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# Eutrophication of Kieler Bucht

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**Abstract**

Prior to 1975, average winter water nutrient concentrations at station Bokniseck in Kieler Bucht (Western Baltic) were 1.23 mmol/m$^3$ total phosphorus and 12.7 mmol/m$^3$ dissolved inorganic nitrogen. Nitrogen concentrations did not change until 1984. The mean of a few total phosphorus data from 1980–1984 is 1.94 mmol/m$^3$. Mean nutrient concentrations in the area between the southern entrance of the Great Belt and Darss Sill increased between 1975 and 1984 from 0.8 to 1.6 mmol/m$^3$ total phosphorus and from about 6 to 10 mmol/m$^3$ inorganic nitrogen. Comparatively higher nutrient concentrations at Bokniseck station are correlated to higher salinity. However, no data are available on nutrient imports into Kieler Bucht with saline deep water. Unchanged nutrient concentrations at Bokniseck prior to 1975 are an argument against any dominant influence of anthroprogenic inputs which until 1974 increased to annually 1500 t of total phosphorus and 12 700 t of total nitrogen, plus 5000 t of nitrogen from the atmosphere. Higher phosphorus concentrations 1980–1984 are correlated to severe oxygen deficiency in the deep water. Mobilization of phosphorus from sediments becoming anoxic could be the reason. Biota could be such sources and sinks of nutrients that influence the nutrient balance of Kieler Bucht. To sum up, there are several processes besides anthropogenic inputs that influence nutrient concentrations in water. An assessment of winter water nutrient concentrations alone is no adequate tool for the evaluation of the effects of anthropogenic nutrient inputs via rivers, sewage, land runoff, groundwater and from the atmosphere.

## Introduction

In 1987, the Helsinki Commission published the results of the First Periodic Assessment of the State of the Environment of the Baltic Sea Area, covering the period from about 1979 to 1984. This assessment includes a chapter on nutrients (NEHRING et al. 1987). For various reasons, however, nutrient data from Kieler Bucht were not available and were thus not evaluated in this assessment. Only data from stations situated north and east of Kieler Bucht are included (Fig. 1): Kelds Nor (50), Fehmarn Belt (52) and Gedser Rev (54).

Under the heading “Fehmarn Belt” results from these three stations have been analyzed together (AERTEBJERG in NEHRING et al. 1987). In the following, I refer to the average values listed under the heading “Fehmarn Belt area”. During the 10 year period from 1975 to 1984 the following trends in winter water concentrations could be established: an increase of inorganic nitrogen concentrations by 0.4 mmol/m$^3$ per year, and an increase of total phosphorus concentrations by 0.1 mmol/m$^3$ per year.

Such drastic increase of winter water nutrient concentrations in the area between Darss Sill and the southern entrance of the Great Belt fits in well with trends in other areas of the Baltic. The winter pool of inorganic nitrogen compounds has increased during the seventies in all subregions of the Baltic, from the Gulf of Bothnia to the Kattegat; the winter

