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No. 64 A

THIRD PERIODIC ASSESSMENT OF THE STATE OF THE MARINE ENVIRONMENT OF THE BALTIC SEA, 1989-1993;
Executive Summary

HELSINKI COMMISSION
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CONTENTS

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"We have not succeeded in answering all your problems. The answers we have found only serve to raise a whole set of new questions. In some ways, we feel we are confused as ever, but we believe we are confused on a higher level, and about more important things."

Lawrence Watkin

The Baltic Sea

is one of the major brackish water basins of the world. The history of this unique aquatic system, which is a product of the last glacial period, covers about the same time scale as the development of the human beings since the stone age. The Baltic Sea has always been of great importance for the people living around it, providing a common bond as well as routes of navigation between the current nine bordering countries. Its fisheries represent a valuable part of each country's livelihood, and its waters are also a recreational resource of increasing value. Otherwise, for the almost 85 million people living in the drainage area, which is shared by 15 countries with mostly high-developed industry and agriculture, the Baltic Sea is exploited also as a huge natural waste-water treatment plant which is expected to cope with discharges of different origin and composition. The Baltic Sea ecosystem is able to assimilate some anthropogenic inputs, but recycled and more persistent compounds may, however, build up in the system with impacts on its functioning and stability.

The very specific hydrographic, chemical and physical conditions, and the geological history of the Baltic Sea explain why it hosts quite unusual aquatic biota. Both marine and fresh water organ-

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A, 1989-93

isms live side by side with a number of living relicts. Although the number of species is relatively small, some occur in abundance but most may be necessary to keep the ecosystem in balance. This is also true for sea birds and marine mammals who are endangered, *inter alia*, by virtue of their high level in the food web, and this influences their uptake of harmful lipophilic organohalogens through bioaccumulation.

The multitude and beauty of coastal landscapes around the Baltic Sea Area represents a heritage for the present society. It deserves protection against the anthropogenic pressure caused by activities in the drainage area, at the shoreline and on sea.

Public opinion about the state of the Baltic Sea is strongly influenced by the media who from time to time pick up certain dramatic events and episodes, frequently judging them in a negative ("*...The Baltic Sea is dying...*") and only occasionally positive ("*...Most of the Baltic Sea problems are solved...*") manner. Without providing at the same time necessary background information about the possible causes and the scale of those events, and how they fit into more general trends and tendencies, a misleading picture may be generated which tends to persist in the minds of the general public.

In the framework of the Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki, 1974, revised 1992), the state of the Baltic Sea is regularly assessed in about 5 years intervals. Hundreds of experts from a multitude of disciplines participate in this assessment process. The outcome is a basically scientific background document covering most of the topics related to the state of the Baltic Sea. The respective situation, trends and tendencies are highlighted. The multidisciplinary approach attempts to secure a balanced view on the different problems. As typical for any science, a compilation of today's results does not provide 'final answers' even when the Baltic Sea belongs to one of the longest and most intensively studied sea areas of the world. The assessments are understood to be a time-limited consensus which has been reached between scientists participating in very long-term studies.

The following chapters represent a balanced overview of an assessment covering the period 1989-93. Without listing a multitude of numbers, a generalised picture regarding observed and even 'missing' tendencies and trends of key factors, which seem to influence the Baltic Sea ecosystem, shall be provided. The structure of this 'condensed public version' follows in principle that of the basic assessment report, but more focussing on certain aspects. For those of the readers which are interested in more detailed information, especially on causal interrelationships, the basic 'expert' version of this assessment or other recent literature cited in that bulk document should be consulted.

Preliminary results of the 1989-93 assessment have been summarized earlier in a brochure prepared by *Lars Rahm* and *Britt Hägerhäll-Aniansson* for HELCOM under the title "The state of the Baltic Sea marine envronment" for the 'Baltic Sea States Summit' held in Visby, 3-4 May 1996. Partly, the present document, which was prepared by *Lutz Brügmann*, Sweden, is similarly orientated, but adds new viewpoints for which a year ago reliable information has not been available.

Natural conditions and their changes during 1989-93

Sub-divided Baltic Sea including the respective drainage areas.

The Baltic Sea is a young (about 10,000 yrs) epi-continental and intra-European shallow (mean depth 52 m) sea with a water volume of >20,000 km³. The drainage area (>1.7 mill. km²) is more than four times the size of the sea area (>400,000 km²). The Baltic Sea is connected to the North Sea, which is a marginal sea of the North-East Atlantic Ocean, via the Kattegat and the narrow and shallow inlets of the Belt Sea and Sound. The bottom topography separates the Baltic Sea into different basins which differ widely regarding the 'bio-geochemical climate' they create. The Gotland Basin in the central part of the Baltic Proper is separated into an eastern and western sub-basin. In the Eastern Gotland Basin, water depths up to 250 m are found.

The Baltic Sea has the character of a huge estuary in which fresh water from rivers mix with sea water to create pronounced horizontal salinity gradients. In the north, the major part of the fresh water input, in total about 450 km³ yr⁻¹, produces almost fresh water conditions in the Northern Bothnian Bay. From the south-western transition zone, i.e., from the Kattegat/Belt Sea area, sea water more or less continuously intrudes into the Baltic Sea. This sea water inflow is, however, small since it is hampered by sill depths of only 8 m (Drodgen) and 18 m (Darß) at the inlets. In addition to the sea water intrusions, the fresh water inflow and precipitation create a near-surface outflow of water with lower salinity into the Skagerrak. Altogether it takes on average about 25-35 years to exchange the water volume of the Baltic Sea as a whole. However, this overall residence time is composed of a number of different residence times for each of the basins. The longest residence times have been estimated for the Central Baltic Proper. In the Gulf of Bothnia, due to the extensive fresh water inflow, the water resides only 4-5 years, in the Kattegat only a few months and in the Belts and Sound just days or weeks.

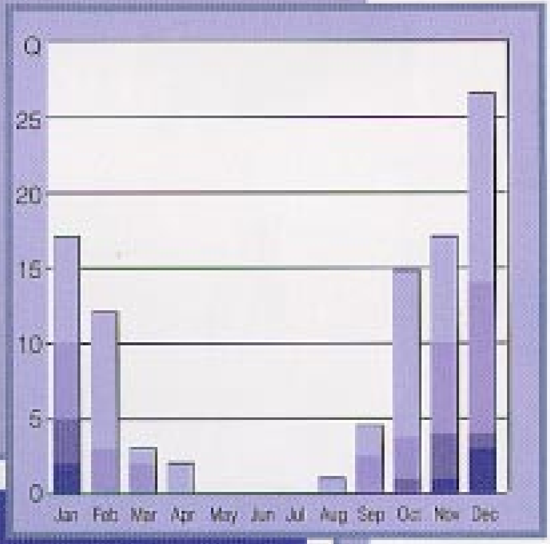
In addition to the horizontal salinity gradients between Kattegat and Bothnian Bay, there are also very pronounced vertical gradients, caused mainly by salinity but also temperature differences. A salinity barrier in the Baltic Proper and Gulf of Bothnia at depths between about 40 and 70 m, the 'halocline', separates bottom water with a higher density from a surface-water layer of lower density (salinity). During summer, a 'thermocline' develops as this provides another density barrier for vertical exchange. In autumn, the cooling of the surface water causes an entire turnover of the water column in the Gulf of Bothnia carrying oxygen-saturated water from the surface to the deeper layers, but this does not occur in the deep basins of the Baltic Proper. Here, the higher saline deep water cannot be exchanged by water from the surface layer whose density despite seasonal cooling is not sufficient for a vertical turnover. This results in stagnant bottom waters which soon become anoxic because of oxygen consumption by the mineralization of dissolved and particulate organic matter in the bottom water layer and at the surface of the sediments.

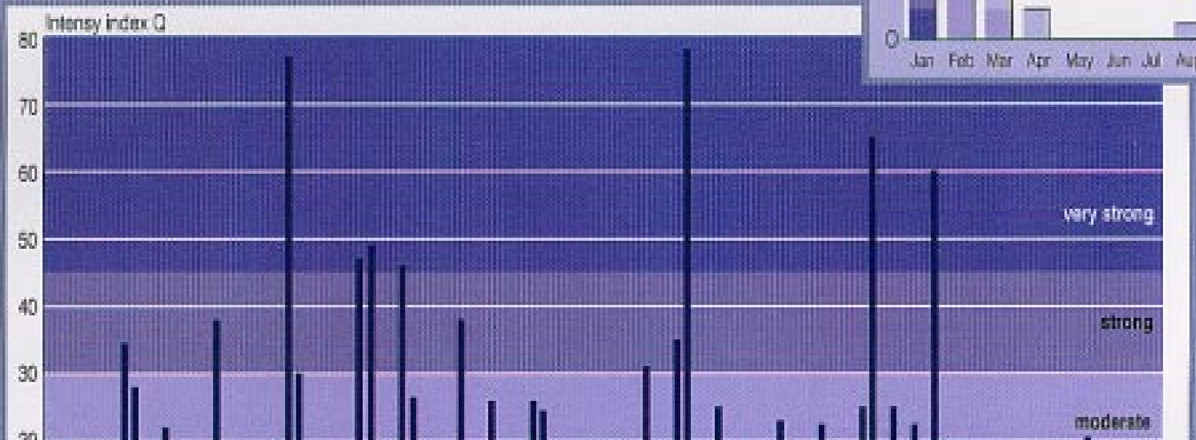
At irregular intervals, major inflows supply large volumes of highly saline and oxygen-rich waters across the entrance sills to the Baltic Sea. Only these inflows are able to renew the stagnant water of the deep basins of the Baltic Proper. How far north they proceed, replacing the water in a cascade-type manner consecutively in the Arkona Basin, Bornholm Basin, (Gdansk Basin), Eastern and finally Western Gotland Basin, depends on their 'strength'. Only the strongest of the major inflows can renew the deep water of the Eastern Gotland Basin.

Inflow events are of fundamental importance for the whole biogeochemical system. They occur mainly in groups or clusters, and about 90 events have taken place during the present century. During the cluster of years 1948-52, a maximum of 12 events was recorded. Until 1976, periods without major inflows extended to a maximum of about 3 years, e.g., during 1927-30 and 1956-59. Between 1976 and 1983, only a few major events of weak or moderate intensity occurred which were insufficient to proceed significantly to the deep water of the Eastern Gotland Basin. However, during 1983-92, i.e., during most of the assessment period, no such event was recorded. This caused drastic changes of the hydrography, hydrochemistry and the biological part of the ecosystem of the Baltic Proper. The salinity of the water decreased at all levels, most significantly near the bottom of the central deep basins, where the highest hydrogen sulphide concentrations ever recorded were developed in the Eastern Gotland Basin. On the other hand, the vertical density-layering was weakened supporting downward transport of oxygen-richer water to medium depths with previously sub-oxic conditions.

In January 1993, during a three-week period of strong westerly winds, about 310 km^3 of water, about half of which had a salinity >17 psu, entered the Baltic Sea, and this led to an increase in the mean water level by almost 0.7 m. In May 1993, the deep water of the central Eastern Gotland Basin (Gotland Deep) was partly displaced and renewed with oxygenated water. This event ended more than 16 years of stagnation, a maximum observed for this century. Further smaller inflows occurred in December 1993 and March 1994 which proceeded quickly to the Eastern Gotland Basin. There, they finally terminated the extremely long-lasting stagnation period. Oxygen concentrations measured below 170 m (3.0-3.8 $cm^3\,dm^{-3}$) were the highest observed there since the 1930s. For the first time since 1977, the whole water body of the Baltic Sea was free of hydrogen sulphide. However, this statement was only true for a limited time period around May 1994.

During the present assessment period, 1989-93, the air temperatures over the Baltic Sea were on average about 1°C above the long-term mean 1880-93. This anomaly was concentrated in winter and spring and led, *inter alia*, to a biased distribution of the annual precipitation, with larger amounts during the winter in the Scandinavian mountains. However, the respective rivers drain mainly forested areas, and their increased winter flow had a relatively low impact on the nutrient load carried by them to the Baltic Sea.





Major inflows of saline water into the Baltic Sea during the present century and their seasonal distribution (top right corner).

STEPHEN F. LINTNER

Oxygen and hydrogen sulphide

The oxygen concentration in surface waters is controlled by fluxes between sea and atmosphere, by assimilative production, and by respiration. The solubility of oxygen depends on temperature and salinity. Trends for oxygen saturation in surface waters have been reported for the 0-2 m layer of the Vistula Estuary, with +1.45 % yr^{-1} from a mean of 101.7 %. This may be interpreted as a result of increasing phytoplankton production but could also be due to meteorological or hydrographic changes.

Deep waters below the pycnoclines cannot equilibrate with the atmosphere and are generally under-saturated with respect to oxygen because of the continuous consumption of oxygen due to respiration by bacteria. Since 1977, the stagnation period has led to extremely low oxygen and high hydrogen sulphide concentrations, respectively, in the deep waters of the Eastern Gotland Basin. While the Gotland Deep exhibited hydrogen sulphide concentrations of more than 150 µmol dm^{-3}, the Bornholm and Gdansk Deeps showed an increasing frequency of events of anoxia-causing layers of the sulphur bacteria *Beggiatoa* which covered the bottom. In contrast, these systems also benefited by the oxygen supply from smaller inflow events. The series of salt water inflows starting in spring 1993 has changed the situation considerably. Temporarily, the Gotland Deep displayed relatively high oxygen concentrations and hydrogen sulphide disappeared completely. Investigations from 1994-96 showed, however, that both basins are returning to anoxic conditions.

