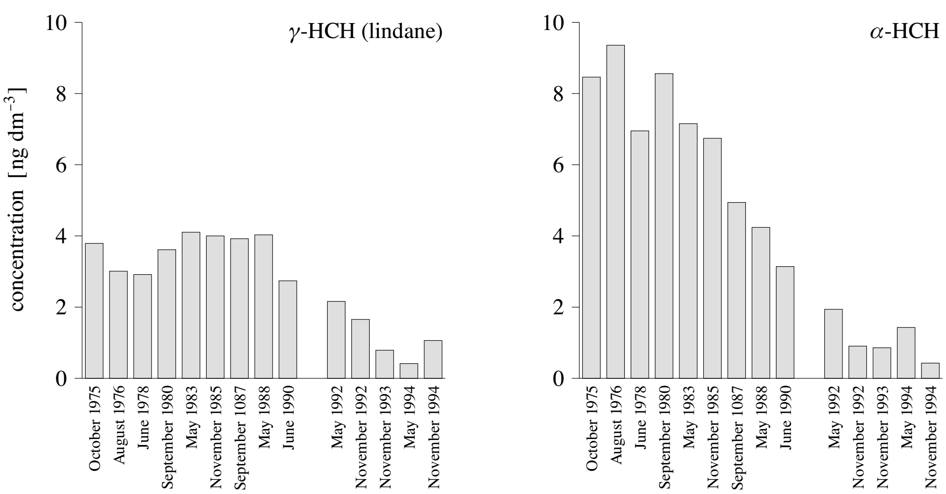


**Fig. 6.** Temporal changes in $\gamma$-HCH (lindane, left) and $\alpha$-HCH (right) in the surface layer of the Baltic Sea (after Gaul 1992 and Dannenberger & Lerz 1995)

Cod liver and muscle tissues of herring are studied for their organochlorine compound load. The monitoring programme additionally covers seals (fat extract) and the eggs of seabirds. Investigations of fish (cod, herring) and guillemot eggs, sampled in Swedish coastal waters during the period 1987–95, revealed a clear decrease of 43% for PCBs, 60% for DDTs, 78% for $\alpha$-HCH, 64% for $\gamma$-HCH and 65% for HCB on average (HELCOM 1996a). In spite of this favourable development, which has also been observed in fish from other Baltic regions, the concentrations remaining are still above those of the corresponding organisms in the North Sea and other shelf seas in northern Europe.

## 2.4. Crude oil products

Sources given for the crude-oil-product load in the Baltic Sea are shown in Table 2. River run-off, municipal sewage and atmospheric deposition account for the greatest inputs, followed by shipping, illegal oil discharges and accidents involving tankers. Refineries, oil terminals and heavy metal industries are less strongly implicated. Vapours from filling operations at petrol stations and the incomplete combustion of oil are also believed to be of relatively minor importance.

**Table 2.** Important, sources of oil inputs into the Baltic Sea (cf. Enkel 1986)

| Sources | Range (in tons per year) |
|---|---|
| municipal sewage | 3 000 – 9 000 |
| municipal storm-waters | 1 000 – 5 000 |
| refineries | 160 |
| steel rolling mills | 300 |
| other industries | 400 – 1 000 |
| oil terminals | 100 – 200 |
| operational shipping | 160 – 6 500 |
| accidental discharges from shipping | 200 – 9 000 |
| oil rigs | <5 |
| rivers | 14 000–25 000 |
| atmosperic deposition | 1 000–10 000 |
| Total | 20 000–66 000 |

Eight tanker accidents with oil spillages of more than 100 tons occurred in the Baltic Sea from 1969 to 1993 (HELCOM 1996a). Fortunately, the number of such serious accidents is decreasing. The most serious one occurred in 1981 when the m/t 'Globe Asimi' became stranded at the entrance to the port of Klaipeda in Lithuania during bad weather and lost 16 000 tons of oil.