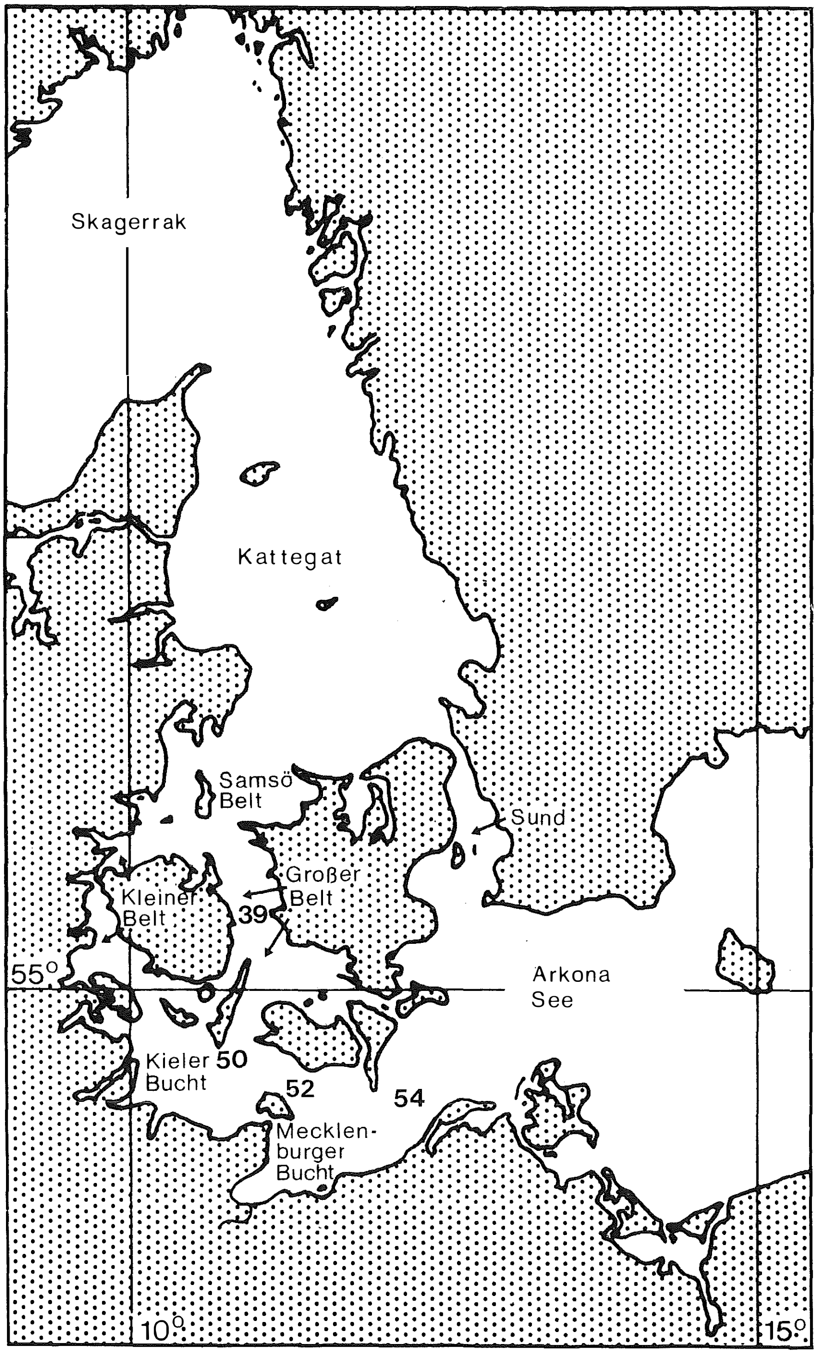


**Figure 1**

The Belt Sea area with Kieler Bucht and stations 50, 52 and 54 referred to as "Fehmarn Belt area" pool of total phosphorus has increased in all subregions as well except for the Bothnian Bay and the Gulf of Riga. At present, the causes for such dramatic increase in Baltic nutrient concentrations are under discussion, as well as the effects such eutrophication process could have on primary and secondary production.

A discusson should start whether higher nutrient concentrations in surface water flowing out off the Baltic proper are the main cause for elevated winter water concentrations in the Belt Sea, or whether input from land plays the dominant role, or what else could be the reason.

In this context I would like to discuss some results from Kieler Bucht from the years 1958 to 1984 which have been achieved by members of a working group “Eutrophication of the North Sea and the Baltic”, financed by the Umweltbundesamt, Berlin. A more detailed discussion of the matter can be found in a previous German language publication (GERLACH 1986).

## Region

I define “Kieler Bucht” as a region separate from Little Belt, Great Belt and Fehmarn Belt (Fig. 2), 2571 $km^2$ large, with a volume of 42 $km^3$ (BABENERD and GERLACH 1986). 23 $km^3$ are above 10 m water depth, 2.4 $km^3$ are below 20 m water depth. The median depth is 17 m. Areas shallower than 8 m are covered either by sand, or by “lag sediment”, a thin layer of coarse sediment over glacial till, with pebbles, cobbles and boulders. Muddy sediments start at about 12 m water depth in sheltered regions, but their contribution is significant in water depths exceeding 18 m.

Most information on nutrient concentrations comes from station Bokniseck (Fig. 2) situated close to the coast of Schleswig, off a steep slope at the entrance of Eckernförde Bay.