For other areas and intermediate depths, the lack of salt water inflows improved the oxygen conditions because the bottom salinity and thus the vertical stability were reduced. Positive bottom-oxygen trends of about 0.5 % yr^{-1} in the Gulf of Bothnia have been explained by improved mixing due to reduced vertical stability. In addition, during the stagnation period, low-salinity inflows have reached the Baltic Proper and areas beyond, at water layers of the halocline and immediately below. Consequently, increasing oxygen concentrations were observed around 100 m depth in the entire Gotland Basin. The deep waters of the Gdansk Basin showed general trends of increasing oxygen concentrations. The maximum increase was observed between depths of 75 and 90 m.

Oxygen deficiencies in bottom waters are common phenomena, not only in the deep basins but also in many coastal areas with seasonal or permanent haline stratification. Here, the oxygen concentrations display a seasonal variability with minima between July and October. These minima are generally assumed to reflect the preceding phytoplankton production, though quantitative correlations are difficult to establish. In the Belt Sea, high autumn/winter fresh water run-off, which is a good measure of the riverine nutrient load, seems to induce oxygen deficiency in the bottom water during the following autumn.

Before 1988, significantly decreasing autumn bottom water oxygen concentrations were found in the Kattegat and Belt Sea. For 1989-93, both very weak decreasing and increasing trends have been found in this area. The long-term development of the oxygen situation in the coastal areas is in general agreement with the phytoplankton development and the nitrogen loads.

Inputs via run-off and atmospheric deposition

Reliable mass balances on contaminants such as persistent organohalogens, heavy metals and petroleum-derived hydrocarbons and of eutrophying substances, mainly nitrogen (N) and phosphorus (P) compounds, are needed, *(a)* to assess the present state of the environment with regard to the importance of the different sources, sinks and internal fluxes and cycles, *(b)* to indicate possible critical points and threats, and *(c)* to describe by models the present system and to be able to predict the future development.

One of the key factors of mass balances are reliable data on the input of those contaminants into the Baltic Sea. The Ministerial Declaration of 1988 called for a 50 % reduction of contaminants entering the Baltic Sea via river run-off and direct discharges from land, through atmospheric deposition, from shipping, aquaculture, offshore installations and other anthropogenic activities on sea or at the coast. Only in the case of the atmospheric and run-off load, is there sufficient reliable and spatial information for an overview on the respective amounts and possible temporal trends during the assessment period. However, this information mainly relates to the nutrients nitrogen and phosporus. Sketchy knowledge exists for selected heavy metals regarding their input via land-run-off and the atmosphere.

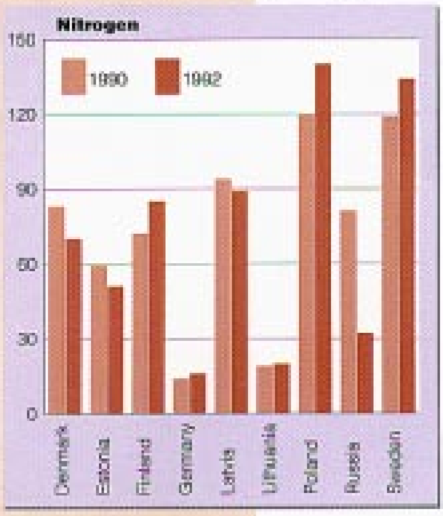
In 1985, HELCOM started periodic evaluations of pollutants entering the Baltic Sea from land-based sources (municipalities, industry and rivers). The first and second Baltic Sea Pollution Load Compilations *(PLCs)* were published in 1987 and 1993, respectively. In 1995, measurements for *PLC-3* were performed. Although, the quality of data emanating from those *PLCs* has gradually improved, the resulting information includes many gaps and may be biased, i.e., could be misleading. For instance, during the 1990 measurements for *PLC-2*, small rivers with a water flow below 5 $m^3 s^{-1}$, small settlements with less than 10,000 'population equivalents' and the diffuse inputs from the coastal zone between the monitored rivers were not considered. This also applies to by-passes and overflows. The precipitation to the drainage area is often very biased, with a major part of the annual deposition occurring in a few weeks. Without measurements of an even event-related frequency, major parts of the riverine contaminant inflow may be discharged into the Baltic Sea without being recorded.

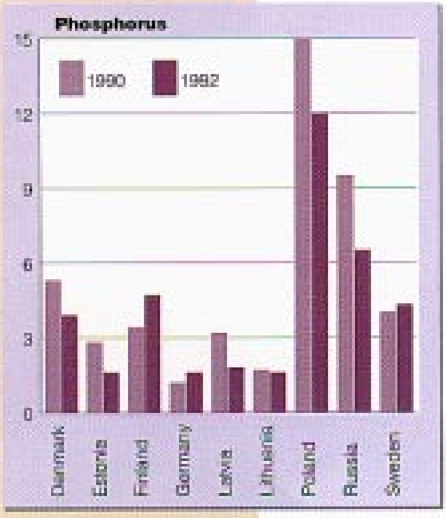
The nitrogen and phosphorus run-off from land into the Baltic Sea was estimated for the year 1990 by *PLC-2* to be 660,000 t and 46,000 t, respectively. Taking into account the missing information, these values may significantly underestimate the true situation. For the nutrient run-off, the data was considered to reasonably reflect the areal density distribution of the population, and agricultural and other potentially contaminating activities in the drainage area. As expected, the major load occurs via rivers draining southeastern and eastern parts of the drainage area which are densely populated. The riverine N- and P-inputs at the western side of the Baltic Proper and towards the Gulf of Bothnia are much lower. However, it should be noted that the Gulf of Bothnia receives a large amount of oxygen-consuming organic substances, in addition to nutrients, from discharges of the pulp and paper industry. For heavy metals, *PLC-2* estimated an annual input of >50 t mercury, >57 t cadmium, >1,300 t copper, >5,000 t zinc and >1,300 t lead. These data are less reliable than the nutrient values because of both the greater gaps in information for many regions and the more doubtful data quality.

The atmospheric load of phosphorus to the Baltic Sea is almost negligible. Not so for nitrogen where about 20 % (Gulf of Finland, Belt Sea, Kattegat, Sound), 30 % (Gulf of Bothnia), and even 40 % (Baltic Proper) of the total load is 'airborne'. During 1986-90, about 300,000 t N yr^{-1} reached the Baltic Sea by wet and dry deposition with little inter-annual variations. About 40 % of this input consisted of the reduced forms of nitrogen, mainly ammonium, the remaining part occurring in oxidised (NO_x) forms. Combined emission/input models estimated that only 65 % of the nitrogen input originated from countries bordering the Baltic Sea. Other prominent contributors were Great Britain, France, the Netherlands and the now Czech Republic.

Quantitative data on the atmospheric input of heavy metals into the Baltic Sea are very scarce and therefore it is only possible to make estimates of the inputs of a few elements, especially lead. A reasonable estimate for the lead deposition during the latter half of the 1980s, derived from both measurements and models, seems to be 1,300 t yr^{-1} with about 70 % of this caused by the riparian countries.

Nutrient discharges into the Baltic Sea in 1990 and 1992 (in kt yr^{-1})





CHRISTOF HERMANN

Nutrients and eutrophication

Nutrients in the Baltic Sea environment do not pose any direct hazardous effects on marine organisms or individuals. On the contrary, their absence would stop growth and production. However, excessive or unbalanced nutrient concentrations may affect the balance of the ecosystem. These impacts can also be magnified by unfavourable hydrographic conditions. Excessive primary production, oxygen deficiency and finally formation of hydrogen sulphide during decomposition and remineralization of the biomass are the main concern in many areas. The nutrient concentrations *per se* do not determine the eutrophication level, it is the specific load, i.e., the ratio between the input and the budget of the ecosystem that determines this factor. The level of the primary production is mainly controlled by the concentrations of inorganic phosphorus and nitrogen compounds and of silicate. In the event that their ratio to each other is not in the optimum range of their uptake by the plankton, one of these nutrients may limit the production. However, a deficit in inorganic nitrogen compounds may be compensated for by cyanobacteria which are able to take up molecular nitrogen.

The majority of the Baltic Sea areas is characterised by a surplus of phosphorus relative to the *Redfield* N:P-ratio of 16, thus the phytoplankton production is mostly nitrogen-limited. Phosphorus limitation plays an important if not dominating role in the Bothnian Bay, in the western coastal areas of the Bothnian Sea, in the Gulf of Riga and in some local areas. Taking into account the additional loads of nitrogen from the atmosphere and by nitrogen fixation, this nutrient is the variable of highest concern with respect to considerations on eutrophication in the Baltic Sea. Silicate exhibits pronounced seasonal concentration patterns but seems not to limit the production.

The horizontal nutrient distribution in the euphotic layer during 'winter', i.e., before the regionally different onset of the spring-diatom bloom, is characterised by pronounced regional differences. The nitrate concentrations decrease from high levels in the Kattegat/Belt Sea area (6-9 µmol dm^{-3}) along a transect through the Bornholm and Gotland Seas (about 4 µmol dm^{-3}), while the phosphate concentrations are rather uniform (0.6-0.9 µmol dm^{-3}). Areas influenced by coastal sources reveal elevated concentrations, e.g., the Mecklenburg Bight, Gdansk Bight, Bothnian Bay and the eastern Gulf of Finland.

The vertical nutrient distribution depends strongly on the regional hydrography. In general, haloclines are also 'nutriclines', separating surface water with low concentrations from bottom water with enriched concentrations. As the remineralization takes place mainly in the deeper and bottom layers, the deep layers represent nutrient reservoirs. However, in layers below a redoxcline, inorganic nitrogen is rapidly removed by denitrification, while phosphate becomes enriched through releases from sediments.

The seasonality of the nutrient concentrations is determined by the annual development of the phytoplankton production. This production is qualitatively rather similar throughout the Baltic Sea, showing a bimodular curve, with a short peak-spring bloom of diatoms and a broader maximum in the late-summer to autumn following the bloom of other species. During the spring bloom, the nutrient concentrations decrease to low or zero levels, indicating an exponential growth phase. This low level is maintained until autumn when the fluxes of regenerated nutrients into the photic layer exceed the consumption during primary production. The fluxes of regenerated nutrients into the photic layer continue and the concentrations rise, reaching their winter plateau in the central parts of the Baltic Proper in the following year.

Analyses of the long-term trends of nutrients in surface water of the Baltic Sea should be based on measurements during the less productive season and must cover periods of more than 10 years to take into account intra- and inter-annual variabilities. The winter concentrations of phosphate and nitrate show positive overall trends in the surface layer of all subregions of the Baltic Proper for the period 1958-93 and 1969-93, respectively. These trends mainly result from the considerable increase between 1969 and 1978. In contrast to phosphate, the increase of nitrate continued until 1983. Thereafter, the concentrations of both nutrients fluctuate strongly at a high level without significant trends.

In the Landsort Deep area, the increase of phosphate- and nitrate winter concentrations continued in the recent assessment period. Also in the Gulf of Bothnia, both total and inorganic nitrogen concentrations continued to increase. Total phosphorus also showed a long-term increase in all areas except the Bothnian Bay. The reason for the increase was primarily the high riverine discharge during the 1980s.

In the Gulf of Riga, the situation is different. The nitrate values dropped sharply in the 1990s due to lower land-based impact. As a result, the highest phosphorus values appeared during 1989-93; these were caused by both the increased release from sediments and the reduced uptake in the water column by the plankton.

In the intermediate water layers of the Bornholm Basin and of the Eastern and Western Gotland Basin, the nitrate concentrations increased significantly during all of the previous assessment periods. Probably as a consequence of eutrophication, the silicate concentrations decreased significantly during recent decades in all depths below the halocline of the Baltic Proper. Decreasing silicate concentrations were also found in the Kattegat, Kiel Bight, Gulf of Riga and Gulf of Bothnia.

The trends of phosphate and inorganic nitrogen in the bottom-water layer of the deep basins are mainly caused by variable redox conditions. In the course of long stagnation periods, those phosphate fractions which are potentially remobilizable from the sediments may become exhausted. This limits the phosphate accumulation not only in the bottom water layer, but possibly also in intermediate depths. In the absence of and at very low concentrations of oxygen, nitrate and nitrite are consumed as oxidising agents for organic material. Parallel to this process, the ammonium concentrations increase. However, as an overall consequence of the biogeochemical processes occurring in stagnant deep waters of the central basins of the Baltic Sea, the pool of inorganic nitrogen compounds will be degraded significantly by denitrification.

In the Baltic Proper, with its mainly nitrogen-limited organic production, the wash-out of nutrients from arable land may be the most important source for eutrophication. For instance, the averaged phosphate- and nitrate winter concentrations in the surface layer of the Central Baltic Proper were compared with the synthetic phosphorus and nitrogen fertilisers annually consumed in the drainage area of the Baltic Sea. Taking into account a delay of five to ten years, a correlation between the increase of those figures could be shown. However, despite first hints for decreasing nutrient winter concentrations in the Arkona and Bornholm Seas, in the Gulf of Riga, and especially in several coastal regions, the drastic reduction of the fertiliser consumption since 1989/90 is not yet significantly reflected in the Baltic Proper. This could be due to the slow 'reaction time' of this huge offshore-water body on input changes. Another reason could be that the major part of the agricultural nutrient input into the Baltic Sea may not be due to the surplus of the applied synthetic fertilisers. In 'modern' agriculture, the 'natural fertilisers', such as liquid and solid manure from intensive stockbreeding, is no longer considered as a part of a balanced production cycle. Instead, it is actually a waste produced in huge amounts and dispersed legally over the land. The nutrient input from these practices may not have been decreasing within the last decade as probably the input derived from synthetic fertilisers did.