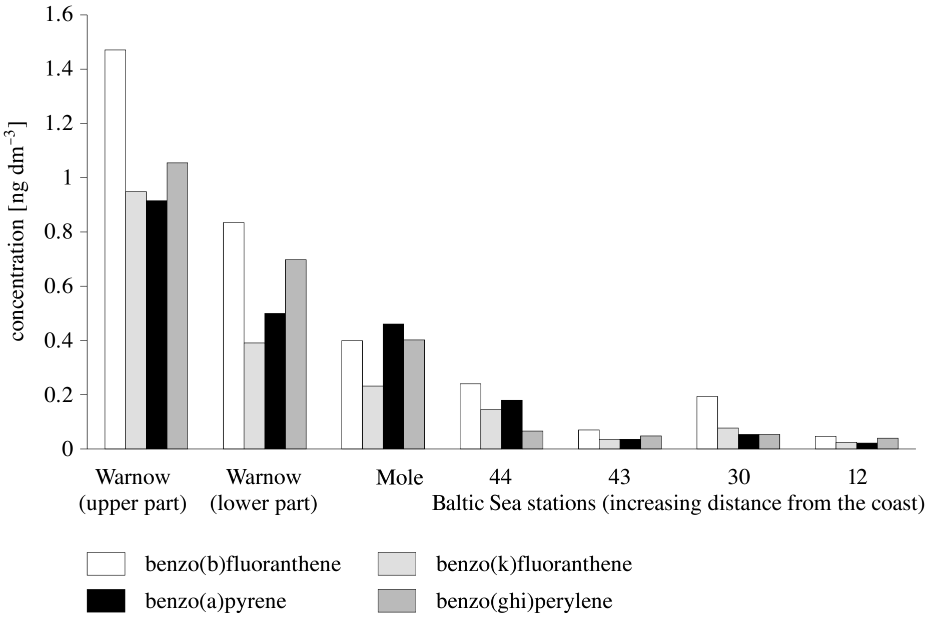


**Fig. 7.** Polyaromatic hydrocarbons in river (the Warnow) and offshore Baltic waters with increasing distance from the coast (after Witt 1995)

Crude oil contains polyaromatic hydrocarbons, which are also produced during industrial cracking processes and as the result of incomplete oil combustion. Strongly carcinogenic, they require special attention. The higher concentrations in river water than in seawater (Witt 1995), as shown in Fig. 7, underline the fact that crude oil products from inland areas contribute to the pollution of the Baltic Sea.

## 3. Environmental protection

Even at the height of the East-West confrontation, cooperation in the form of marine environmental monitoring continued between the riparian states of the Baltic Sea Area and led to important recommendations for the protection of the Baltic ecosystem. This was largely thanks to the Helsinki-Commission (HELCOM), which was founded in 1974. The aims of the HELCOM convention are to protect the marine environment of the Baltic Sea Area and also to conserve nature.

The data systematically collected in the Baltic Monitoring Programme (BMP) by the riparian countries since 1979 serve as the basis for the assessments of the state of the marine environment of the Baltic Sea produced by HELCOM every 5 years. These periodic status reports also contain recommendations serving the protection and restoration of the Baltic ecosystem. The proposals must be adopted by the Environment Ministers of the Baltic countries. Although these decisions are not binding in the sense of international law, they place the signatory states of the convention under a moral obligation to take action.

The measures adopted at the conference of Prime Ministers in Rønneby (Sweden, 1990) were of decisive importance for the restoration of the ecological balance corresponding with the conditions obtaining in the Baltic Sea in the 1930s. They are based on the recommendations of the second periodic status report (HELCOM 1990). As a first step, the measures called for the identification of pollution 'hot spots' within the Baltic Sea catchment area. A total of 132 municipal (only cities with populations exceeding 50 000 inhabitants), agricultural and industrial hot spots were identified, 92 of them in the former East Bloc countries (Fig. 8). Eliminating them will cost an estimated 18 billion EURO. These funds are being provided under a graduated plan during the period 1993–2012. The interim report prepared in May 1996 (HELCOM 1996) showed that 10 hot spots had already been eliminated and progress was being made on the elimination of another 96. Regarding the remaining hot spots, work had not yet begun or no information was available. Already one year later, 15 further hot spots had been deleted from the list, and 81 others were in the process of elimination (HELCOM 1997).

Inorganic nutrient concentrations in the offshore regions of the Baltic Sea are no longer increasing, indeed, they have even been decreasing in recent times; the changes are more pronounced in the case of phosphates than nitrates. This progress is not merely the consequence of modern waste-water treatment plants and stack gas filters being implemented, but is attributed partly to the drastic reduction in the use of fertilisers in the Baltic Sea catchment area. As Fig. 9 shows, changes in the application rate of inorganic phosphorus fertilisers are reflected in the winter nutrient concentrations between 5 and 10 years later. Similar correlations exist between the consumption of synthetic nitrogen fertilisers in the Baltic catchment area and the winter nitrate concentrations in the surface layer of the Baltic Proper (Nehring et al. 1995b).