## Results

From Bokniseck station the following sets of data are available for January und February (integrated over the water column of 26 m depth; Fig. 3):

a) 1969 to 1984 total inorganic nitrogen concentrations. The average concentration was $12.70 \pm 0.67$ $mmol/m^3$, no significant changes could be detected over the period 1969 to 1984 (v. BODUNGEN 1986).

b) 1958 to 1975 total phosphorus concentrations. The average concentration was $1.23 \pm 0.26$ $mmol/m^3$, no significant changes could be detected over the period 1958 to 1975 (data of KREY et al. 1978, analyzed by BABENERD and ZEITZSCHEL 1985, recalculated in GERLACH 1986).

c) 1980 to 1984: only a few total phosphorus data, average concentration $1.94 \pm 0.51$ $mmol/m^3$ (BABENERD and ZEITZSCHEL 1985).

Average nutrient concentrations in the area between Kelds Nor and Gedser Rev, called the “Fehmarn Belt area” are lower than at Bokniseck station, corresponding to lower salinity which is 14–16 at Fehmarn Belt lightvessel, but 19–20 at Bokniseck station. Trends of nutrient increase between 1975 and 1984 are obvious in the “Fehmarn Belt area”: from about 6 to 10 $mmol/m^3$ inorganic nitrogen, and from about 0.8 to 1.6 $mmol/m^3$ total phosphorus (AERTEBJERG in NEHRING et al. 1987).