Nitrate + nitrite (NO) and phosphate (P) winter surface concentrations (*µmol dm⁻³*) in the Baltic Sea, 1989 – 93.

Pelagic biology

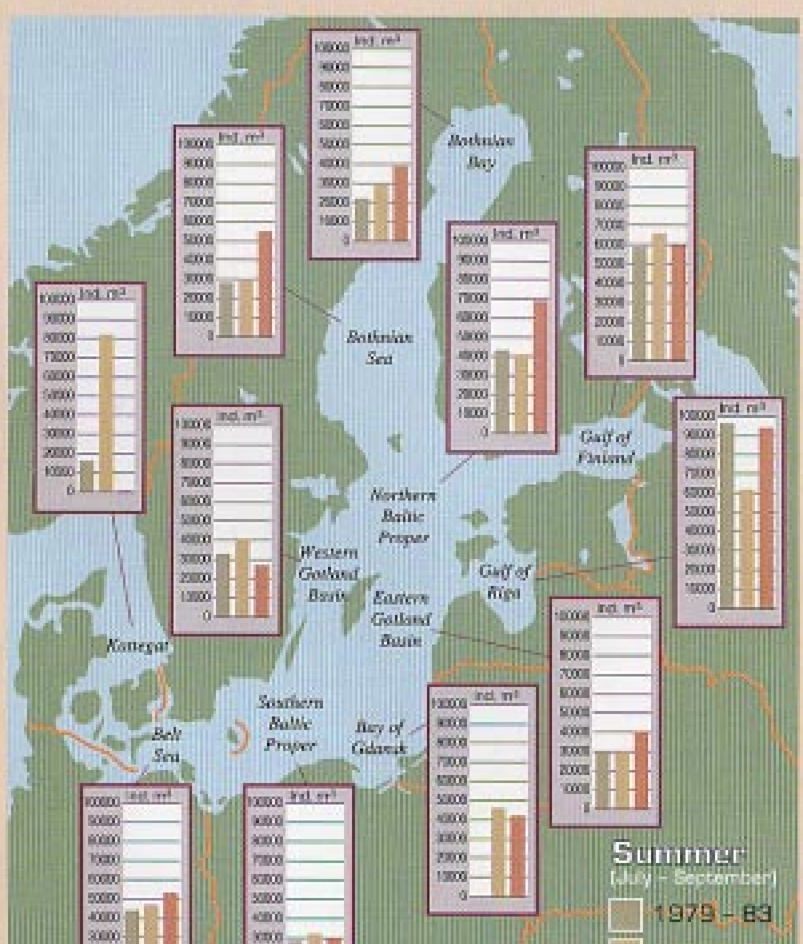
The Baltic Monitoring Programme (BMP) on pelagic biology comprises measurements on chlorophyll *a*, primary productivity, biomass and species composition of phyto- and zooplankton and, tentatively, on the production and biomass of bacterioplankton. The resulting data will provide information about the state of the ecosystem, i.e., its structure and signs for eutrophication. Due to pronounced and short natural temporal- and spatial-scaled variability, the BMP phyto- and bacterioplankton primary data collected from the open sea have only a very limited value for trend analysis. The low frequency of measurements excludes reliable trend assessments. In addition, there are methodological problems which complicate the comparability of data from different sources. However, besides phytoplankton, also bacterioplankton constitutes an important part of the biota and of material fluxes within the Baltic Sea. The bacterioplankton variables may be especially valuable for monitoring purposes in waters receiving marked riverine discharges.

In relation to regional differences, the Gulfs of Riga and Finland exhibited significantly higher chlorophyll concentrations in spring and summer than the Baltic Proper during 1979-93. This probably reflects the higher specific nutrient load to those areas. The bacterioplankton data showed large seasonal and spatial differences, but do not yet allow conclusions about general regional patterns. The species composition of the phyto- and zooplankton reflected the differences in salinity and in the duration of the growth period between the different areas. In summer, the highest zooplankton abundances were recorded for the Gulf of Riga. The lowest abundances were observed in the central and southern parts of the Baltic Proper.

With respect to long-term variations, there were no major differences in the dominance of phytoplankton species between the three assessments periods 1979-83, 1984-88 and 1989-93, except that during 1989/90 in the Bornholm and Southern Gotland Basins the proportion of diatoms in the spring bloom decreased and this benefited the flagellates. This may be due to the mild winters or to an exhaustion of silicates during the latter part of the bloom. With the exception of the Gulf of Riga, coherent patterns of eutrophication could not be demonstrated in the plankton community. The only significant trend observed was an increase in chlorophyll *a* during summer in the Bothnian Sea. However, this could not be confirmed by data on the phytoplankton biomass or carbon fixation from that area. This was in accordance with the lack of negative trends of oxygen concentrations in the deep layers of the Bothnian Sea. The low sampling frequency and the high variance of pelagic variables resulted, however, in a low statistical *power* hampering the detection of trends.

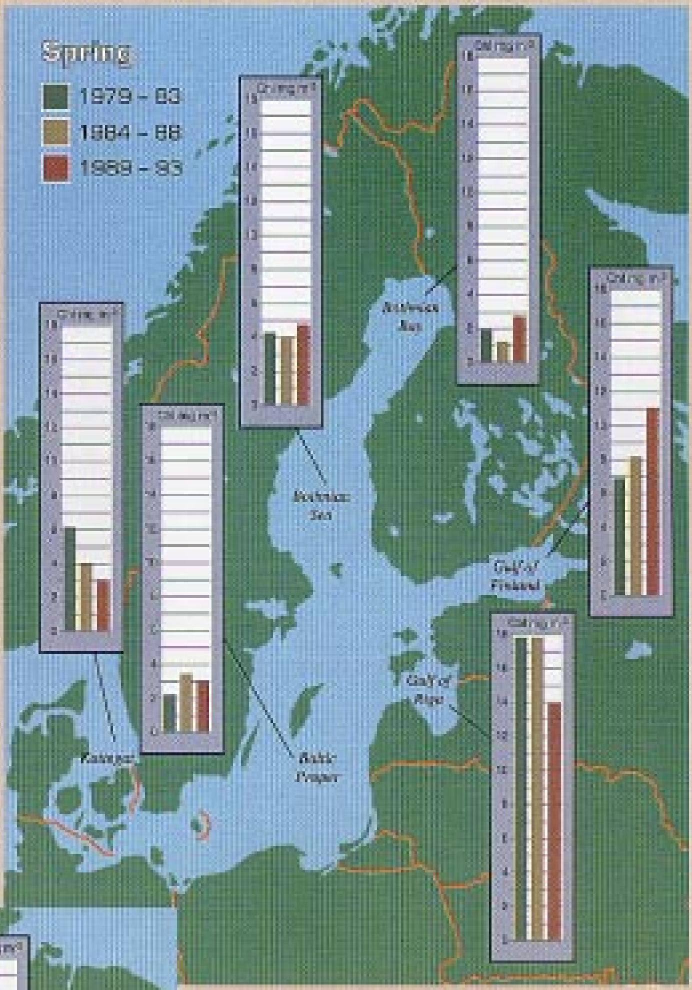
The decrease of the N/P-ratio within the nutrient pool of a marine area may cause a higher frequency of blooms of the nitrogen-fixing cyanobacteria. This mechanism could have contributed to the occurrence of intense cyanobacteria blooms in the Gulf of Riga during the early 1990s.

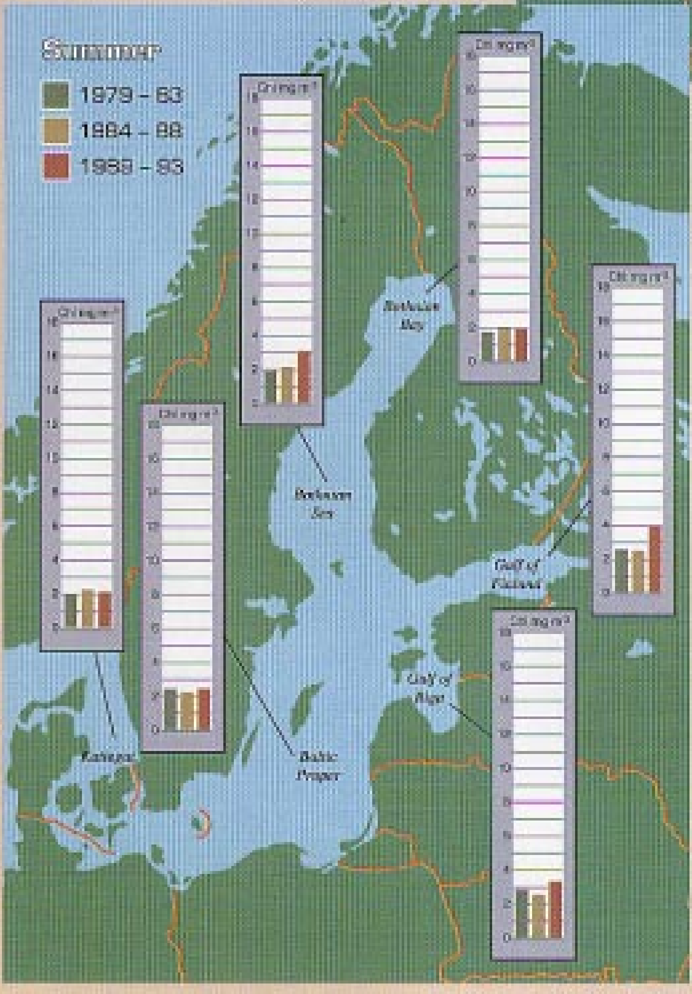
Until the 1950s, the total abundance of zooplankton decreased from the southwestern parts of the Baltic Sea towards the oligotrophic eastern and northern regions. This pattern has changed with eutrophication. During previous assessment periods, the summer abundance of zooplankton in the surface waters of the Gulf of Finland and the Northern Baltic Proper was found significantly higher than those in the remaining parts of the Baltic Sea. Additionally, during the 1980s, the Åland and Archipelago Seas showed increased zooplankton concentrations. During 1989-93, there was now a coherent area, including the Northern Baltic Proper, Gulf of Finland, Åland, Archipelago and Bothnian Seas, with abundances about one third above the average for the other

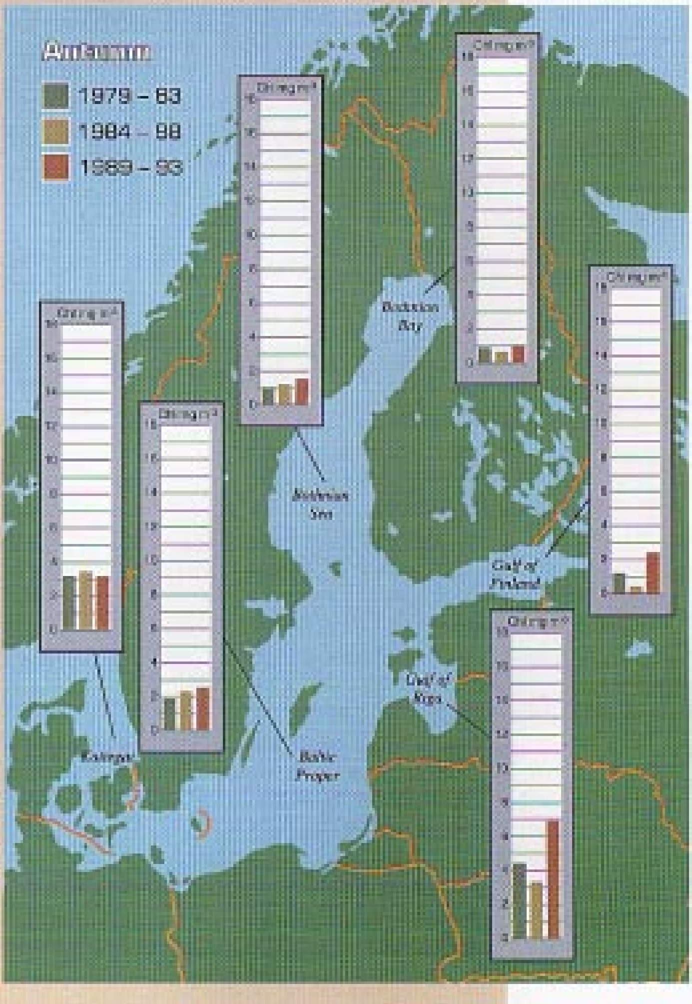


Mean total mesozooplankton abundance in the surface water layer of the Baltic Sea, averaged by areas and monitoring periods. (Summer) regions. In the Baltic Proper, from 1984-88 to 1989-93, the decreased salinity during the stagnation period led to a shift in both the species numbers and dominant species. For instance, the species numbers in the Northern Baltic Proper and Gulf of Finland increased due to the expansion of euryhaline and fresh water species. Rotifers can react very quickly to an increasing food supply. The increase of this species during 1989-93, compared with that during the previous assessment periods, can be interpreted as a sign of a changing trophic state and/or as a reflection of mild winters and a decreasing salinity.

The occurrence of two particular zooplankton species in the Baltic Sea is noteworthy. *Acartia tonsa* was introduced to the south-western parts of the Baltic Sea during the 1930s, and has now spread to the central basins of the Baltic Proper. Since 1992, the cladoceran *Cercopagis pengoi* invaded the Gulfs of Finland and Riga. This carnivorous species, which originates from the Caspian and Black Sea regions, may play an important role in the pelagic food web.







Mean chlorophyll *a* concentrations in surface waters of different areas of the Baltic Sea, shown for the three periodic assessment periods and different seasons.

