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THE REGIONAL DISTRIBUTION OF SOME WATER QUALITY VARIABLES IN FINNISH COASTAL WATERS

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Regional distribution of oxygen, phosphorus, nitrogen, silicate and iron concentrations in Finnish coastal waters outside the direct effect of rivers and waste waters were studied. The levels of concentrations in the late 1960's were compared with those of the late 1970's. The distribution of concentrations was found to be dependent in the first place on the water quality in the open sea. The effects of rivers and waste water effluents on the concentrations were modified by the extent of loading, the morphometry of the coastal region and ice coverage in winter. Total nitrogen concentrations increased between the two studied periods, and an increase in total phosphorus was noticed in the late summer samples. In the coastal waters of the Gulf of Bothnia the level of total phosphorus somewhat decreased according to the winter data of these two periods. The ratio of inorganic nitrogen to inorganic phosphorus decreased elsewhere but increased in the coastal waters of the Bothnian Bay. These changes resulted mainly from variation in the Baltic Sea hydrography but to a minor extent also from changes in loading from the land.

Index words: water quality, nutrients, phosphorus, nitrogen, coastal waters, monitoring, Baltic Sea

1. INTRODUCTION

Nutrients play a major role in the regulation of primary production in the Baltic Sea and its coastal waters (e.g. Niemi 1975, Foselius 1978, Alasaarela 1980, Hällfors et al. 1982). The concentrations and interrelations of phosphorus and nitrogen compounds indicate the degree of trophy and loading of the water body. The level of these nutrients has an indirect effect on the oxygen balance of the water body which is also affected by inputs of organic matter from the land.

Besides being an essential nutrient for diatoms, silicate indicates the spreading of river water (Voipio 1961, Niemi 1975). The concentration of iron indicates both river waters and certain industrial waste waters (Voipio and Niemistö 1975, Häkkilä 1983). Iron also plays an important role because of its reactions with phosphorus in water and sediment (Voipio 1969, Grasshoff and Voipio 1981).

Oxygen concentrations and salinity of the Baltic Sea have been monitored since the beginning of this century. The longest continuous series of observation data on nutrients extend to the 1950's, although studies concerning inorganic nutrients were performed as early as in the 1920's (Buch 1932). In the sea areas around Finland, chemical monitoring has been carried out on regular basis since the beginning of the 1960's.

In this work the regional distribution of salinity, oxygen, nitrogen, phosphorus, silicate and iron in Finnish coastal waters was surveyed and changes in the concentration levels between the periods 1966—1970 and 1976—1980 were investigated.

2. MATERIALS AND METHODS

The material consisted of data from 24 sampling stations (Fig. 1). They were usually sampled once in late winter and once in late summer. Samples were taken at depths of 1 and 10 meters and from the water overlying the sea bottom at depths of 10—50 m (st. 16: 80 m). The stations were situated so far from the coast that none of them was permanently affected by any individual polluter or river. The data were obtained mainly from the monitoring programme carried out by the National Board of Waters, Finland. Additional data were obtained from the Finnish Institute of Marine Research.

Analyses were carried out using standard methods (Koroleff 1976, 1979, National Board of Waters 1981). Most of the analytical methods were