Modern waste-water treatment plants are now equipped to eliminate phosphorus and nitrogen compounds. Phosphates can be removed fairly easily with ferric or aluminium hydroxide. But this requires refuse tips where the precipitation residues can be deposited. The elimination of nitrogen requires the use of multi-step microbial processes that include

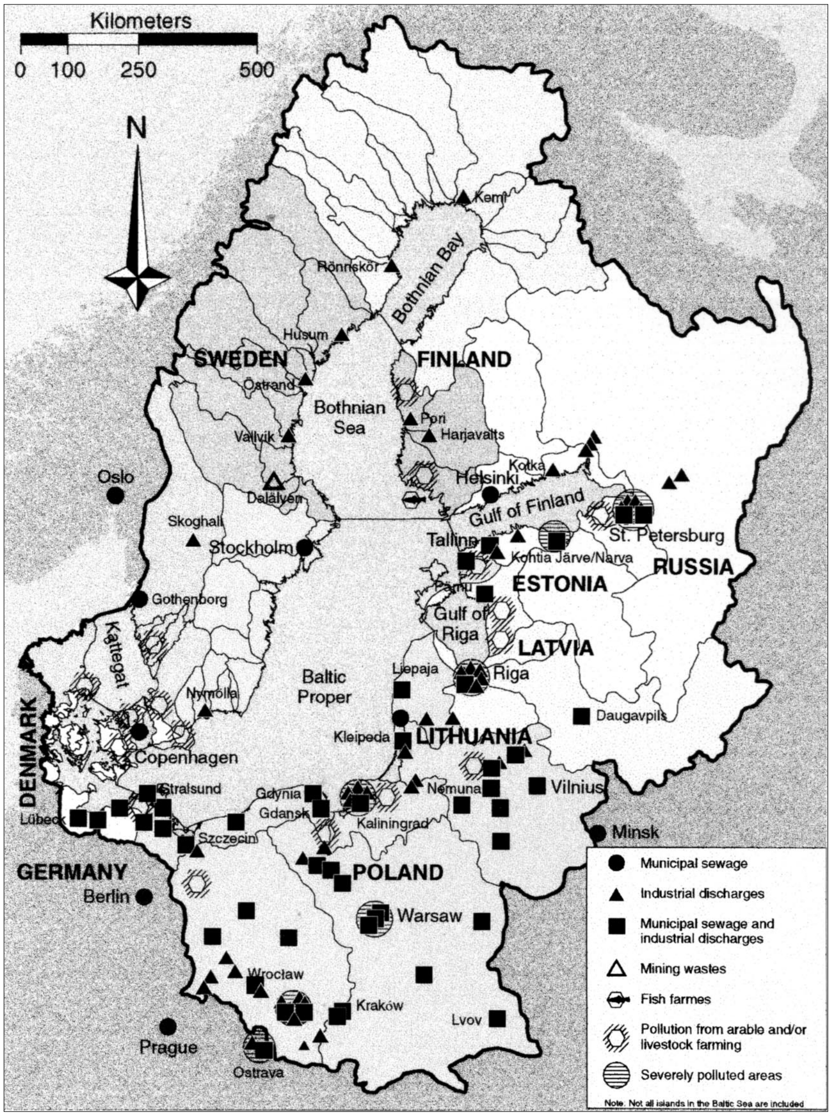


**Fig. 8.** Pollution hot spots in the Baltic Sea catchment area (HELCOM 1993)

nitrification and denitrification. The optimal solution would appear to be the combination of activated sludge and biofiltration plants, in which both phosphorus and nitrogen compounds can be removed (Strohmeier 1996). The residues from the digested sludge can be used to improve soil fertility.

The most important way to prevent diffuse nutrient inputs from agriculture consists in restricting the use of fertilisers and semi-liquid manure to the amounts needed to satisfy only the immediate demands of

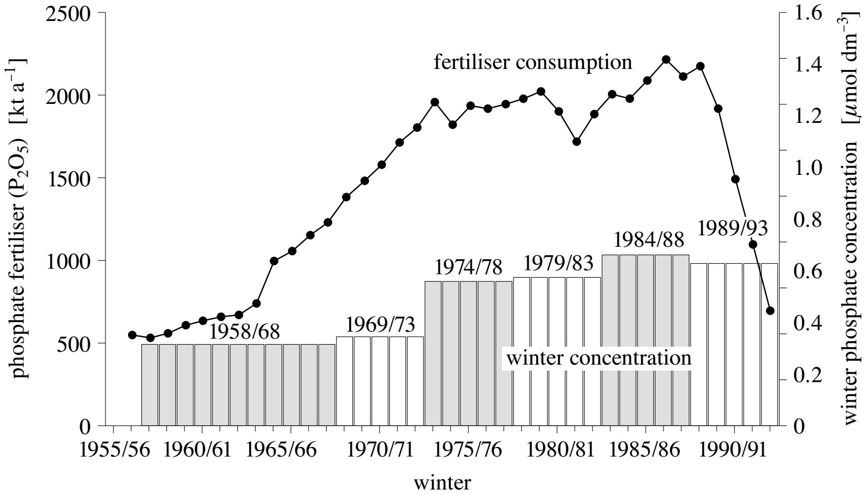


**Fig. 9.** Consumption of inorganic phosphorus fertiliser in the catchment area (calculated from FAO 1952–93) and 5(11)-year-averaged winter phosphate concentrations in the surface layer of the Baltic Proper (after Nehring et al. 1995b)

crop plants. This is particularly important in the case of nitrogen compounds because, unlike phosphates, they are not retained in the soil.