RIITTA OLSONEN

Harmful algae

Among the 5,000 species of marine phytoplankton, 75 to 150 may cause harm by poisoning human seafood, killing fish and other organisms, and can affect the recreational use of coastal waters through its blooms. In addition to its toxic effects, the algae may also be harmful to fish by clogging their gills and by causing oxygen deficiency in water during its decomposition.

It has been estimated that on a world-wide basis, there are annually up to 150,000 cases of human poisoning from toxic algae. Spatially, harmful algal events have significantly extended during the last decades. In the Baltic Sea, about 30 phytoplankton species have been proved to be harmful. The most common among them is the nitrogen-fixing blue-green algae (cyanobacteria). Almost every summer they form spectacular blooms which can cover up to 60,000 km², i.e., about 15 % of the total area, as shown by satellite imagery. There are scientific reports of such blooms in the Baltic Sea dating back to the mid-1800s, and toxic events and poisoning caused by blue-green algae have been documented since the early 1960s. Fish and sea birds, and even cattle and dogs have died from intoxication, and humans have suffered from stomach complaints, headaches, inflammation of the eyes and allergic reactions.

Many species of dinoflagellates produce toxins which may bioaccumulate within the food chain. As a result, mussels, which are filter feeders, may become unfit for human consumption. To date, the most spectacular event was the blooming of a small flagellated chrysophyte, *Chrysochromulina polylepis*, which covered an area of 75,000 km² in 1988 in the Skagerrak, Kattegat and Sound. The environmental and economic impact of this bloom was considerable, causing for example losses for the fish-farming industry and directly killing a range of marine organisms through both toxic and physical effects.

Harmful algae species are a natural component of the Baltic Sea ecosystem. Observations on their spatial and temporal occurrence may be biased by the intensification of such studies during the last decade. Nevertheless, there are indications that the frequency, the areal coverage and the strength of harmful blooms in the Baltic Sea may have increased. This may be partly due to changes in the seasonal availability of nutrients, both in terms of concentrations as well as in their ratios to each other.

Benthic biology

The mean total abundance of the benthic macrofauna was rather similar in the Gulfs of Bothnia, Finland and Riga, and in the Kattegat and Belt Sea. In contrast, the macrofauna biomass, which is a good predictor of the secondary production, was much lower in the Gulfs compared with the western parts of the Baltic Sea. This difference may be due to different eutrophication levels and/or a different degree of coupling between the pelagic and benthic production. In the basins of the Baltic Proper, the abundance and biomass of the macrofauna were generally low, most likely due to adverse oxygen conditions.

In the Gulf of Finland and at the slope of the Eastern Gotland Basin, the oxygen conditions improved during 1989-93. Consequently, these areas, previously classed as 'dead bottoms', were recolonised by macrofauna. For other areas, which were already defaunated before 1989, and for the previously faunated areas, no general changes were observed for this assessment period. Considering the macrofauna development since the 1970s in the faunated areas, the increasing trend in biomass has levelled out. In the Kattegat, the abundance of crustaceans and polychaetes decreased since the beginning of the 1980s. The abundance and biomass of these two animal categories in the Kattegat and Gulfs of Bothnia and Riga showed a bimodal pattern with peaks in the early 1980s and in the late 1980s/early 1990s. Changes in external, large-scale factors like climate and/or eutrophication are thought to be one reason for this pattern. It is hypothesised, that there is a causal link between climatic changes - altered land-run-off-mediated nutrient input to the sea - differences in phytoplankton biomass, especially of the fast-sinking diatoms - and altered food supply for the macrofauna. The decreasing diatom biomass in spring, observed during the late 1980s in the Kattegat, and also partly in the Bornholm and Gotland Basins, may be caused by either insufficient nutrient concentrations, an unfavourable N/P-ratio, and/or silica deficiency in surface waters. The connection between macrofauna and diatoms is supported by correlative evidence from the Kattegat, but it is at present premature to establish a cause for the observed pattern. This should be an important topic for future studies.

Macrophytobenthos is not a part of the Baltic Monitoring Programme. Information from the previous assessment period is scattered and therefore precludes an assessment of changes since 1984-88. However, several data sets on benthic vegetation exist, enabling comparisons over longer time periods.

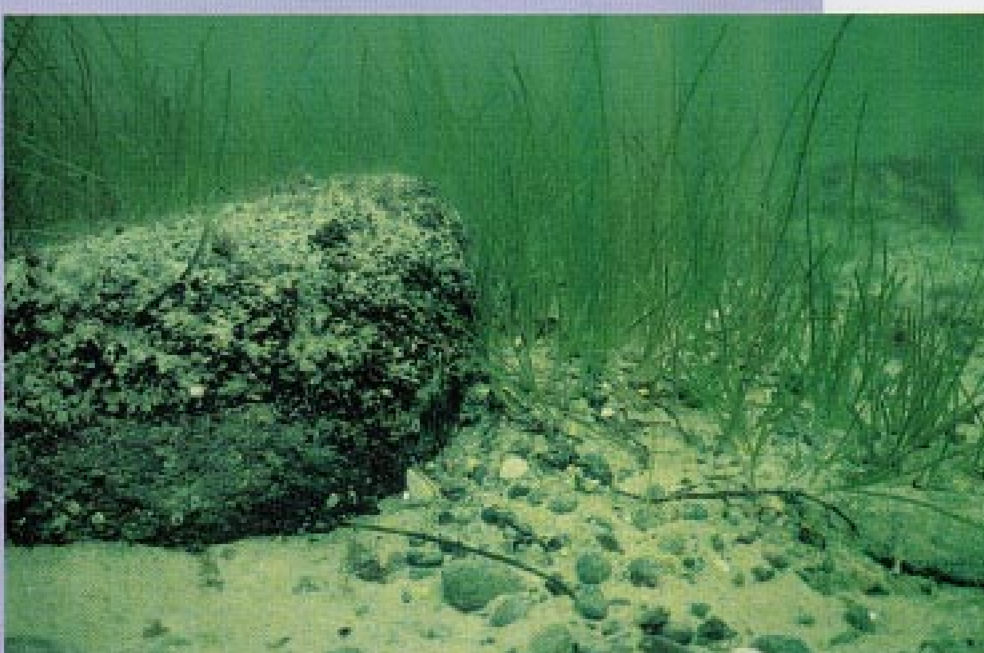
In the Kattegat and the Belt Sea, two major changes were observed in this century, *(a)* a decreasing depth distribution of eelgrass *(Zostera marina)* and other perennial macroalgae, and even the disappearance of one *Fucus* species in some parts of the Belt Sea and the southern Kattegat, and *(b)* an increased coverage by quick-growing epiphytic or drifting algae, which are favoured by nutrient enrichment. Both types of changes have been attributed to increasing nutrient loads, which decreased the light penetration as a consequence of increased primary productivity in case *(a)*, and increased the nutrient concentrations in case *(b)*.

In the Gulf of Bothnia, the major feature was a decreased coverage and depth distribution of the perennial bladder wrack *(Fucus vesiculosus)*, and an increased coverage of fast-growing filamentous algae in the Archipelago Sea and in the Åland Archipelago. These changes took place between the 1960s and the 1980s, and were attributed to increasing eutrophication. In the Gulf of Finland, great changes in the littoral systems on the Finnish coast were observed and attributed to a changing degree of eutrophication. The bladder wrack declined in the late 1970s and recovered in the late 1980s/early 1990s. The previously dominating littoral vegetation seems to some extent to have been replaced by drifting algal mats of filamentous algae like *Cladophora* spp. Similar changes were reported from the Estonian side of the Gulf. In the Gulf of Riga, a decrease in diversity was reported, with the green algae *Cladophora glomerata* increasing in importance over the last 30-70 years. Finally, along the coasts of the Baltic Proper, especially in the Gdansk Bight and Greifswald Bodden, a general feature is a decreased depth distribution of the phytal zone in recent decades. In some of the southern and eastern parts of the Baltic Proper, the biomass of *Fucus* species and of *Zostera marina* were considerably reduced. Increased dominance of filamentous algae (*Ectocarpus* spp.) has been reported from the Polish coast.

The information available on macro-phytobenthos strongly suggests, that general changes have taken place during the recent decades along the coasts of virtually the whole of the Baltic Sea area. The depth distribution of perennial macrophytes, attached to the bottom, has decreased, and short-lived filamentous or thin-bodied epiphytic or drifting algae have become increasingly important in recent time. These changes are most easily explained by a higher input of nutrients, with increased primary production as one consequence (eutrophication), during this period.

The consistency of the reports and the apparent significance of the observed changes call for a serious consideration whether or not macrophytes should be part of a future HELCOM monitoring programme. However, since most of the information so far is 'soft', in some cases even anecdotal, further work is needed to standardise the methods, to make the observations more objective than they have been to date.

Eelgrass *Zostera marina* (above) and *Fucus vesiculosus* (below).



W. PACZYNSKI

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Heavy metals

Metals may affect marine ecosystems in two different ways. As 'heavy metals', they may be harmful to marine organisms and, following transfer and accumulation via the food web, may even constitute a problem for man. On the other hand, numerous trace metals have, as 'nano-nutrients', essential functions within the food web. There is increasing evidence from marine areas outside the Baltic Sea, that temporal deficiencies of metals such as iron and zinc may limit the production of phytoplankton. It has been hypothesised that an over-supply of other metals, or changes in their respective ratio, may influence the plankton species composition, including the occurrence of 'unusual blooms'. Field studies related to the essential and production-limiting effects of trace metals are still very low in number, and even missing for the Baltic Sea, whereas measurements of the concentrations of 'heavy metals' are quite intensive within monitoring programmes.

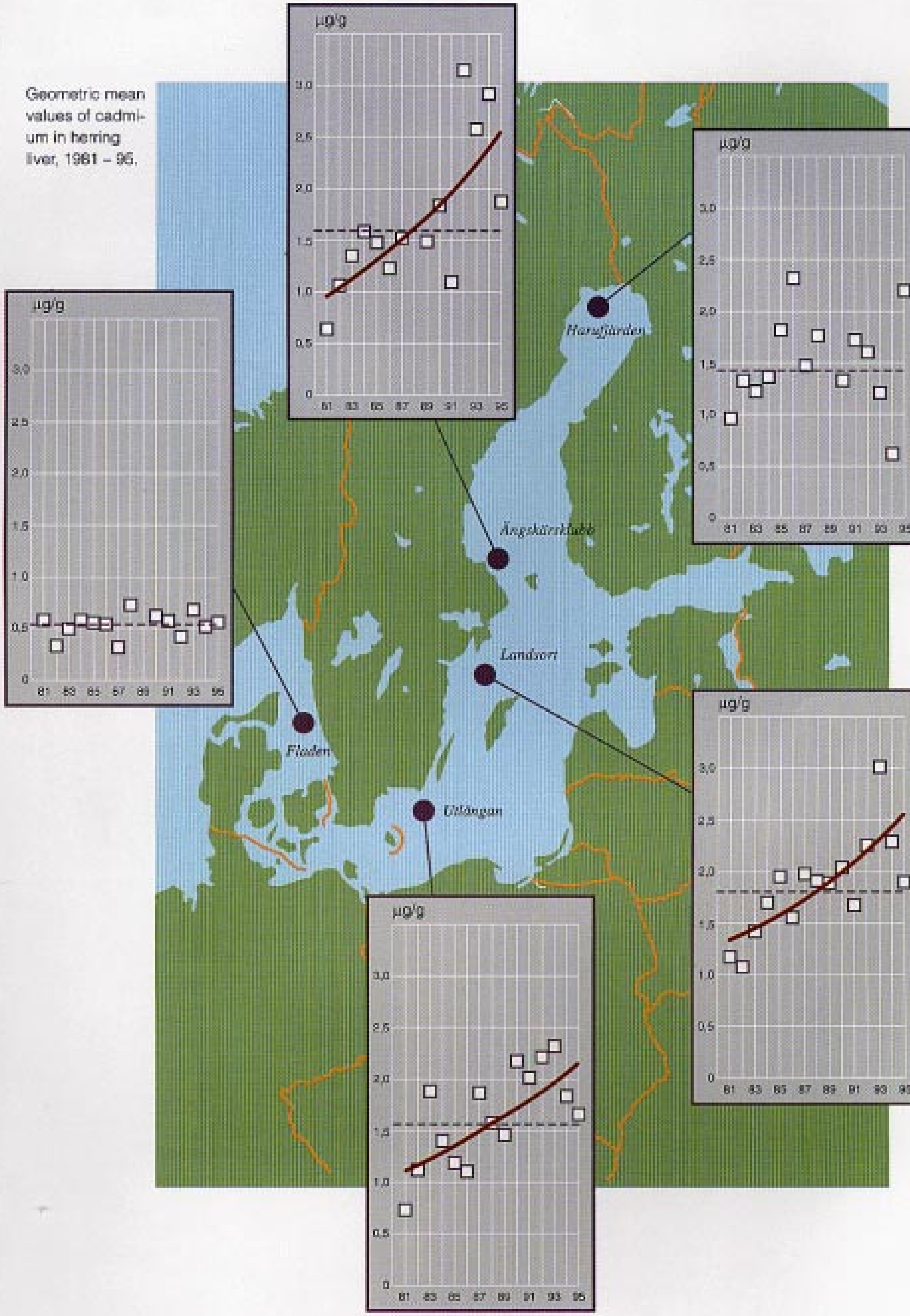
Within the BMP, mercury, lead, cadmium, copper and zinc have been defined as those heavy metals to be monitored with high priority in different matrices, i.e., obligatory in the tissue of selected organisms, voluntary in water, and through repeated baseline studies in sediments. The first of the sediment baseline studies was performed in 1993. Samples were taken from all major net-sedimentation areas of the Baltic Sea and analysed, *inter alia*, for metals. These results will be available soon and will certainly provide valuable information for the assessment of the areal distribution of metals in surface sediments and the geochronology of the metal load into the different sub-basins.