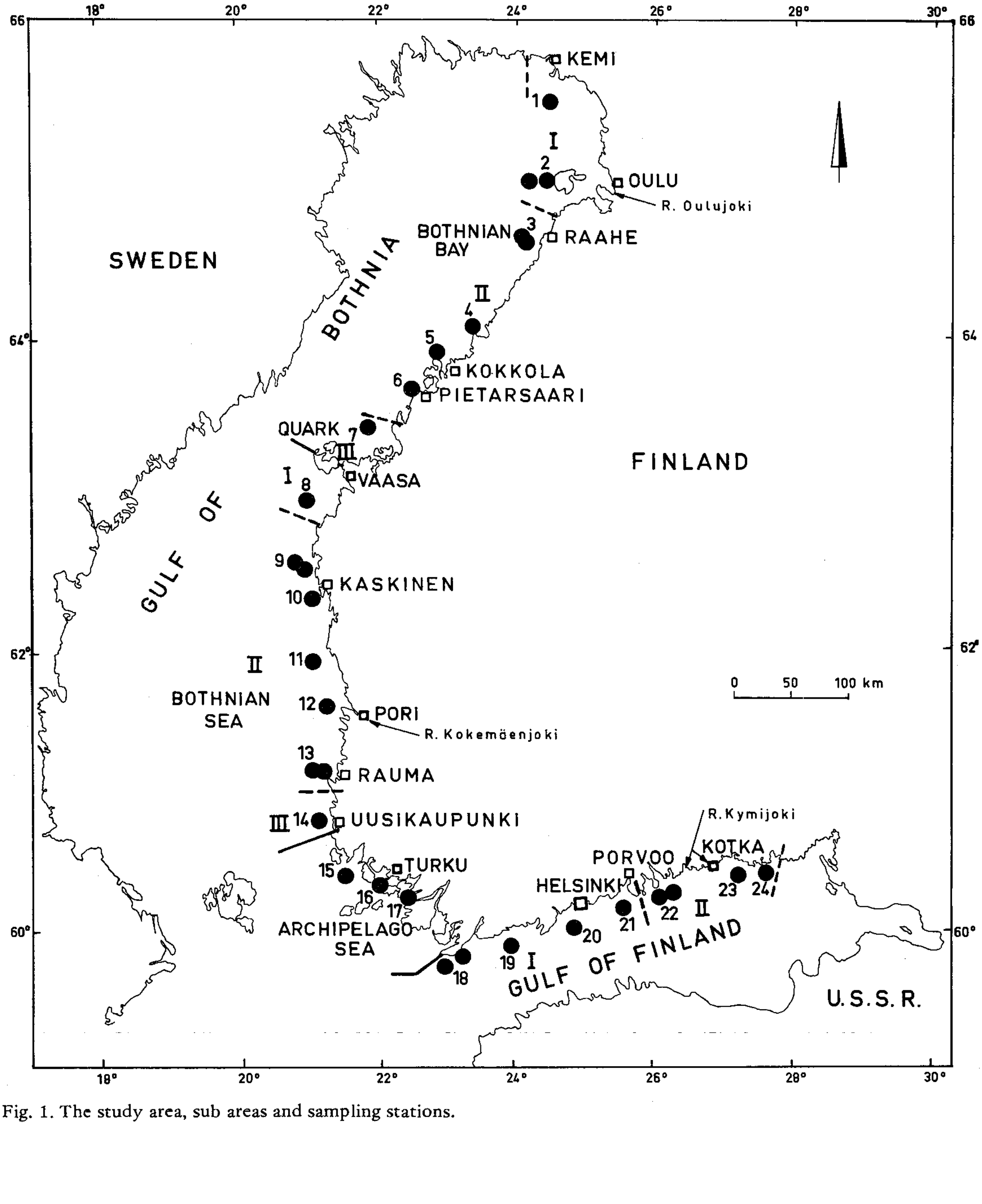

Fig. 1. The study area, sub areas and sampling stations.

changed at the beginning of the 1970's (Erkomaa et al. 1977) and therefore some unreliable trends may appear in the data series.

Mean values and standard deviations were calculated for late winter (usually March) and late summer (usually August) data of each sampling station of the period 1976—1980. Surface waters (1 and 10 m) and bottom water layers were handled separately. Data on inorganic nutrients were, with a few exceptions, available only for the years 1979—1980.

The t-test was used to compare the mean values of salinity, oxygen, total phosphorus, total nitrogen and total iron of the period 1966—1970, formerly reported by Kohonen (1974), with those of the period 1976—1980. The number of data of inorganic nutrients was insufficient to allow statistical treatment; changes in the concentration levels of these variables are, however, discussed.

It should be emphasized that the data of each sampling station are small and the results should therefore be considered merely tentative.

3. RESULTS AND DISCUSSION

3.1 Regional distribution of concentrations

Salinity. The highest mean values (6.5—7.5 ‰, Fig. 2) occurred in the Archipelago Sea and at the entrance to the Gulf of Finland. Salinity decreased with increasing proportion of river water towards the north and the east. Particularly in late summer, the regional distribution in the coastal waters was quite similar to that in the adjacent open sea areas studied e.g. by Pietikäinen et al. (1978) and Perttilä et al. (1980a). In the late winter samples, salinity was, however, clearly lower in the surface layer of the north-eastern Bothnian Bay because of considerable volumes of river water below the ice (Alasaarela and Myllymaa 1978, Alasaarela 1979). In the eastern part of the Gulf of Finland, a clear salinity stratification was observed both in winter and summer due to a strong input of river water into saline water (Perttilä et al. 1980a).

Oxygen. In the winter samples oxygen saturation was in general around 90—95 % both in the surface and at the bottom (Fig. 3). In the eastern Gulf of Finland the concentrations near the bottom were 70—80 % of the saturation values due to decreased vertical mixing caused by the density gradient (cf. salinity, Fig. 2).

In late summer the average surface level of oxygen was around 100 % in all coastal areas, while the bottom values were 85—100 % for the Bothnian Bay, 75—90 % for the Bothnian Sea, 55—70 % for the Archipelago Sea and 35—80 % for the Gulf of Finland. It seems that the degree of trophy of each sea area (e.g. Lassig et al. 1978) was in close correlation with the level of oxygen saturation: the higher the degree of trophy, the lower the saturation level and the greater the deviation in oxygen concentrations in the water near the bottom.

In late summer the average values in the 1—10 m layer were usually smaller by 5—10 units of percentage than the values for the open sea (Pietikäinen et al. 1978, Perttilä et al. 1980a). The winter values were slightly reduced while the standard deviations simultaneously increased in the north-eastern Bothnian Bay, outside the estuary of the River Kokemäenjoki and off the cities of Pietarsaari and Rauma, in the inner Archipelago Sea and in the eastern Gulf of Finland (Pitkänen 1979, Pitkänen and Malin 1980, Perttilä et al. 1980a). This was probably caused by the oxygen — consuming substances in the river and waste waters discharged into these areas (Isotalo and Häkkilä 1978, Jokela 1978, Alasaarela 1979, Kettunen and Lempinen 1983) but also by the vertical density gradient in the eastern Gulf of Finland.