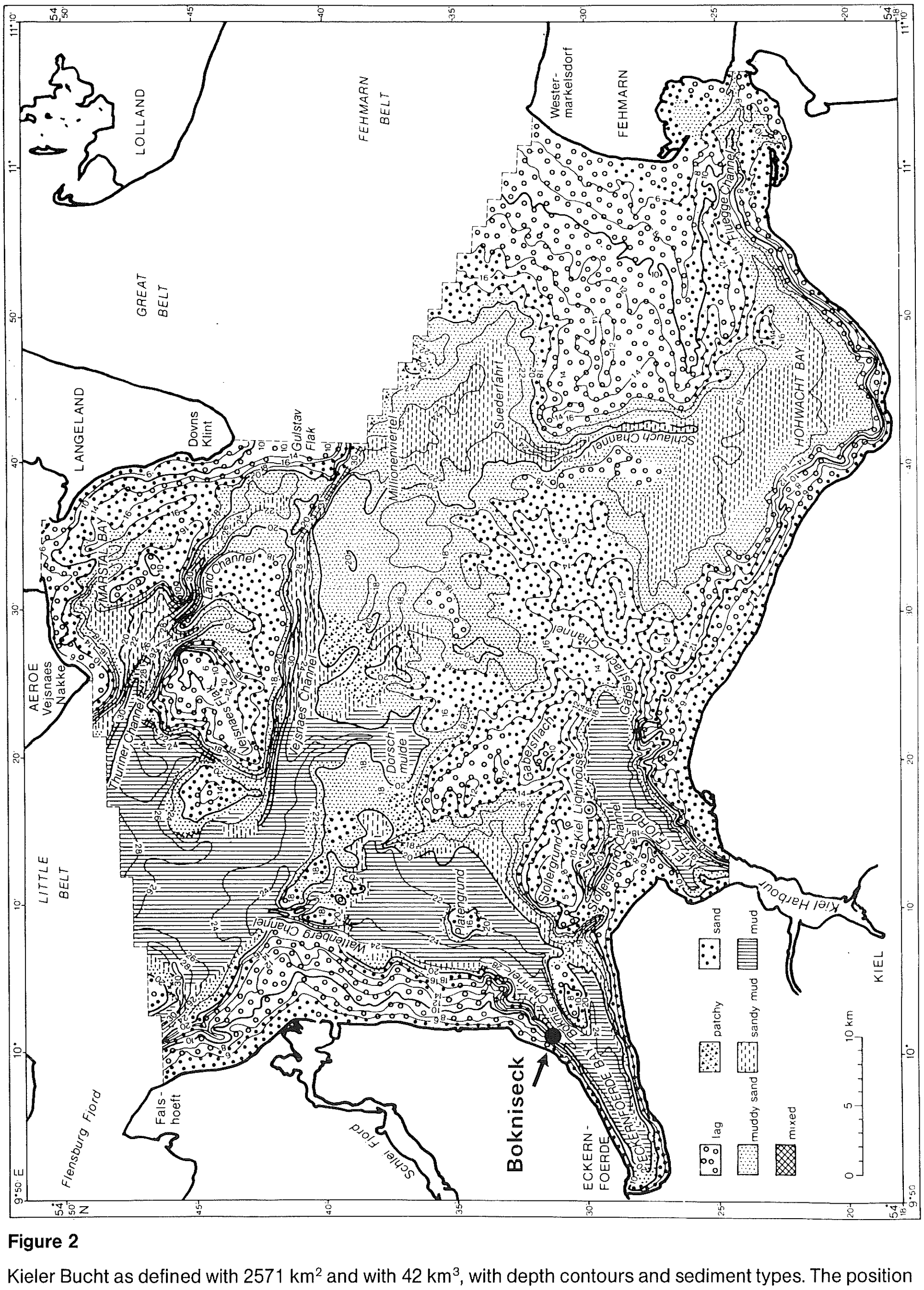


**Figure 2**

Kieler Bucht as defined with 2571 $km^2$ and with 42 $km^3$, with depth contours and sediment types. The position of station Bokniseck is indicated. From GERLACH (1986)

The following questions should be answered:

1) Why are the nutrient concentrations higher at Bokniseck compared with the "Fehmarn Belt area"?
2) Why did nutrient concentrations at Bokniseck not increase during the period prior to 1975?
3) Why were total phosphorus concentrations at Bokniseck higher in the period 1980 to 1984, compared to the period 1958 to 1975?
4) Why was there no increase of total inorganic nitrogen concentrations at Bokniseck during the period 1980 to 1984?