A statistical analysis of metal concentrations, determined in Baltic Sea waters during 1980-93, revealed significant decreasing trends for cadmium and copper of about 7 % and 5-6 % yr^{-1}, respectively, in the Mecklenburg Bight, Arkona Basin and, above the halocline, in the Bornholm and Gotland Seas. For zinc and for samples taken below the halocline in the Bornholm and Gotland Seas, no significant trends were observed. It must be remembered that the relatively low number of samples, several changes in the methodology and unsufficient quality control may have affected the trend detection. However, data in the literature seem to confirm the observed trends. The reason for the decreasing concentrations of cadmium and copper may be the effects of reduced inputs via rivers and/or the atmosphere. Recent investigations revealed a drastic decrease of the atmospheric concentrations of cadmium and other trace metals since 1986. As a consequence, it is also likely that the atmospheric deposition will have decreased. On the other hand, it is also conceivable that eutrophication has caused increasing production of settling particles, to which metals have become adsorbed, and thus an enhanced removal of metals from the surface layer.

Because of the obligatory status of heavy-metal studies in biota, around 165 data series from the Baltic Sea, covering the period 1979-94, were available from Denmark, Finland, Poland and Sweden for a statistical trend assessment, which was performed by an expert group of ICES. The matrices primarily analysed were fish muscle and liver tissue, mainly from cod and herring, but also from flounder and dab. For lead, some indication was found for a decline of the levels in biota. This confirms the earlier findings that lead concentrations had declined in the water. For mercury, the available information was partly rather scattered. For different time spans and areas, the concentrations showed both increasing and decreasing trends. Recently, low levels of mercury, but increasing with about 4 % yr^{-1}, were observed in the Baltic Proper and Kattegat. Higher mercury levels prevailed in the Sound and the Gulf of Bothnia. The available information on copper and zinc was inconclusive since both elements are regulated within tissues and organs.

Contrary to the decreasing trend in water for the same period, data on the cadmium content of herring liver collected from the Baltic Proper and the Bothnian Sea 1981-94 showed a significant increase of 5-8 % yr^{-1}. This may be disturbing for the experts and possibly alarming for the public, despite the fact that for other areas and species, e.g., cadmium in cod liver collected southeasterly from Gotland, significant decreasing trends have also been found. In the absence of sufficient reliable information about the spatial and temporal development of total concentrations, and on the speciation of cadmium in water, plankton and herring muscle, one can only speculate about the reasons for this unexpected trend.

Geometric mean values of cadmium in herring liver, 1981 – 95.



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Oil pollution

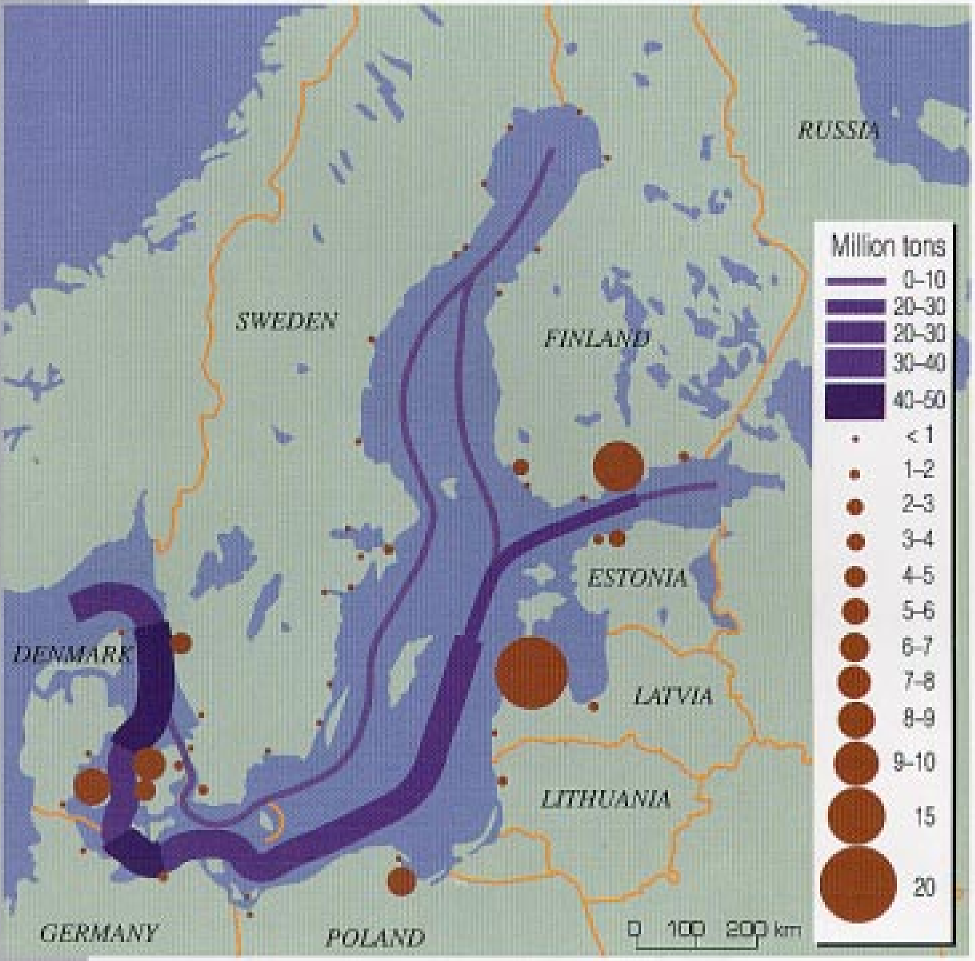
Petroleum-derived hydrocarbons in the Baltic Sea environment stem from different sources, and are composed of a multitude of single substances which give rise to different problems. It is difficult to trace them back to their sources and to quantify them properly. To separately measure all of the different substances in the 'oil', requires considerable effort, and this can only be justified for selected samples. On the other hand, however, the much cheaper and commonly used UVF-monitoring method determines the 'oil concentration' solely on the basis of one specific physical property, i.e., the fluorescence, of a small fraction of the total hydrocarbon mixture. In spite of this limitation, the UVF-method has provided comparable results when applied by different laboratories. However, the true 'oil content' of environmental samples may both be under- or over-estimated by this method. Not surprisingly, the presently available monitoring data do not allow any conclusion about trends of oil concentrations in Baltic Sea waters.

The biologically most harmful substance group within the petroleum-derived hydrocarbons are the polycyclic aromatic hydrocarbons (PAHs). They occur in tiny amounts within fossil oils, and are mainly anthropogenic products of many combustion processes with oil-products or coal, but can be synthesised by micro-organisms. The number of substances belonging to this group is comparatively low. They can be reliably separated and measured with high sensitivity, and their mainly anthropogenic origin makes them a potential monitoring tool. Unfortunatelay, the limited number of available data prevents conclusions being made about temporal trends. Their spatial distribution patterns, however, suggest that concentrations in the Baltic Sea are about three times higher than those in the North Sea, and that atmospheric deposition is the main source of these compounds.

It is difficult to estimate not only the concentrations in the Baltic Sea but also the input of oil-related compounds into this aquatic system. Exploration and exploitation of oil in the Baltic Sea is a minor input source due to *(a)* the low number of related activities, *(b)* the relatively high technological and protection standards on those platforms, and *(c)* the fact that Baltic oil unlike North Sea oil is not under pressure which minimises risks of blow-outs. Another quantifiable source are oil spills from ships caused by accidents on sea or at the shores. These spills are often spectacular. During 1969-95, about 40 major oil spills >100 t were registered. At places where they occur, they can cause severe damages, especially polluted beaches and mass-stranding of oiled sea birds.

A most recent case was noted during winter 1994/95. A number of dead, contaminated and oiled birds were found along the coasts of Sweden, Poland, Lithuania and Latvia. Altogether about 25,000 dead birds, mainly long-tailed ducks, were recorded.

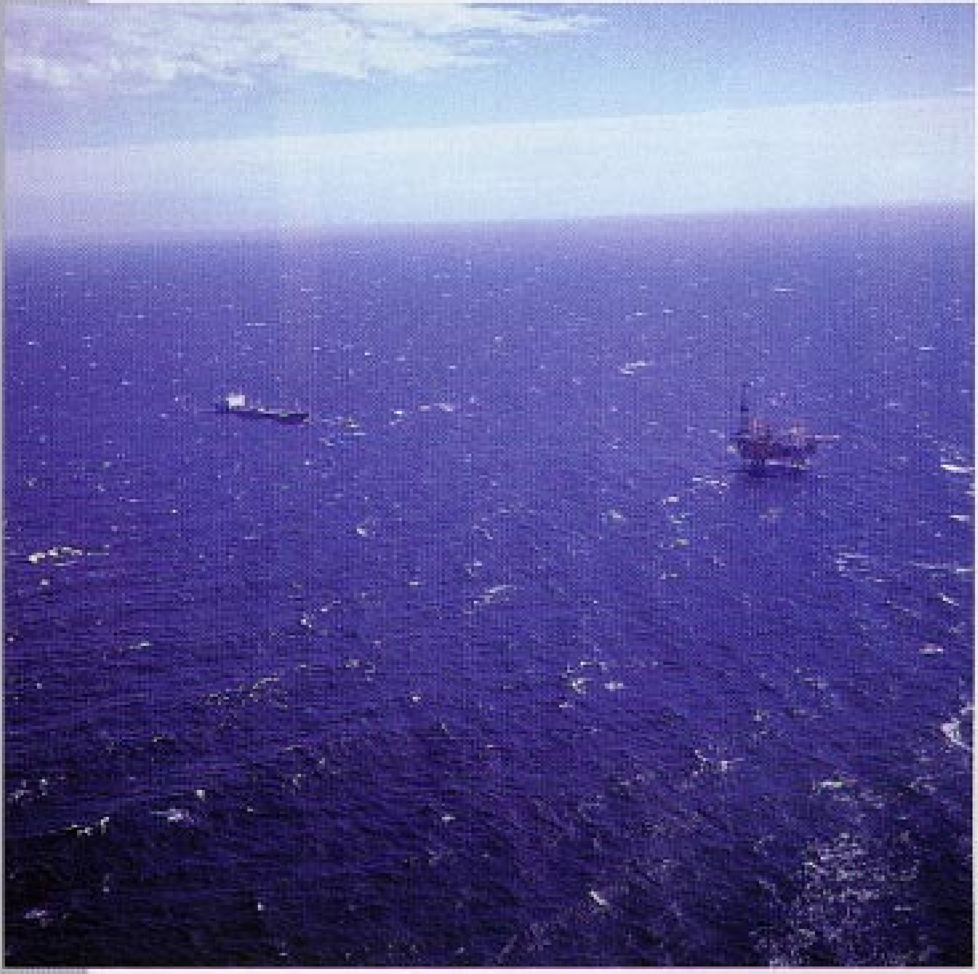
Estimated quantity of oil transported via the Baltic Sea and handled in harbours, 1995. (Excluding data from Russia)



On average, about three accidents happen each year in the Baltic Sea, each spilling about 225 t oil. This is not surprising for an area where annually >7,000 sailings (1995), involving the transport of oil, take place. A risk assessment shows that the number of accidents may rise during the next decade when the oil transported via sea will increase from its current level of 77.4 to 177 million t yr^{-1}. The greatest risks for the environment are major oil spills in areas with ice coverage, or otherwise low temperatures, where oil clean-up operations are very complicated, inefficient and expensive, and where only a minor fraction of the oil may evaporate into the atmosphere and degrade.

For the Baltic Sea, illegal oil spills are often either undetected or there is no prosecution of the offenders. Between 1988 and 1993, about 600-700 such spills were detected every year by aerial surveillance. The spatial pattern of these spills, which are estimated to be mainly within the range of 0-1 m^3, but may even amount to >100 m^3, follows the main navigation and oil transportation pathways via the Baltic Sea. They are most frequently met in the Kattegat/Belt Sea area and along transects from the Bornholm Channel to the northeastern Gotland Basin. They are less frequent towards the Gulfs. For instance, in 1994, there was no oil spill recorded for the Bothnian Bay. However, it should be noted that spill records are strongly biased by the surveillance activities performed by the different riparian countries. Whereas, for instance, during 1988-94 the flight hours reported from Sweden increased from about 2 to >2,000, the Russian activities decreased from about 2,700 to almost zero.

Rough estimates provide a total oil input into the Baltic Sea of somewhere between 20,000 and 70,000 t yr^{-1}. In the absence of catastrophic events with super-tankers, the actual spills may contribute only about 10 % of this amount. Also the atmospheric deposition is considered a minor source. The remaining part, which is difficult to quantify, originates mainly from land-based diffuse sources, and reaches the sea via run-off.



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STEPHEN F. LINTNER

Halogenated hydrocarbons

Halogenated hydrocarbons such as the technical mixture of polychlorinated biphenyl congeners (PCBs), the pesticides DDT and *lindane*, including their metabolites and isomers, or unintentional by-products of combustion processes, such as polychlorinated dibenzo-dioxines (PCDDs) and -furans (PCDFs), are classed as 'xenobiotics', i.e. unknown to the environment before their production by man. Most of them are lipophilic, i.e., they are potentially accumulated in fatty tissue of organisms, and many are harmful even at low body burdens. Over the last decades, their content in different compartments of the marine environment has increased due to anthropogenic activities. It is because of a continuous input, and their often very low degradation rates, that they have been categorised as 'persistent organic pollutants' (POPs).