Phosphorus. The values of *total phosphorus* (Fig. 4) were lowest in the coastal waters of the Bothnian Bay (5—15 mg m^{-3}), increasing slightly through the Bothnian Sea (10—20 mg m^{-3}) to the Archipelago Sea (15—40 mg m^{-3}). In the coastal waters of the Gulf of Finland the concentrations at the western sampling stations were roughly on the same level as those obtained in the Archipelago Sea and increased, depending on the depth and season, up to 20—100 mg m^{-3} in the east.

There were considerable differences in concentrations of phosphorus between the seasons and between the surface and bottom layers in the Archipelago Sea and in the coastal waters of the Gulf of Finland. This was in the first place caused by a higher level of primary production and decomposition in these coastal waters and, in the Gulf of Finland, also by the density stratification (see salinity, Fig. 2).

The distribution of phosphorus is greatly determined by the general hydrography of the Baltic Sea. In the Gulf of Bothnia, a significant source of phosphorus is the surface water of the Baltic Proper (Pietikäinen et al. 1978) with additions of loading from the land and air. The level of phosphorus is lower than in the discharging rivers and in the surface water of the Baltic Proper both in winter and in summer. It has been suggested that phosphate is coprecipitated by iron, great quantities of which are discharged into the Gulf of Bothnia (see Voipio 1969, Niemistö et al. 1978, Kremling and Petersen 1984).

In the Gulf of Finland, surface phosphorus is also replenished by upwelling of phosphorus-rich water from deeper layers. In the middle and eastern parts large quantities of nutrients are discharged by rivers, municipalities and industry (e.g. Niemi 1979, Perttilä et al. 1980a, Finnish-Soviet Working Group 1984).

The concentrations of total phosphorus were usually somewhat higher than those measured in the corresponding open sea waters studied by e.g. Voipio and Särkkä (1969), Voipio (1973a, b, 1976), Kohonen (1974), Pietikäinen et al. 1978), Pitkänen (1979), Perttilä et al. (1980a), Pitkänen and Malin (1980) and Koljonen et al. (1984). Exceptions were the coastal waters of the central Bothnian Bay, the central Bothnian Sea and the western Gulf of Finland, all characterized by good mixing conditions or relatively low levels of loading (see Wartiovaara 1978, Enckell-Sarkola et al. 1984).