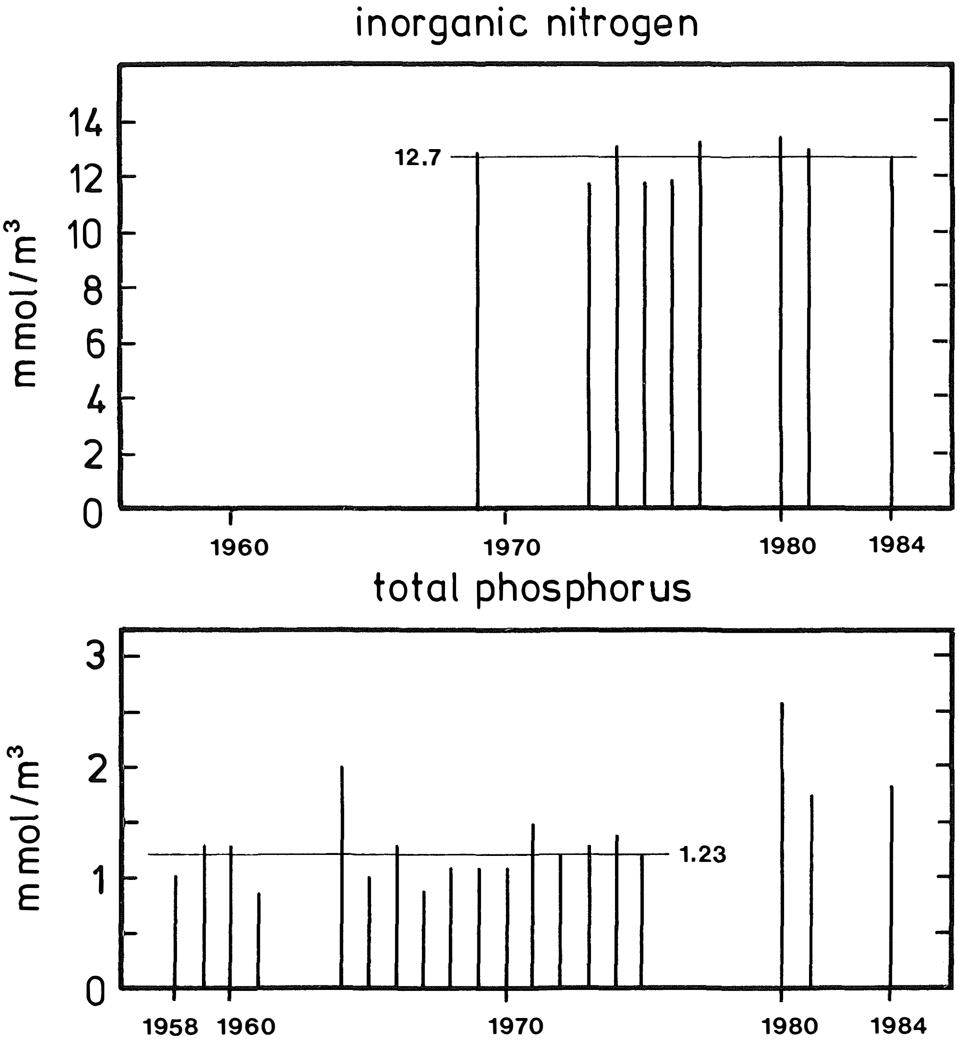


**Figure 3**

Nutrient data from Bokniseck station, mean of January and February data integrated over the water column of 26 m depth. See text regarding sources

**Discussion**

1) Higher nutrient concentrations at Bokniseck station compared with "Fehmarn Belt area"

If winter water nutrient concentrations at Bokniseck station in the West of Kieler Bucht are higher than concentrations in the "Fehmarn Belt area" (Kelds Nor to Gedser Rev), then there must be an extra input of nutrients into the water masses of Kieler Bucht. This extra input, in principle, could have several sources:

a) Inflow with salt water. Salinity is also higher at Bokniseck station than at the Fehmarn Belt station, as Kieler Bucht is more intensely influenced than "Fehmarn Belt area" by salt water intrusions and by inflowing salty bottom water from Great Belt and Little Belt. Unfortunately we have no adequate data on the amounts of water transported and on the nutrient concentrations in this water. Therefore at present it is not possible to quantify this input to compare it with the amounts of nutrients which are exported from Kieler Bucht with outflowing water.

b) Natural and anthropogenic inputs from land, via rivers, sewage, land runoff, groundwater, and via the atmosphere. Data for inputs from Schleswig-Holstein into the Western Baltic, based upon an evaluation for 1972 to 1974, have been published by LARSSON et al. (1985) and were calculated for the Kieler Bucht area (Fig. 2) by GERLACH (1986): 12700 t of total nitrogen and 1500 t of total phosphorus per year, plus 5000 t of nitrogen per year from the atmosphere. In the winter period with higher precipitation and land runoff this could mean 64 t of nitrogen and 4 t of phosphorus per day.

In winter 1975, the 42 $km^3$ water in Kieler Bucht contained about 5900 t of inorganic nitrogen and 1430 t of total phosphorus (8 $mmol/m^3$ N; 1 $mmol/m^3$ P; GERLACH 1986). Thus the amounts calculated as input from land are important. However, as long as no data are available for the import of nutrients with inflowing water masses, no comparative evaluation seems possible. It should be mentioned that input data refer to total nitrogen. Calculations for the water masses of Kieler Bucht, however, refer to inorganic dissolved nitrogen only.

2) Unchanged nutrient concentrations at Bokniseck station prior to about 1975

The fact that nutrient concentrations at Bokniseck station remained unchanged between 1958 (total phosphorus) or 1969 (total inorganic nitrogen) and 1975, is a strong argument against dominant effects of inputs from land or from the atmosphere, regarding the winter situation. During the period prior to 1975 the German economy went up, septic tanks were abandoned and sanitary pipes constructed to connect more and more households with the waters of Kieler Bucht. Sewage treatment facilities were not installed in that period. Nutrient rich imported fodder became the basis for the production of cattle and fowl, the application of nitrogen in mineral fertilizer doubled, and air pollution with nitrogen oxides from burning processes and with ammonia from agriculture increased. If at all, then in this period prior to 1975 one should expect an effect of increasing anthropogenic inputs on the nutrient concentrations at Bokniseck station, but such increase cannot be documented.

Therefore we have to look for other sources and sinks in Kieler Bucht which could mask the effects of increasing nutrient inputs during the period prior to 1975, in addition to possible but undocumented changes via import with saline Skagerrak water.