Before becoming partly banned, e.g. by the Baltic countries, the PCBs were used extensively in both closed and open systems, i.a. as plasticisers, insulators and fire retardants. Of the world-wide production of about 1 million t PCBs, about one third ends up in mobile environmental reservoirs. The occurrence of PCBs in the environment was detected in 1966, i.e., about 36 years after its first use. The toxicological importance of the mixture of PCBs, theoretically up to 209 single substances (known as congeners), was repeatedly demonstrated by numerous unintentional large-scale experiments around the world. The range of species whose reproduction abilities are affected, include many terrestrial and marine birds, mammals and other animals. Spectacular accidents in Japan 1974 and Taiwan 1979, have caused the death of up to 15,000 persons and this has inspired a multitude of research activities. Consequently, PCBs belong to the best investigated group of xenobiotics.

In the Baltic Sea Area, PCBs were identified as the main reason for a decrease of the seal and mink population. Bans on the production and restrictions on the use of PCBs in the Convention Area caused a gradual decrease of the environmental concentrations. Data on PCBs in water are too scarce and not reliable enough to reflect those trends. However, studies on different marine biota show clearly this long-term decrease, e.g., in herring muscle for the period 1972-95 with about 9 % yr^{-1}, in cod liver for 1980-95 with 11 % yr^{-1}, in juvenile grey-seal blubber for 1970-92 with 4 % yr-1, and in guillemot eggs for 1969-95 with 8 % yr^{-1}. Obviously, the slope of the decrease depends on both the species selected and the area under investigation. For instance, the PCB content of herring muscle samples from the Baltic Proper is about twice that in both the Kattegat and the Bothnian Bay. Despite a decline of almost one magnitude over a period >20 years, the PCB levels in compartments of the Baltic Sea ecosystems are still several times higher than in similar samples from the open North Sea and ocean, and therefore continue to be a matter of concern.

Although it was synthesised in the previous century, DDT was first applied as insecticide in 1939 and soon became a corner stone of the anti-malaria programme of the WHO after World War II. In the 1960s, up to 100,000 t DDT were produced annually. In 1973, the countries bordering the Baltic Sea applied about 1,000 t. Currently, the use of DDT is banned for this area but it is still used by tropical and sub-tropical countries in great amounts. The long-range transport of DDT from lower to higher latitudes is supported by the general atmospheric circulation pattern, and by the temperature gradients which facilitate evaporation in the tropics and condensation and precipitation in the colder regions. Unfortunately, because of the lack of monitoring data on organohalogens in the air and in precipitation, those substances reaching the Baltic Sea via long-range transport cannot be quantified, either as their total amounts or as a percentage of the total input.

DDT and its even more stable metabolite DDE have been shown to be responsible for similar harmful effects to those produced by the PCBs. Eggshell thinning in sea birds such as guillemots and the white-tailed eagle was taken as a spectacular but also rather reliable indication of DDT pollution of the marine environment. Monitoring of DDT and its metabolites in different biotic samples in the Baltic Sea indicates, for time series covering the period of the late 1960s/early 1970s until the early 1990s, a rather regular decrease of 11-13 % yr^{-1}. Compared to the Kattegat and the Bothnian Bay, the DDT levels in herring and seal samples from the Baltic Proper are about 4-7 times higher.

Currently, the shells of the guillemot eggs have become thicker, the grey-seal population is increasing, at least in the northern parts of the Baltic Sea, and the white-tailed eagle has also increased in numbers. This has been partly attributed to decreasing levels of DDT and PCBs. However, the DDT concentrations in the Baltic Sea are more than five times higher than in the open ocean and the state of the environment has not returned to the situation which prevailed before the 'industrial revolution'.

Among the isomers of hexachloro-cyclohexane (HCHs) there is one, the γ-HCH *(lindane)*, which has been used since about 1950 in great amounts as an insecticide. In the earlier technical formulations, however, which were predominantly in use, it is α-HCH, the useless by-product, which dominates. During more recent years, in the western European countries, products containing only the γ-isomer were applied. *Lindane* is less lipophilic, i.e., more hydrophilic, more easily degradable and of less toxic concern for the environment than DDT. In contrast to DDT and PCBs, there are plenty of reliable data on HCHs in water of the Baltic Sea since the mid-1970s. For the Arkona Basin, a steady decrease of α-HCH by a total of 50 % can be shown for the period 1975-90. Also the *lindane* concentrations in the Baltic Sea water have decreased. For fish and mussel tissue, the available results on α- and γ-HCH also indicate a mostly downward trend. Its low persistence and the decreasing concentrations in both water and biota indicate that *lindane* and other HCH-isomers may also disappear in time from the Baltic Sea, where their present levels are still several times higher than those in the adjacent areas of the Northeast Atlantic Ocean.

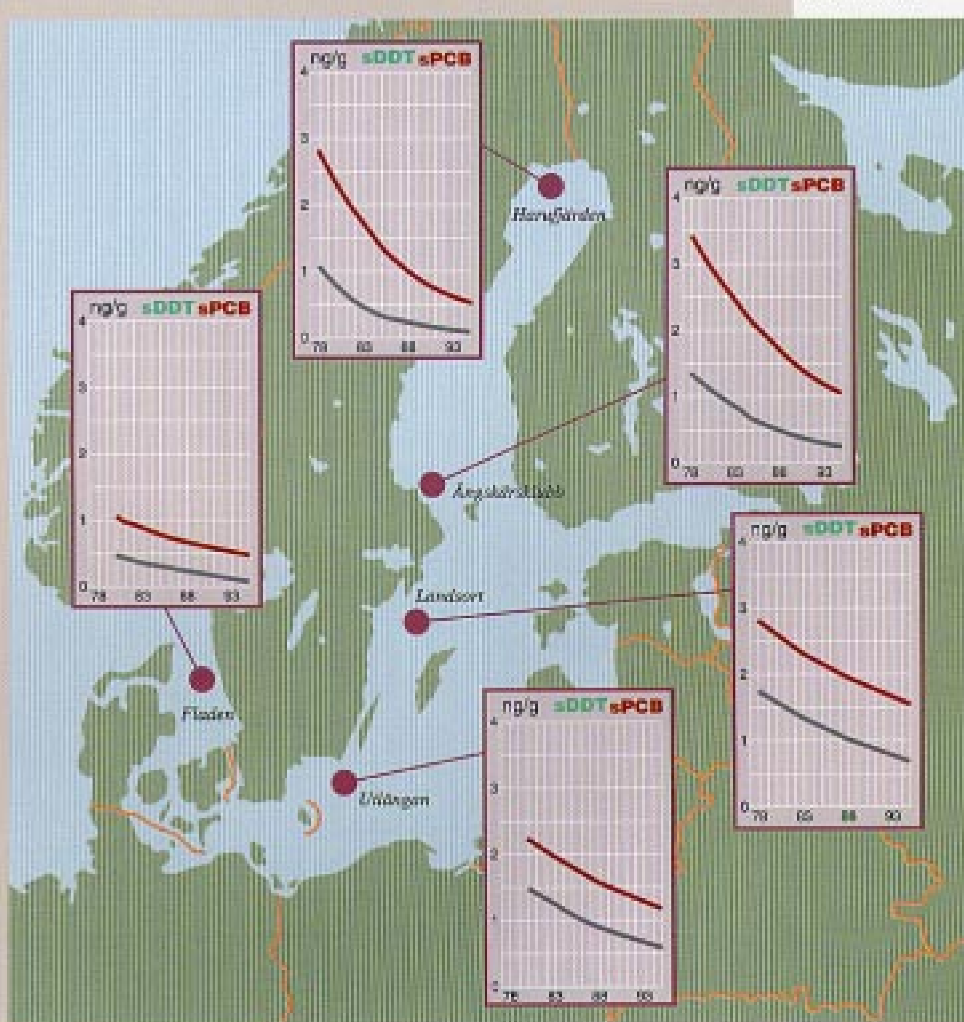
The statistical analysis of 10 data series on herring muscle, cod liver and guillemot eggs, sampled along the Swedish coast during the period 1987-95, revealed a clear decrease for the investigated organohalogens. Compared to the aim of a 50 % reduction in discharges for those substances, stipulated in the HELCOM Ministerial Declaration of 1988, the median values of these decreases came close to this goal for one group of substances (PCBs 43 %) and was even surpassed for other groups (DDTs 60 %, α-HCH 78 %, γ-HCH 64 %, HCB 65 %).

Studies on the increasingly produced brominated aromatic flame retardents have shown a world-wide distribution, increasing levels in the environment and even biomagnification. In guillemot eggs from the Baltic Sea, the concentrations of these substances significantly increased from 1969 until the early 1990s. Since then, they have started to decrease, which may reflect changes in their production and/or handling. Like other organohalogens, their concentrations in seals and herring from the Baltic Proper were significantly higher than those in samples taken in the Kattegat. The concentrations decreased from south to north.

About one dozen compounds of the 75 different PCDDs and 135 PCDFs are extremely toxic, with the planar and symmetrical 2,3,7,8-tetrachloro-dibenzo-dioxine (2,3,7,8-TCDD) being used as toxicity reference point. In a time series based on measurements in guillemot eggs, a significant decrease of TCDD equivalents could be shown for the Baltic Sea. However, the levels of these substances, for instance in herring from the Baltic Sea, are several times higher than those found in the adjacent sea areas and continues to be a matter of concern, especially for the fish-eating population.

More recently, some new contaminants have been reported for the Baltic Sea which may create future environmental problems. The persistent bis(4-chlorophenyl)-sulfone (BCPS) is known to be used in the production of polymers. It has been found in perch, grey-seal blubber and guillemot eggs from different parts of the Baltic Sea. The concentrations were comparatively high, i.e., of the same order of magnitude as classical contaminants such as PCBs. Tris(4-chlorophenyl)-methane and -methanol are by-products of DDT production and have been detected in ringed seals from the Baltic Sea.

DDT and PCB levels in herring muscle samples have decreased significantly.



Artificial radionuclides

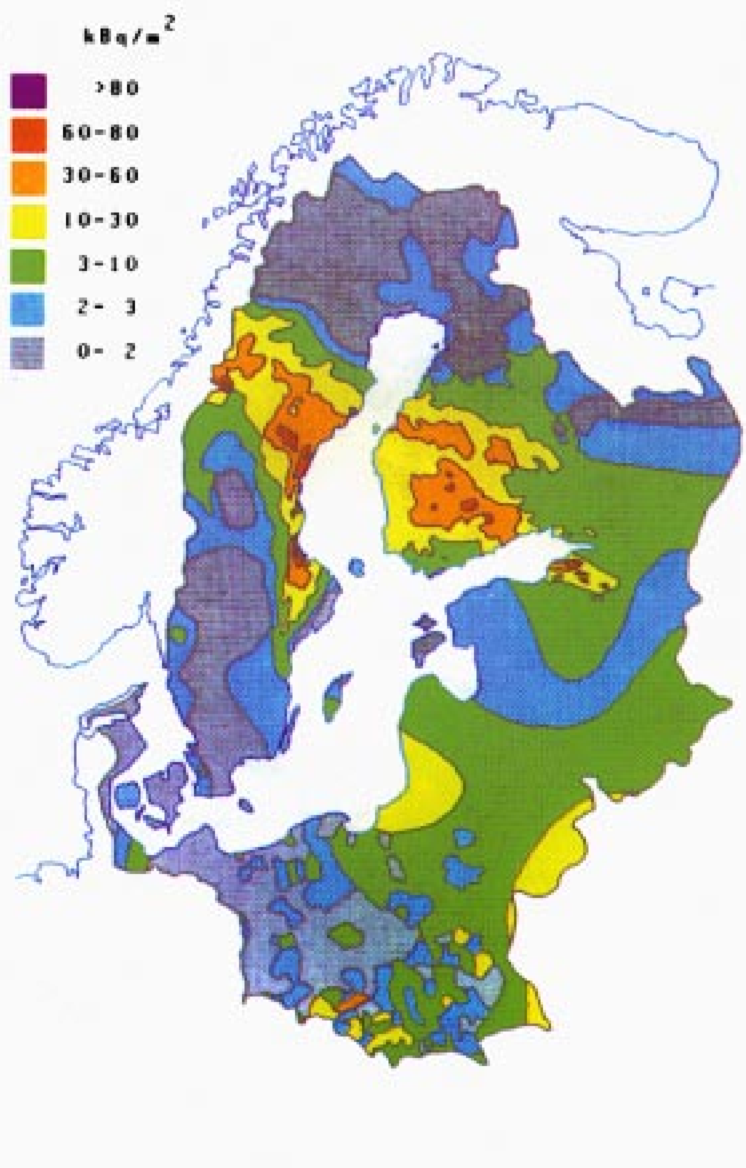
The dominating artificial radionuclides in the Baltic Sea environment are ^{137}Cs and ^{90}Sr. Their occurrence is mainly based on four sources which contributed very differently to their total input. Until 1991, about 4,850-5,750 TBq ^{137}Cs and 720 TBq ^{90}Sr entered the Baltic Sea, i.e., (a) 76-80 % of the ^{137}Cs and 11 % of the ^{90}Sr from fallout of the *Chernobyl* accident of April 1986, (b) 16-19 % and 83 %, respectively, from the global fallout due to the atmospheric nuclear weapon tests during the 1960s, (c) 4.3-5.2 % and 5.6 %, respectively, from discharges of the reprocessing plants at *Sellafield* (*Windscale*/Irish Sea, Great Britain) and *La Hague* (English Channel, France), which partly are transfered to the Baltic Sea with salt-water inflows, and (d) only about 0.01 % and 0.04 %, respectively, from nuclear installations within the drainage area of the Baltic Sea.