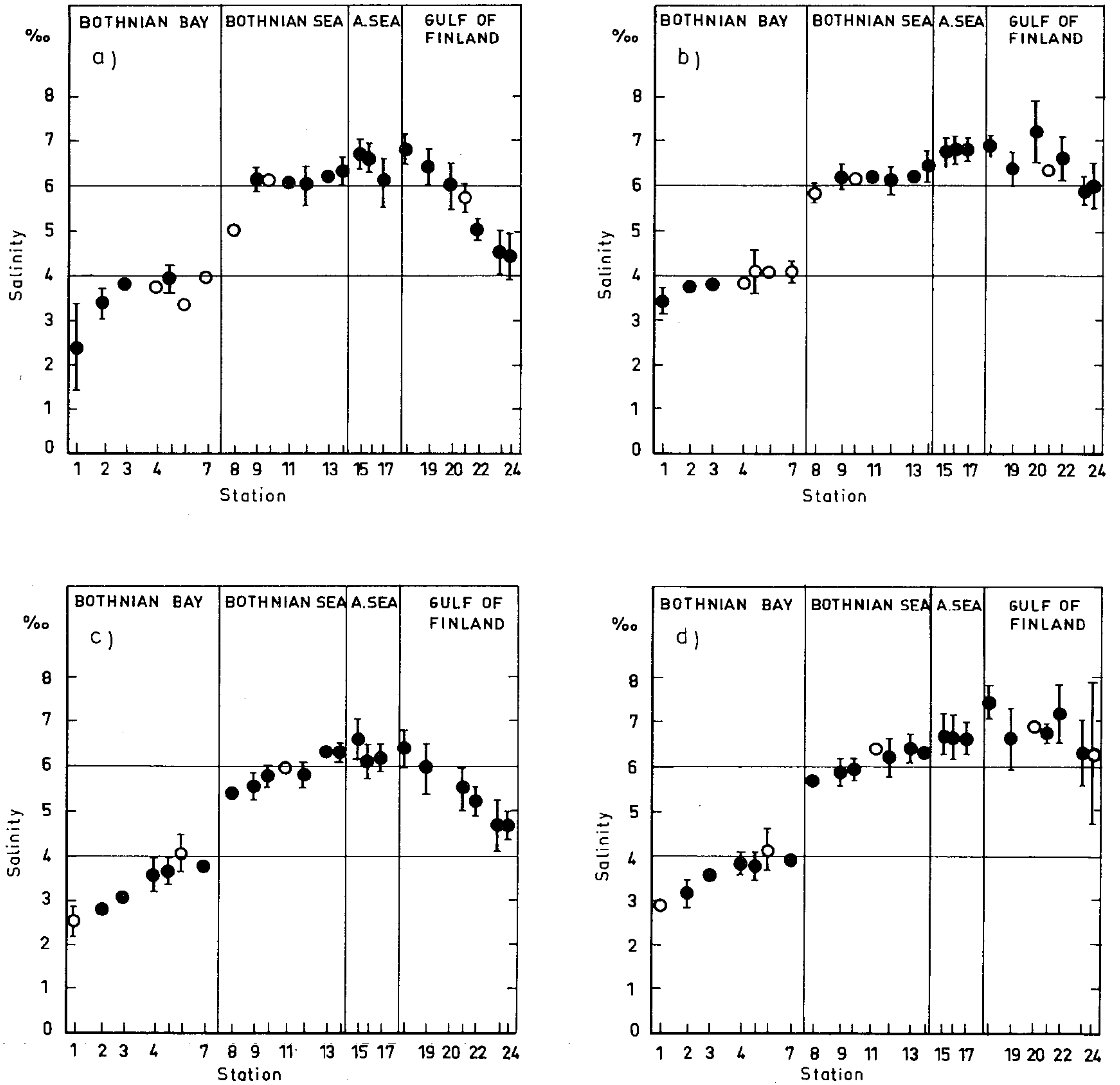

Fig. 2. Distributions of salinity (x̄ and SD). Each dark spot (●) represents the mean value of 3–5 samples, the mean values representing fewer than 3 samples are marked with light spots (○).

The distribution of *phosphate phosphorus* (Table 1) in late winter was similar to that of total phosphorus. Mean values from 1 to 55 mg m^{-3} were recorded. In summer the values in surface water were in general close to zero due to primary production. Increased concentrations in the bottom layer occurred particularly in the Archipelago Sea and in the Gulf of Finland. High values of water near the bottom off Uusikaupunki were probably connected with discharges of the fertilizer industry (Isotalo and Häkkilä 1978, Jumppanen 1982 a).

Nitrogen. Variation in the concentrations of *total nitrogen* was less marked than that of phosphorus with regard to both sampling season, region and depth of sampling (Fig. 5). Variations within the

Table 1. Levels of phosphate phosphorus concentration (mg m^{-3}) in the coastal water areas in 1979—1980. The range of the mean values in each subarea is presented.

Coastal area (see Fig. 1)		Phosphate phosphorus concentration (mg m^{-3})			
		late winter		late summer	
		surface	bottom	surface	bottom
Bothnian Bay	I	7—8	3—6	4[1)]	4[1)]
	II	2—7	1—5	1—6	1—5
	III	3	3	2	2
Bothnian Sea	I	5	7	5	7
	II	5—8	4—8	1—3	2—6
	III	7	55	7	15
Archipelago Sea		15—20	13—21	2—6	12—24
Gulf of Finland	I	21—30	22—40	3[2)]	44[2)]
	II	29—35	34—49	3—7	30—117