Any reductions in nitrogenous oxide emissions from motor vehicles will probably be balanced by increasing traffic in the east European countries (Enkel 1986). Therefore, only the optimisation of agricultural practice can be expected to yield a reduction in the inputs of nitrogen compounds from non-point sources to the Baltic Sea.

As nutrient loads decrease, the problem of eutrophication will gradually lose importance for the Baltic Sea area. However, dealing with the subsequent mesotrophication will be a lengthy process, as it will be impossible to reverse the changes resulting from a 60-year-long anthropogenic input of nutrients in just a few years. The incomplete elimination of non-point sources as well as the unknown residence times of nutrients make it difficult to give estimates of realistic time scales for the Baltic ecosystem. More specifically, knowledge is lacking concerning the accumulation of nutrients in, and their remobilisation from, the sediments.

Although mercury-containing fungicides have been forbidden and improvements have been made in cleaning stack gases, mercury concentrations in tissues of fish from the Baltic Sea have not appreciably diminished. Mercury accumulated in the sediments in former times, which is remobilised as a methylated compound, appears to be responsible for this.

The decreasing lead concentrations found in Baltic organisms is linked to the increasing use of unleaded petrol. This finding is in agreement with aerosol samples from the Baltic region, which also indicate lower lead concentrations (Lakaschus 1996). Cadmium, which behaves like a 'nutrient-like' element, is involved in the cycles of plankton organisms (Schneider 1995). The decreasing concentrations of this element found in the surface waters may also be linked to the eutrophication of the Baltic Sea, as well as to improved applications and processing technologies in heavy metal industries.

Restrictions and prohibitions in the application of chlorinated hydrocarbons, as well as the introduction of technologies that avoid the generation of organochlorine wastes in the paper and wood pulp industries (substitution of $Cl_2$ by $Cl_2O$), have reduced the environmental load in the Baltic Sea. Not only the prohibition of the use of contaminated lindane but also the recommendation to reduce the consumption of pure lindane is the reason that the concentrations of both $\alpha$-HCH and $\gamma$-HCH have been decreasing in Baltic waters in recent times (Fig. 6). Among the higher organisms living in the Baltic Sea area, the stocks of ringed seal and white-tailed eagle in the northern Baltic and of common seal in the Belt Sea and Kattegat have recovered (HELCOM 1996a, v. Nordheim 1997) owing to the lower concentrations of organochlorine compounds in fish, the main food source for marine mammals and seabirds. Severe hunting restrictions must also be mentioned as a reason for the recovery of the seal stocks.

The loading of the Baltic Sea area with crude oil products continues and requires special attention. Cases of illegal disposal at sea are increasing, since most countries no longer accept oil residues free of charge at their ports. The introduction of a fixed contribution to port dues covering the cost of legal disposal ashore is being considered as a countermeasure.

Oil films and carpets/slicks as well as oiled seabirds and seals arouse considerable public protest. It is hoped that more airborne monitoring will help to identify and punish the polluters. The amounts of oil residues illegally disposed often do not exceed 1 $m^3$. Although 600–700 such offences a year were recorded in the Baltic Sea Area (HELCOM 1996a), and the trend is increasing, the polluters can rarely be identified. Proposals by HELCOM to reduce shipping risks, which are particularly great due to the narrow straits and the dense traffic in the Baltic Sea Area, and improved safety standards for tankers are aimed at reducing the danger of accidental oil pollution.

The new convention introduced by HELCOM in 1992 also covers nature conservation (HELCOM 1994). The Contracting Parties nominated 62 'Baltic Sea Protected Areas' (BSPAs), some of which are not physically connected with the coast. The realisation of protective measures in these offshore BSPAs requires new strategies.

In the status report completed in 1996, it was the first time that HELCOM could strike a positive balance with regard to the decreasing environmental load in the Baltic Sea Area. Some of the reasons for this progress are the protective actions initiated by HELCOM as well as the economic collapse in some countries of the former East Bloc, the latter resulting in a sharp drop in industrial and agricultural production. However, the complete restoration of the Baltic ecosystem is only possible if the protective actions already introduced are continued vigorously and unabated. Besides international cooperation, this requires the mobilisation of funds by the governments of the Baltic countries and possibly by the EU. Although the restoration of the Baltic ecosystem is still in its preliminary stages, the measures introduced to achieve this aim can serve as an example for solving similar problems in other semi-enclosed basins and shelf seas.

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