The *Chernobyl* fallout increased the ^{137}Cs inventory of the Baltic Sea water by a factor of five. During 1986-91, due to losses via the outflow to the North Sea, and decay and sedimentation, this inventory decreased by 50 %. However, the concentrations in the Baltic Proper were about five times higher than those in the Southern Bothnian Sea, and even ten times higher than those in the central North Sea.

Most of the artificial radionuclides are now located in the sediments, where for 1991 inventories of 1,400 TBq for ^{137}Cs and 18 TBq for ^{239,240}Pu were estimated. Compared to the values of the early 1980s these inventories have increased by factors of 5.1 and 1.2, respectively.

The main pathway of radiation exposure to humans from contamination of the marine environment is through the consumption of marine fish. Very extensive studies on radionuclides in mainly cod, herring, flat fish and pike were performed after 1986 in all Baltic countries. The results clearly reflected the spatial distribution pattern of the *Chernobyl* fallout. The temporal change in radioactive levels in fish in principle resembled that for water, but there was a time lag before the latter trend began.

In the countries bordering the Baltic Sea, the radiation doses due to terrestrial pathways range between 2 and 5 mSv yr^{-1}. An individual from a 'critical' group, i.e., those who consume plenty of fish, takes up about 1.2 mSv yr^{-1} due to natural radioactivity based on ^{210}Po. It can be estimated that for this individual the consumption of radioactively contaminated fish in 1986 contributed <10 % of additional radiation exposure. Since, at present, the contribution to man from marine contamination adds about 1 % of the total exposure to radioisotopes, this source should not be considered as a matter of concern for the general population in the Baltic Sea Region.



Distribution of the Chernobyl fallout over the Baltic Sea region.

Chemical munitions

Chemical weapons were used in World War I, causing the deaths of about 100,000 men and disabling another 1.2 million. During World War II, chemical warfare agents were not used in Europe. However, large amounts of them had been produced and stock-piled, by Germany between 1935 and 1945, i.e., about 65,000 t, comprising mainly 10 agents, among them *mustard gas* as vesicant (39 %), the nerve gas *tabun* (18 %), tear gases (11 %) and the lung irritant *phosgene* (9 %).

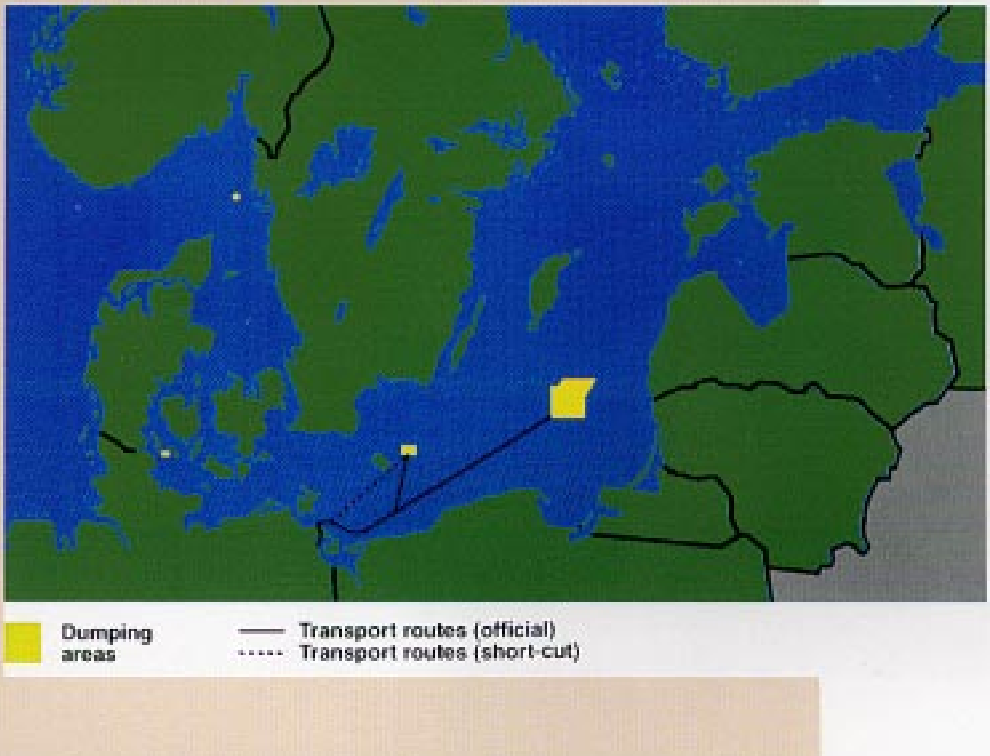
In the early 1990s, an intensive public discussion started once again about possible threats caused by chemical munitions dumped in the Baltic Sea after World War II by the allied forces. Within HELCOM, this issue was taken up and available information was compiled by a special working group. The compilation showed that major parts of the remaining German chemical munitions were dumped outside the Convention Area. During 1945-48, on the orders of the British and American occupation forces, >30 ships containing about 130,000 t of chemical munitions and conventional ammunition were sunk in the Norwegian Trench, inside the Skagerrak.

In the Baltic Sea area, in 1947 and 1948, about 34,000 t of chemical munitions, containing about 12,000 t of warfare agents, mainly *mustard gas*, were dumped east of Bornholm and south-east of Gotland on the orders of the Soviet Military Administration in Germany. The dominating types of the munitions were aircraft bombs and artillery shells. There are unconfirmed reports that, in 1946, 15,000 t and 8,000 t of chemical munitions were dumped south-west of Bornholm (Rønne) and east of Bornholm, respectively. At the southern entrance to the Little Belt, 5,000 t chemical muntions containing 750 t of *tabun* and *phosgene* were dumped.

Surveys of the dump sites have shown that the present conditions of the chemical munitions range between completely corroded shells, free of warfare agent, and intact munitions. The multitude of parameters, such as background conditions at the dumping ground (water depth, sediment type, redox conditions,...), original wall thickness and composition of the shells, water solubility and degradability of the agent, exclude reliable predictions about the state of the munitions at a certain dumping ground.

Because of the addition of thickeners, viscous *mustard gas* is the only warfare agent which may occur in large lumps, that are mechanically relative stable, less degradable and may be caught or displaced by fishing nets. When in contact with the unprotected skin, this agent causes severe damages. Therefore, it involves a potential threat for fishermen. Despite the fact that the dumping grounds are marked as "anchoring and fishing not recommended", Danish fishermen reported on 342 catches of a total of 17 t chemical munitions from the area east of Bornholm between 1985 and 1992. The total number of reports from fishermen of other countries, e.g., from Poland (16), Germany (13) and Sweden (4), are much less numerous. The density of the viscous *mustard gas* lumps is 1.3-1.5 g cm^{-3}. This should prevent their transport to the beaches.

Based on present knowledge, a widespread risk to the Baltic Sea environment from dissolved warfare agents can also be ruled out. At the dumping grounds, near-field effects on the benthic flora and fauna may have occurred during previous decades. Whether or not these sites still suffer from significant disturbances, needs to be investigated. Regarding human health, the control procedures for fish and other types of seafood in use by the Contracting Parties combined with the small risk of contaminated catches suggest that these materials will not constitute a toxicological problem.



Dumping sites for chemical munitions in the Baltic Sea.

JARI KOSTET

Sanitary conditions in coastal waters

ARJEN RAATELAND

For many people living around the Baltic Sea, the beaches and the adjacent bathing waters are the places where they may experience the quality of the Baltic Sea. The sanitary conditions in the coastal waters are of great importance for their well-feeling during recreation at sea sites. The assessment of the hygienic quality, i.e., whether or not the beaches are fit for bathing and swimming, is mainly based on the result of bacteriological investigations, especially on faecal coliforms, streptococci, salmonella and enteroviruses. Quality problems are mainly due to missing or unsufficient treatment of sewage from municipalities and intensive and extensive fish farming and stockbreeding. In addition, low transparency of the water due to the input of nutrients, causing (hyper-)eutrophication, and of large amounts of dissolved and particulate organic matter, can make the water unfit for recreational purposes. Microbial contamination often decreases exponentially from the coast towards the open sea.

For the last 5-10 years, most countries have reported significant improvement of the hygienic conditions along their coasts. According to a recent compilation, the number of beaches with doubtful water quality or of those which had to be closed for bathing has decreased. The improvement recorded during those surveys is mainly due to new or improved sewage-treatment plants that are operating at previously polluted sites. This is for example true for the Pärnu Bight/Estonia, for the Helsinki area, for the coast of Mecklenburg-Vorpommern/Germany, for the beaches of Jurmala/Latvia at the Gulf of Riga, and for numerous Polish beaches, especially in the Gdansk Bight.

With regard to the occurrence of potentially dangerous bacteria, there are, however, still many remaining problematic areas. In addition, many of the beaches bordering shallow inner coastal waters may still for decades create another type of sanitary problems. This is because the coastal waters have accumulated huge amounts of nutrient-containing muddy materials over a long period. These nutrients will be continuously mobilised and will provide the basis for a high plankton production even when the land-based inputs have been drastically reduced. Last but not least, floating algal mats, decomposing at or near the beaches, and unusual algal blooms may become increasingly important with respect to the sanitary conditions.

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Nature conservation

Nature conservation in the Baltic Sea Area is related to a multitude of activities such as

- protection of the coastal strip, extending 100-300 m both sea- and landwards from the mean water line, against increasing pressure through anthropogenic impact caused by the building of new roads, harbours, marinas, hotels, private summer houses and camping grounds, and by intensive farming and forestry,
- establishment and management of areas with high biodiversity, with habitats of migratory, endemic, rare or threatened species, with important nursery and spawning grounds, with rare, unique or representative geological or geomorphological structures and processes, as 'Baltic Sea Protected Areas' (BSPAs) under which the Contracting Parties have already adopted 62 sites in March 1994,
- preservation of natural coastal dynamics, which reduces or even excludes coastal defence measures outside human settlements, accepting also episodic flooding and erosion of cliffs as sediment suppliers,
- proper management of coastal lagoons and wetlands which may serve as important buffers for pollution of the Baltic Sea from land run-off,
- elaboration of a 'Red Data Book' identifying the different landscape types, biotope complexes and biotopes in the Baltic Sea Area as tools to evaluate the threats to which habitats are exposed, and
- to collect, categorise and update information about threatened species as a 'Red List'.

During the first 15 years since the signing of the Helsinki Convention in 1974, HELCOM has become the main regional forum for handling environmental issues within the Conventional Area, which was at that time restricted to the sea areas off the national territorial waters. However, this could not stop the ongoing loss of habitats and biotopes, and hence the permanent threat to the biodiversity in many parts of the Baltic Sea. This was one reason for a revision of the convention. A new article was included in the revised Helsinki Convention signed in April 1992. Article 15 of this new Convention states: *"The Contracting Parties shall individually and jointly take all appropriate measures with respect to the Baltic Sea Area and its coastal ecosystems influenced by the Baltic Sea to conserve natural habitats and biological diversity and to protect ecological processes. Such measures shall also be taken in order to ensure the sustainable use of natural resources within the Baltic Sea Area. To this end the Contracting Parties shall aim at adopting subsequent instruments containing appropriate guidelines and criteria"*. Hence, not only the Baltic Sea itself is now included within the framework of HELCOM, but also terrestrial biotopes of the Baltic Sea coasts, as far as nature conservation aspects are concerned. The protection of habitats, species and ecological processes, both marine and coastal, are important tools in the improvement of the future environmental situation in the Baltic

Sea Area. With "Article 15 - Nature Conservation and Biodiversity", environmental work in the Baltic Sea has changed to a different level, since it now includes nature conservation as an important tool.

For selected species, the present situation was assessed as follows:

– More than 30 species of water birds breed along the coasts of the Baltic Sea, among them the common eider, tufted duck, red-breasted merganser, redshank, sandpiper, herring gull, arctic and common tern, and the black, razorbill and common guillemot. Decreasing contamination of themselves and their prey by organochlorines has resulted in recent years in a higher reproductive success. Eutrophication has also led to an enhanced food supply and was probably another reason for increasing populations of some birds, e.g., the cormorants. For diving sea birds, gill-net fishing is a continuous threat. For instance, during 1982-88, about 25,000 birds were accidentically caught by this mean in the south-eastern Kattegat. Oil spills are a potential threat for the impressive numbers of sea birds wintering in the Baltic Sea.