[1)] only station 2
[2)] only station 18

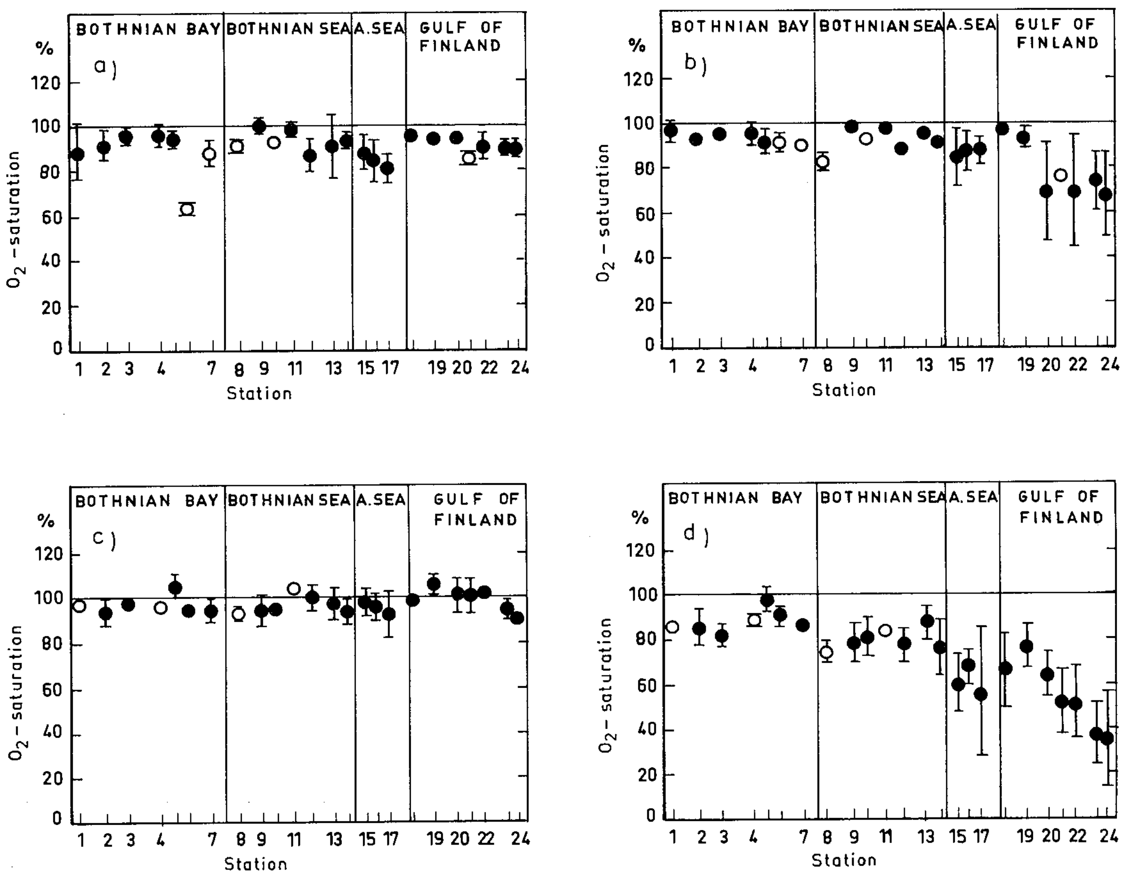

Fig. 3. Distributions of oxygen saturation.

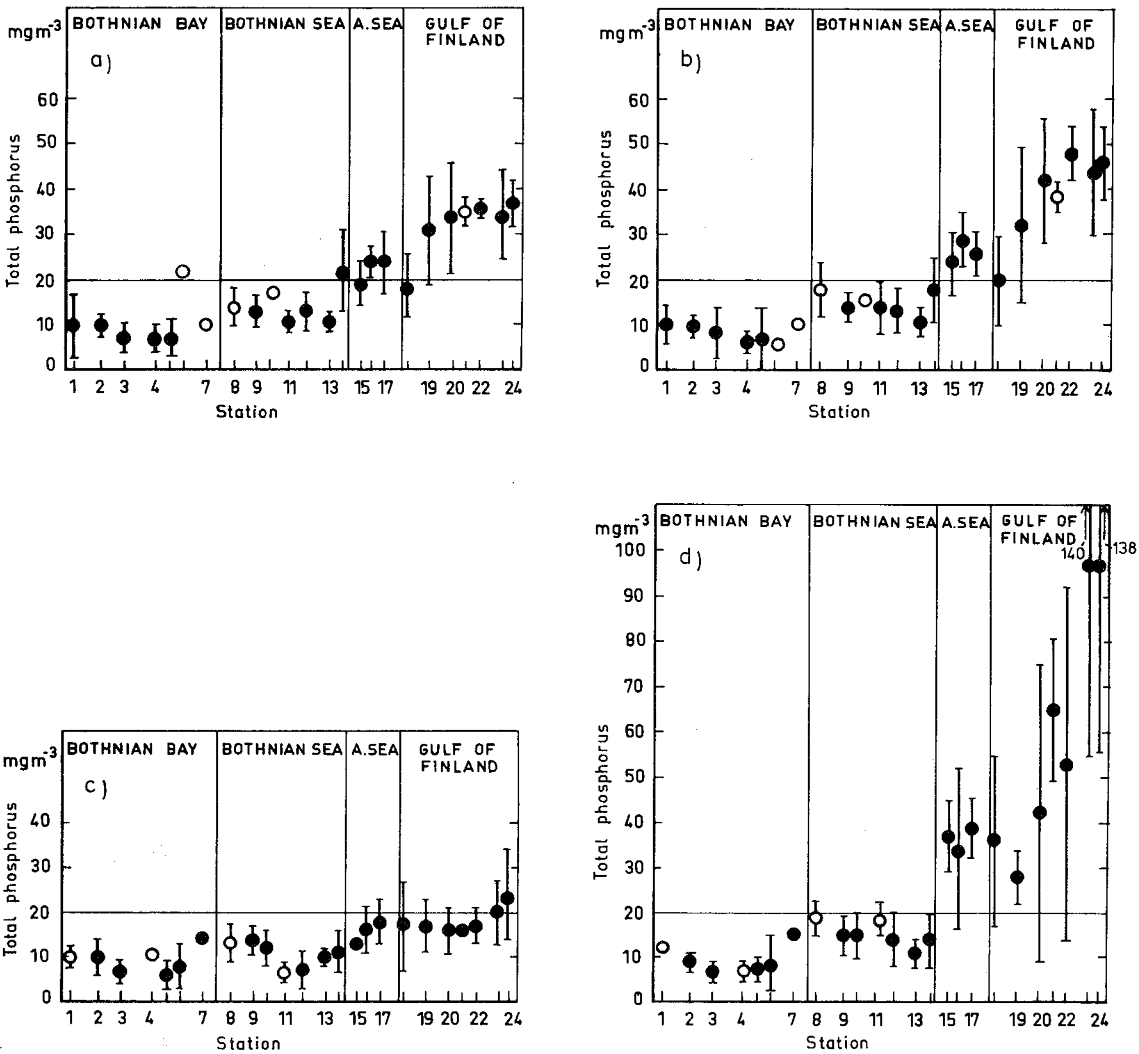

Fig. 4. Distributions of total phosphorus.

individual stations were rather large. The inaccuracy of the analysis method is known (e.g. Gundersen 1980).