3) Higher phosphorus concentrations at Bokniseck station in 1980–1984 compared with the period prior to 1975

In the period from about 1972 onwards, many waste water treatment plants have been installed which drastically reduced the input of organic matter, and to some degree the input of phosphorus and nitrogen into Kieler Bucht. A preliminary assessment for the entire Federal Republic of Germany is a decrease of total phosphorus loads by 22 % in the 10 years period 1975 to 1985 (German contribution to the Second Meeting of the Working Group on Nutrients, 1987, Paris Commission). At least for phosphorus it seems therefore that by 1984 the amounts that reached Kieler Bucht via rivers and sewage must have been lower than the 1500 t per year calculated for the period 1972–1974. When nevertheless total phosphorus concentrations at Bokniseck station were higher in 1980 to 1984 compared to 1958 to 1975, this is an additional argument that there are other processes than inputs from land involved which control total phosphorus concentrations in winter water, in addition to inputs from land.

Sources and sinks for dissolved phosphorus in Kieler Bucht are the following compartments: biota, sedimentation of dead organic matter, and the sediment.

a) Biota

According to very crude estimates (GERLACH 1986), in certain seasons of the year up to 460 t of phosphorus might be bound in phytoplankton, 100 t in macrophytes, 320 t in macrozoobenthos, and more in sediment microbes. The phosphorus is recycled between plant biomass, animal and microbial biomass, dead organic matter and dissolved components in the water. We do not know enough about the seasonality of the mineralization processes and therefore we cannot estimate whether differences in biomass from year to year have an impact upon winter water concentrations. In September, 1981, about 3000 t of macrozoobenthos biomass were killed by the wide ranging oxygen depletion which affected all areas of Kieler Bucht deeper than about 20 m (WEIGELT and RUMOHR 1986). About 270 t of nitrogen and 26 t of phosphorus could have been released from these dead animals during their decomposition in the subsequent weeks.

b) Sedimentation of dead organic matter

From cores it is evident that, in the shape of nondegradable organic matter, about 700 t of phosphorus per year are buried in deeper sediment layers (BALZER 1986) via the process of sedimentation. This is a 50 year average. Actual rates of removal of phosphorus from the biosphere by sedimentation will differ very much from year to year. Rates depend not only on sedimentation of organic particles and on mineralization processes in the sediment, but on bioturbation as well. All these processes may have different intensities in different years.

c) Fixation in and remobilisation from the sediment

A large fraction of the phosphorus in the sediment is bound to trivalent iron which occurs in the oxic layers of the sediment above the chemocline. Should this surface layer become anoxic, or should it be reduced in vertical extension, phosphate will be mobilized and released from the sediment into the overlying water masses (Fig. 4). This process is reversible under oxic conditions. BALZER (1986) calculated how much phosphorus could be released from Kieler Bucht sediments in case they become anoxic: up to 1.6 $g/m^2$ from mud, up to 4.0 $g/m^2$ from sandy mud or muddy sand. In Kieler Bucht there are about 300 $km^2$ of mud, 165 $km^2$ of sandy mud and 160 $km^2$ of muddy sand below 20 m water depth. In theory, therefore, up to 1800 t of phosphorus could be released during situations of oxygen depletion, if these should persist over longer periods of time. In September 1981, the oxygen depletion persisted only for a few weeks and therefore, the quantities of phosphate released should have been lower.

However, even when the overlying water masses have been replaced by water masses rich in oxygen, the sediment will continue to be anoxic close to the sediment surface until recolonization by macrofauna capable of bioturbation occurs (WEIGELT 1987).