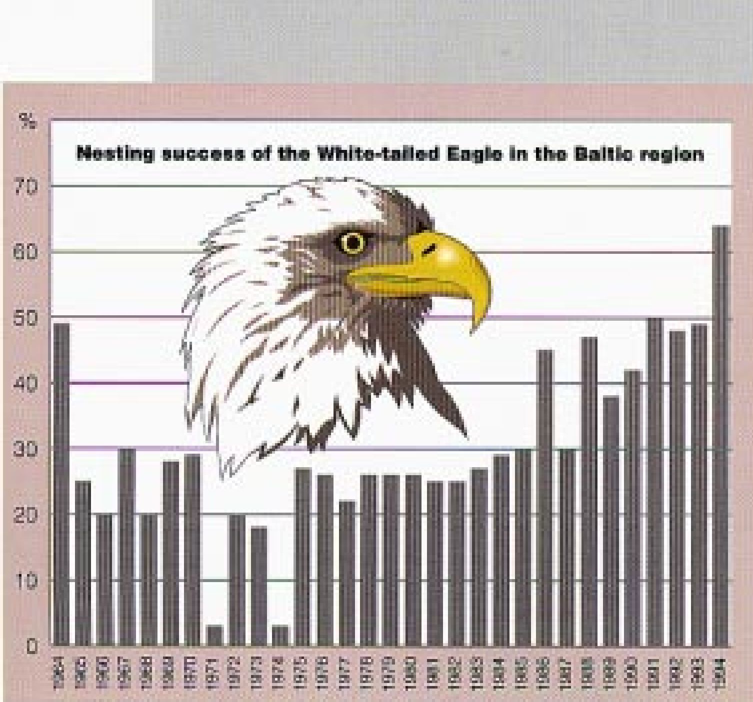
– The Baltic Sea is one of the two European breeding areas for the largest of the terns, the Caspian Tern, hosting some 25 colonies and about 1,500 solitary pairs. At the breeding sites, the presence of the American mink and occasional parasite out-breaks can cause problems. In contrast, at the West African wintering sites, hunting and droughts are the greatest threats.

– The white-tailed eagle was the first species, associated with the Baltic Sea aquatic environment, which experienced reproduction problems due to pollutants such as DDT and PCBs during the mid-1950s. It took 15 years after the ban of DDT to reverse the negative effects, and another ten years to return to the situation as it was before the high contents of those organochlorines and disturbances by man, including illegal hunting, reduced the population drastically. Before 1950, the nesting success was about 72 %, with an average of 1.8 fledglings per nest. During the late 1960s and the 1970s, these figures dropped to 25 % and 1.2 fledglings. In recent years, the Baltic Sea population of the white-tailed eagle has demonstrated the highest reproduction rates of the last 30 years (1994: 68 %) and has regained former territories.

– The cormorant is probably the most successful bird in the Baltic Sea area in terms of recovery of numbers. After being hunted to near extinction during the 19th century, in the 1940s, the cormorant returned and nested for the first time after its disappearance. During the 1980s, the number of breeding birds in Denmark increased by 25 % per year. However, during the early 1990s this trend levelled out, and the cormorant became classed as a pest at several sites, since they conflict with the economic interests of fishermen.

– The dunlin is a typical representative of wader species and a common bird in the Baltic Sea area, where the number of breeding sites and breeding pairs for its subspecies *Calidris alpina shinzii* during this century has alarmingly decreased. In the bordering countries, the situation of this species is described as either 'endangered' or 'vulnerable'. The main reasons for the decline in population are habitat changes, i.e., the decline of grazing pastures, draining and cultivation, but also serious threats from crows and foxes.

– Following a history of decreasing populations and severe problems with diseases and organochlorines, resulting in skeleton and uterine deformations leading to sterility, the situation for seals in the Baltic Sea is improving. The total number of grey seals in Swedish, Finnish and Estonian waters now amounts to 5,300. The Swedish population north of 59°N, for instance, has increased annually by 12 % during 1982-94. During 1988-95, the population of the Baltic ringed seal increased in the Gulf of Bothnia from about 2,300 to 3,000 specimens. The common (harbour) seal stocks in the Kattegat and Skagerrak have now recovered from the *phocine distemper virus* disease of 1988, and the size of the stocks now equals that of



the pre-disease times (about 6,500). Based on reliable data, which has been available since 1994, it is estimated that the population of the harbour porpoise in the western parts of the Baltic Sea is >8,000. It is believed that the Baltic harbour porpoise is genetically specific and reproduces exclusively within the Baltic Sea. Gill-net fishing comprises a serious threat for this animal.

The proportion of seals with uterine deformation has decreased from about 36 % during 1977-86 to 25 % for 1987-93. However, pathological changes in non-reproductive organs, for example in intestines, arteries, kidneys and skin, still exist and the mortality rate of young seals in some areas is still very high, i.e., >50 % among grey seals in the Southern Baltic Proper, and 95 % among the southernmost Swedish common seals. The incidence of intestinal lesions has actually increased during the last 5-10 years. Other problems arise from the unresolved conflict between the rising seal population and the economic interests of fishermen.

– Introduction of alien, or non-indigenous, species - also referred to as 'biological pollution' - is a more recently recognised threat to marine ecosystems. Marine organisms disperse by natural means, but human activities have increased the speed and intensity of this dispersal. During this century, at least 50 new species have been introduced into the Baltic Sea because of human activities. The main part of these species has entered with ballast water or attached to the hulls of ships, but species have also been deliberately introduced. The species-poor communities of the Baltic Sea are probably more sensitive to introductions of alien species than those in the more species-rich marine areas. It is anticipated that more species will be introduced in the future because of the increases in shipping.

A few alien species have become common and have affected the original natural communities. In the Baltic Sea, the polychaete *Marenzelleria viridis* was first found in 1985 along the German coast, and has since spread to both Sweden and Finland (1990). It inhabits muddy bottoms down to a depth of 60 m and may constitute up to almost 100 % of the macrofauna biomass. Its presence might affect native species like other polychaetes and amphipods. Other successful invading species to, for example, the Gulf of Finland are the bivalve *Dreissena polymorpha* and the mysid shrimp *Hemimysis anomala*. Both species first appeared during the 1990s in that area, but are still relatively poorly studied.

Among fish, the round goby is a successful invader, and this species was probably introduced with ballast water from the Black Sea and Caspian Sea. Occupying similar niches as, for example, flounder, black goby and eelpout, the round goby is expected to compete with these species. The barnacle goose is a successful self-introduced newcomer to the Baltic fauna of breeding birds. Among mammals, the American mink is a good example of a deliberate introduction which has severely affected natural communities. Several islands, serving as nesting sites in the Stockholm Archipelago, have recently experienced drastic reductions in the number of breeding sea birds, probably due to predation by mink.

Number of grey seals in various parts of the Baltic Sea.

Fish stocks and diseases

For the period 1973-93, >90 % of the total commercial fish catch (about 0.5 to >1 million t yr^{-1}) consisted of cod, herring and sprat. This catch depends on both the fishery effort and the available stocks. Cod is distributed over the entire Baltic Sea except the Bothnian Bay. In the Bothnian Sea and in the Gulf of Finland, the amount of cod is rather limited, except in periods with large stocks. The reproduction of the demersal species cod needs a certain level of salinity (>10-12 psu) and oxygen concentrations (>1.5-2 cm^3 dm^{-3}) for successful fertilisation and survival of eggs. Due to the absence of effective salt-water inflows, from the late 1970s to 1993, the deep water in the Baltic Proper, which fulfil such minimum requirements, has decreased drastically. Since 1984, the cod stock has decreased, from about 400,000 tons to only one tenth of this level in 1992/93. This negative trend was amplified by an unjustified increase in the fishery effort. Although the environmental reproduction conditions have now changed, further regulations, aiming low annual catches and minimum length classes, are needed to enable a full recovery of the stock and its sustainable development. For 1997, however, the International Baltic Sea Fishery Commission (IBSFC) has allowed a total catch of 180,000 t cod in the Baltic Sea.

Sprat and herring stocks have been influenced both by changing exploitation levels and by the dramatic fluctuations in abundance of cod, their main predator. The landings of sprat decreased from 200,000 t in the 1970s to <50,000 t at the beginning of the 1980s, but increased during recent years to about 300,000 t (1994). The increase of the stock during the last five years was caused by the decreasing mortality from predation by cod and a previous period with low catches. For 1996, a sprat-catch quota of 500,000 t (1997: 550,000 t) is valid for the Baltic Sea.

The landings of herring in the Baltic Sea area have fluctuated during the last decades around 500,000 tons per year. Due to a declining market for herring, the fishing mortality was estimated to be at a comparatively low level for the Baltic Proper and the Gulf of Bothnia (20-25 %). Together with the decline in cod, this under-utilisation caused an increase of the different stocks during recent years. Consequently, for 1996 a catch quota of 560,000 t for the Baltic Proper and 110,000 t for the Gulf of Bothnia was agreed within the IBSFC.

Naturally reproducing salmon stocks exist in about 30 rivers draining into the Gulf of Bothnia (12), the Baltic Proper (12) and the Gulf of Finland (6). At the beginning of this century, such stocks were present in >100 rivers. Since many of those rivers have been dammed, spawning and nursery areas have disappeared. To compensate, hatcheries have been built on many rivers and reared stocks are released to feed in the sea, to provide future potential spawners. Presently, the stock of wild salmon (0.4-0.6 million) constitutes only about 10 % of the production of reared smolts (5-6 million). Since 1945, the annual catch of reared and wild salmon on sea by drift nets and long lines is rather stable around 3,000 t yr^{-1}, however, with a slightly increasing tendency. The increase is due to both a higher growth rate and a higher number of released smolts. Since the beginning of the 1990s, the catch quotas of the IBSFC for salmon have been step-wise reduced, from 670,000 (1991) to 410,000 individuals (1997). But still, the landings represent an extremely high fishing mortality, with only <0.5 % (Gulf of Bothnia) and 1-2 % (Baltic Proper) of the adults managing to get back to their rivers for spawning. This increases the risk that some of the naturally spawning populations may be totally wiped out. To avoid this, a 'Salmon Action Plan' and, for 1997, a mora-

Rivers and reaches of rivers supporting salmon runs in the past (thin lines) and present (thick lines).

torium on fishing of wild salmon have been agreed.

The problem of decreasing stocks of the naturally spawning salmon has become acute after the appearance of the *M-74* syndrome, which was first observed in 1974. In 1994, this syndrome caused high (50-90 %) mortalities in the offspring of salmon spawning in Swedish and Finnish rivers. The occurrence of the syndrome was demonstrated in the reared fish but only assumed for the wild yolk-sac fry. There have been several hypotheses about the causes of this syndrome, e.g., appearance of 'new' and synergistic effects of 'old' contaminants, defective immune systems, or changes in the prey composition, but no one has obtained proof so far that these factors are important. The prognosis for the production of wild smolt in 1996 is pessimistic with the smallest stocks at risk of extinction.

The eel enters the Baltic Sea as 'glass eel', grows to a 'yellow eel' and matures into a 'silver eel'. There are no internationally agreed catch quotas or any stock management arrangements for this species. This is because the matured silver eel leaves the Baltic Sea for spawning in the Sargasso Sea after which it dies. Since 1955, the first year for which there are reliable catch data, the commercial catch has decreased steadily, from >6,500 t (1955) to <2,000 $t\ yr^{-1}$ (1993). However, there are no reliable stock size estimates, and the landing figures are also uncertain. The reasons for the decrease are unknown. The number of glass eels arriving in the Baltic Sea seemed to have decreased. This may be due to less eels spawning but also because of changes in the circulation of the North Atlantic Ocean which could prevent a higher return quota by relocating the larvae forms to another sea area. However, influences of a higher fishing pressure resulting in a recruitment overfishing have been considered as the most probable reason for the decline.

The annual landings of the Norway lobster in the Kattegat decreased from 2,000 t in 1984 to <1,000 t in 1993 and 1994. There are no reliable estimates of the lobster stock, but the decline was related to more frequently occurring oxygen deficiencies in the bottom waters of this area.

Numerous sedentary and migratory fish species are common for the coastal waters of the Baltic Sea. Eutrophication and the presence of toxic contaminants may influence their species composition, reproduction biology and migratory habits. The size of their stocks may serve as indicator for the degree of the local or regional contaminant load. At a few sites, such kind of studies have been performed or are in progress. However, for the majority of the coastal areas of the Baltic Sea, reliable information on stocks, landings, health conditions etc. of commercial and other coastal fish species is still missing.

The occurrence of diseases and parasites in fish from the Baltic Sea is frequently a matter of concern for the public, i.e., for the potential fish consumers. Their prevalence causes economic losses and is often considered to reflect the state of the marine environment. In flounder, the viral lymphocystis disease occurred in 5-38 % of animals ≥20 cm, with a clear decreasing spatial trend from the western to the eastern parts of the Baltic Sea. The prevalence of this disease increased during 1986-93. In flounder, liver nodules may also occur with prevalences of 3 % for animal lengths ≥20 cm, or even as high as 10 % for animal lengths ≥30 cm, as for example those observed in the Finnish coastal waters. Bacterial skin ulcers were observed in up to 12 % of the flounders. Both diseases increased from the western to the north-eastern parts of the Baltic Sea.

The most easily externally visible disease of Baltic cod is the bacterial skin ulcer. For different sites, prevalences between 15 % and 40 % have been described, however, with a general tendency to decrease from the 1980s to the 1990s. Other diseases, such as visible skeletal deformities and pseudotumors, occurred in cod with <1 %. Although there is no apparent temporal trend, several external visible parasites occur mainly in cod from the south-western parts of the Baltic Sea with 3-20 %.

During the past 20 years, the parasitic nematode *Anisakis* spp., and since 1991, the epizootic caused by the parasitic fungus *Ichthyophonus* spp. have been the subject of many studies on herring in the Baltic Sea. *Anisakis* spp. ist most typical for the spring-spawning herring stock west of Bornholm (1987/88: 30-45 %). The prevalence increases with size (age), without a significant temporal trend. East of Bornholm, the prevalences drop to <1 %. In summer 1991, *Ichthyophonus* spp. caused massive mortalities of the spring-spawning herring along the Swedish coast. The 'real' Baltic herring stocks, however, e.g., from the Gulfs of Finland and Riga, showed very low prevalences. Meanwhile, the herring from west of Bornholm have recovered from this parasite.

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