Nitrogen concentration was lowest in the coastal waters of the Bothnian Sea (200—300 mg m^{-3}) and increased to about 350 mg m^{-3} in the north-eastern Bothnian Bay. In the Archipelago Sea and the Gulf of Finland the levels recorded were 300—500 mg m^{-3}. Concentrations increased with decreasing salinity.

In most cases, total nitrogen concentrations found in the coastal waters were 50—150 mg m^{-3} higher than those found in the corresponding open-sea areas. However, in the coastal waters of the central Bothnian Sea, the level was almost the same as in the open sea areas. The exceptionally high mean value and deviation recorded in the western part of the Gulf of Finland (station 18) may be a result of nitrogen fixation by blue-green algae, favoured by the low N:P ratio characteristic of this area (Rinne et al. 1979, Niemi 1979, Hällfors et al. 1982). The high winter values off Pietarsaari and Kokkola (stations 5 and 6) were presumably an indication of river and waste waters (Jokela 1978).

The distribution of *nitrate nitrogen* (Table 2) in late winter was rather similar to that of total nitrogen. The relative differences between sea areas

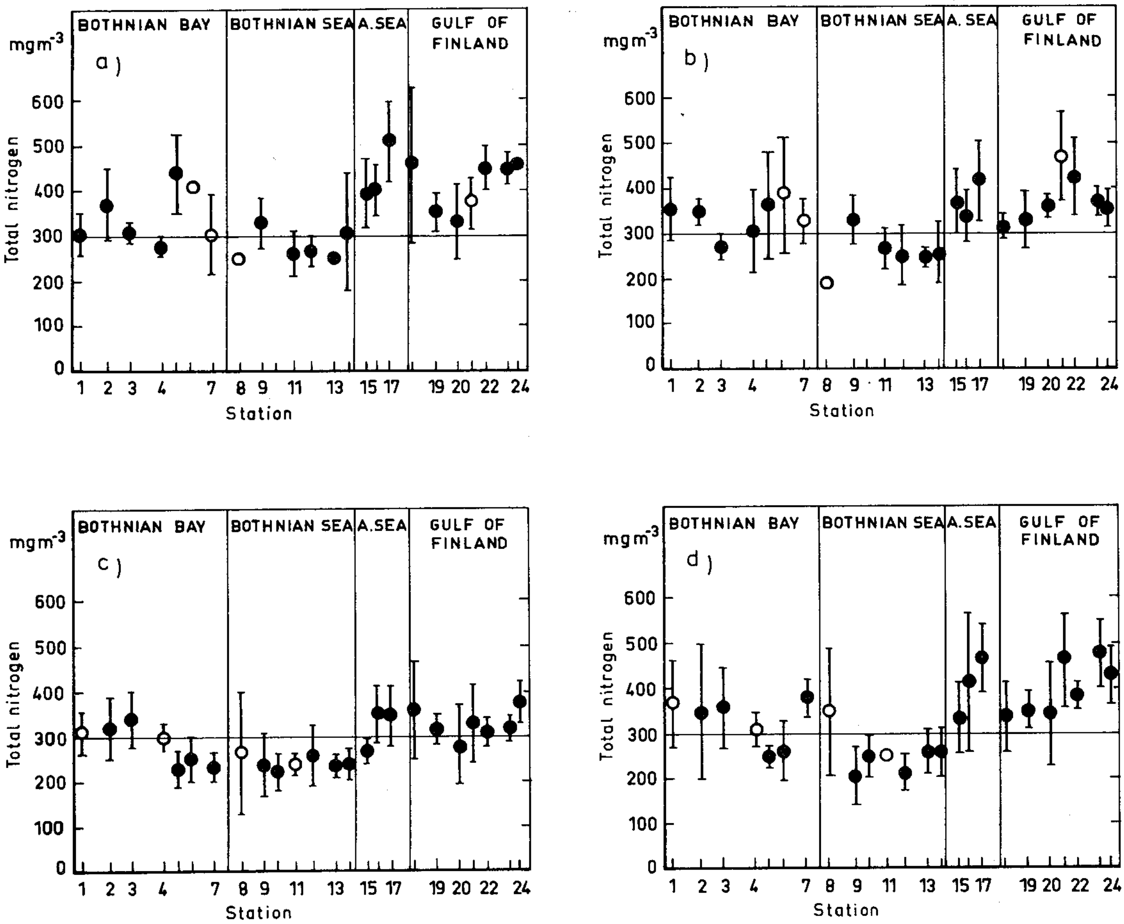

Fig. 5. Distributions of total nitrogen.

Table 2. Levels of nitrate nitrogen concentration (mg m^{-3}) in the coastal water areas in 1979—1980. The range of the mean values in each subarea is presented.