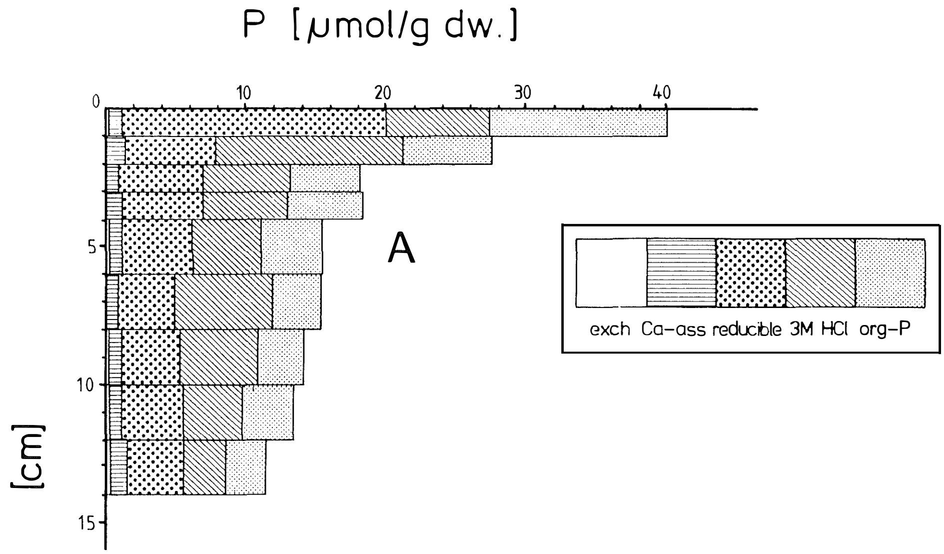


**Figure 4**

Phosphorus concentration in sandy mud from Kieler Bucht, 24 m water depth (54°32′N; 10°41′E, sampled May 20, 1985), exch = absorbed and exchangable P; Ca-ass = Calcium-associated or carbonate-bound P; reducible = easily or moderately reducible P; 3 M HCl = total inorganic P; org P = organic P. From BALZER (1986)

The amounts of phosphorus involved seem to have the same order of magnitude as the amounts which come from land, or are even greater. Therefore changes in phosphorus mobilization from the sediment and from biota may mask effects of changed inputs from land.

Apparently, one can expect large scale mobilization of phosphorus when conditions become anoxic at the sediment-water interface or when the chemocline in the sediment moves upwards due to poor ventilation. Via these mechanisms oxygen depletion is the cause for higher phosphorus concentrations in the overlying water masses. Unfortunately we do not know enough to assess the effect of oxygen depletion in late summer on winter water concentrations of phosphorus. But there is evidence that the oxygen situation of Kieler Bucht became worse in the years 1979 to 1984.

1975 was a year with poor oxygen conditions, as was documented by oxygen measurements at Bokniseck station. There are no data available for the years 1976–1978. Unpublished data (quoted from RUMOHR, WEIGELT, BABENERD and MASKE, manuscripts) indicate that each year from 1979 to 1984 either had negative anomalies in oxygen concentrations close to the seabed, or there are macrofauna records which point to oxygen problems of some degree.

To be sure, the intensity of scientific research increased in the past decade, and many events of oxygen depletion in former times may not have been detected because nobody took notice. Oxygen depletion occurred in Kieler Bucht in 1967 and in 1972, and oxygen depletion has several times been recorded during the past 100 years (RUMOR 1986). But nevertheless a comparison of data from 1957 onwards points to more frequent situations of oxygen depletion since the seventies. This could, in theory, explain higher phosphorus concentrations in winter water.

4) Unchanged nitrogen concentrations at Bokniseck station 1965 to 1984

In the period 1975 to 1984 when inputs of posphorus from land into Kieler Bucht probably decreased somewhat, the inputs of nitrogen did further increase. During this period an increase of winter water inorganic nitrogen concentrations has been observed in the "Fehmarn Belt area" (see Introduction). It is strange not to find a corresponding increase of nitrogen concentrations at Bokniseck station. One has to look for processes in Kieler Bucht which eliminate nitrogen.

Denitrification, or simply spoken the microbial transformation of nitrate nitrogen into atmospheric nitrogen, is a process which works at its best under suboxic conditions, when nitrate is still available, but oxygen is nearly depleted. Frequent events of oxygen depletion should increase the efficiency of the denitrification process. Events of oxygen depletion have been observed more frequently in the period 1979 to 1984. Thus during this period the environmental conditions for the bacteria that produce denitrification were optimal.

## Conclusions

1) Higher nutrient concentrations in the western part of Kieler Bucht compared with the Fehmarn Belt region are correlated with salinity and could be caused by the inflow of Skagerrak water.
2) More frequent events of oxygen depletion in late summers 1979 to 1984 could be the cause for increased mobilization of phosphorus from Kieler Bucht sediments, explaining partly the increased winter water phosphorus concentrations in spite of decreased anthropogenic inputs of phosphorus.
3) Therefore, an assessment of winter water nutrient concentrations alone is no good tool for the evaluation of the effects from anthropogenic nutrient inputs via rivers, sewage, land runoff, groundwater and from the atmosphere.
4) Future research should concentrate a) on sediment-water fluxes of nutrients, and b) on the role of nutrients during the vegetation period following the spring phytoplankton bloom.

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