Coastal area (see Fig. 1)		Nitrate nitrogen concentration (mg m^{-3})			
		late winter		late summer	
		surface	bottom	surface	bottom
Bothnian Bay	I	80—100	89—96	56[1)]	64[1)]
	II	83—103	90—105	21—50	46—100
	III	98	101	25	37
Bothnian Sea	I	90	83	1	55
	II	38—55	43—70	1—10	9—28
	III	89	57	3	20
Archipelago Sea		77—210	83—90	6[2)]	110[2)]
Gulf of Finland	I	76—102	87—95	1—4	22—53
	II	121—200	96—140	2—3	64—112

[1)] only station 2
[2)] only station 16

were greater than in the case of total nitrogen. The mean concentration varied from 38 mg m^{-3} in the Bothnian Sea to 200 mg m^{-3} in the eastern Gulf of Finland and in the inner Archipelago Sea. The high values were clearly connected with nitrogen-rich river discharges (Niemi 1973, 1975, Wartiovaara 1978).

In late summer the surface concentration of nitrate was near zero in all areas except off the coast of the Bothnian Bay, where phosphorus was apparently the limiting nutrient for primary production at that time (Niemi 1979, Alasaarela 1980, Koljonen et al. 1984). Concentrations in the bottom water varied a lot (9—112 mg m^{-3}) because of depth variation between different stations.

Table 3. Levels of ammonium nitrogen concentration (mg m^{-3}) in the coastal water areas in 1979—1980. The range of the mean values in each subarea is presented.

Coastal area (see Fig. 1)		Ammonium nitrogen concentration (mg m^{-3})			
		late winter		late summer	
		surface	bottom	surface	bottom
Bothnian Bay	I	11—16	9—10	16[1)]	20[1)]
	II	3—8	3—10	3—15	3—18
	III	10	8	18	20
Bothnian Sea	I	13	16	13	15
	II	6—34	6—31	2—20	4—32
	III	43	19	22	57
Archipelago Sea		6—21	5—22	9—14	27—82
Gulf of Finland	I	6—12	4—9	13—34	41—230
	II	4—10	5—25	1—12	40—117

[1)] only station 2

The *ammonium nitrogen* distribution in late winter was irregular (Table 3). Mean concentrations from 3 to 43 mg m^{-3} were recorded. In late summer the surface values were on about the same level as in winter. Near the bottom, however, the distribution was rather similar to that of total and nitrate nitrogen with concentrations from 3 mg m^{-3} off the coastline of the central Bothnian Sea to 230 mg m^{-3} in the Gulf of Finland.

Except the coastal waters of the central Bothnian Bay and the central Bothnian Sea the ammonium nitrogen level exceeded that of the corresponding open sea waters, where concentrations usually lay below 15 mg m^{-3} according to Pietikäinen et al. (1978), Perttilä et al. (1980a) and Koljonen et al. (1984). Off the cities of Helsinki and Kaskinen this level was exceeded probably due

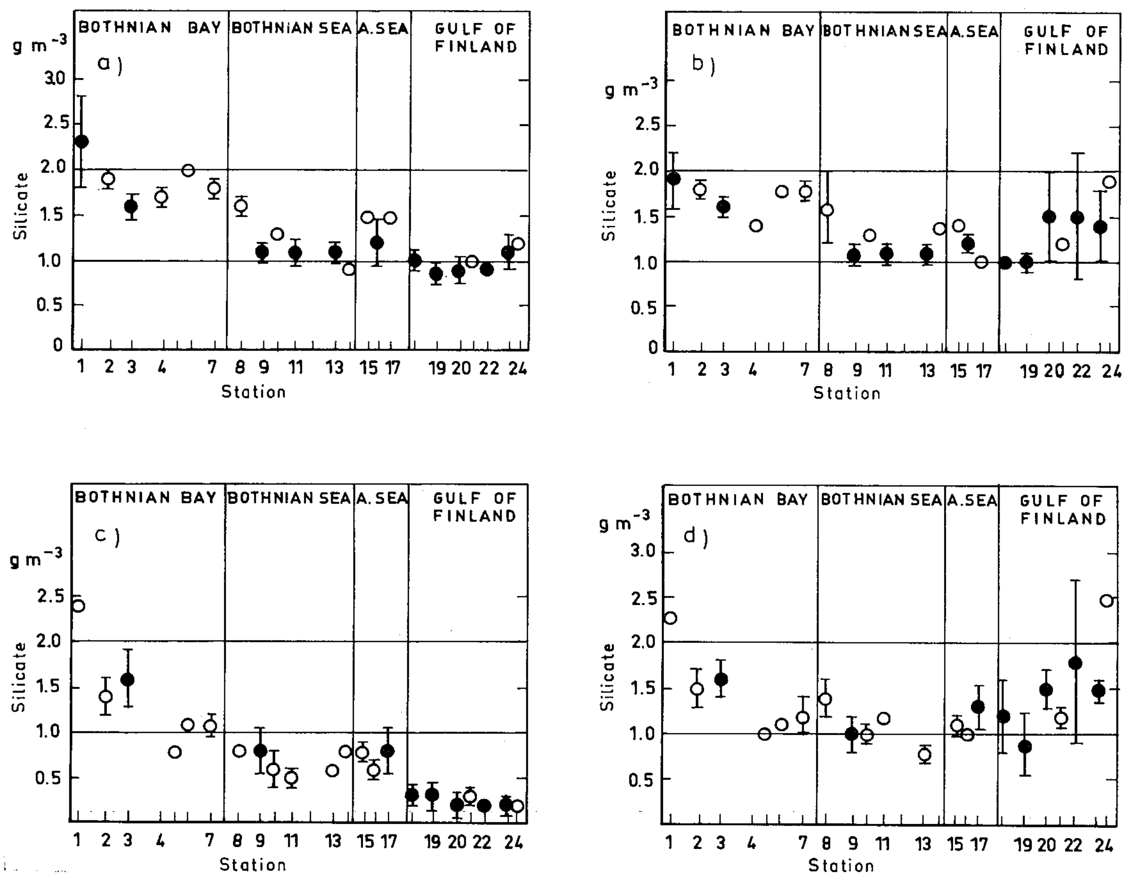

Fig. 6. Distributions of silicate (g SiO_2 m^{-3}).

to direct or indirect effects of municipal waste waters in the first case (Pesonen 1980) and waste waters from chemical wood processing industry in the latter (Talsi and Rekolainen 1982). Off the city of Uusikaupunki the effect of waste waters from the land was also evident (Isotalo and Häkkilä 1978).

Silicate. Mean values of the sampling stations varied from 0.9 to 2.3 g SiO_2 m^{-3} in late winter and from 0.2 to 2.4 g SiO_2 m^{-3} in late summer (Fig. 6). The highest values prevailed in the north-eastern Bothnian Bay and the lowest values in the surface layer of the Gulf of Finland. In general, the concentrations in the coastal waters were close to those of the open sea except in the areas where great quantities of river water were discharged or limited mixing conditions prevailed (Voipio 1961, Niemi 1973, 1975).

The difference between the summer and winter level in the surface layer was clear at all stations because of the effective biological removal of silicate from the surface layer. In the Gulf of Bothnia the concentration of silicate clearly correlated with the ratio between the concentrations of river water and sea water. In the Gulf of Finland, this ratio was less indicative, because most of the silicate originates from the deep water of the Baltic Sea and not from the rivers (Voipio 1961, Niemi 1975). A slight concentration gradient in the winter surface layer of the coastal waters was, however, observable towards the east. Despite the small summer concentration (0.2–0.3 g SiO_2 m^{-3}) in the Gulf of Finland it is supposed that silicate does not act as a limiting nutrient for primary production, even during the vernal diatom maximum (Niemi 1975, Hällfors et al. 1982). In the spring of 1985 silicate was, however, completely exhausted in the coastal waters off Tvärminne, western Gulf of Finland (Niemi, Å., pers, comm.).

Iron. Concentrations of iron varied markedly according to time, place and depth. Mean values from 10 to 600 mg m^{-3} were recorded (Fig. 7). In general the summer values were higher than the winter ones. A vertical gradient towards the bottom also existed at most stations. In winter, in the north-eastern Bothnian Bay where large amounts of river water are discharged into the sea, surface concentrations were greater than the bottom ones.

The level of iron concentrations was usually clearly higher than that in the adjecent open sea as observed by Koroleff (1968), Kohonen (1974), Pitkänen (1979), Pitkänen and Malin (1980), Tulkki et al. (1983). This is caused by high concentrations of iron in river waters. Iron is, however, rather rapidly removed from the water phase during the mixing of river water and saline water (e.g. Sholkovits 1976).

The exceptionally high concentrations in the bottom layer of station no. 12 in the Bothnian Sea originated from the iron contained waste waters of a pigment factory in Pori. High wintertime surface concentrations were additionally caused by the River Kokemäenjoki (Voipio and Niemistö 1975, Häkkilä 1983). It is possible that the iron load from Pori has increased the concentrations in the northern part of the Bothnian Sea as well (Voipio and Niemistö 1975, Pitkänen 1979, Tulkki et al. 1983). Besides river water, industrial iron discharges probably contributed to the elevated wintertime concentrations off Kokkola (Jokela 1978).

3.2 Changes in concentration levels between 1966—1970 and 1976—1980

In general, the concentrations of salt, nutrients and iron increased and the level of oxygen saturation decreased between the two observation periods (Fig. 8). The winter phosphorus concentration in the coastal waters of the Gulf of Bothnia, however, was lower during the latter period. These observations are mostly in accordance with the recorded trends in the outer sea (Pitkänen 1978, Pietikäinen et al. 1978, Perttilä et al. 1980a, Pitkänen and Malin 1980, Koljonen et al. 1984). It should be kept in mind that the analytical methods of nutrients and iron have become more accurate between these two periods and this may affect the results.

Salinity. The average rise of salinity in winter was around 0.5 ‰ in the studied coastal waters. In the late summer this trend was less distinct. The increase in salinity is in accordance with the observed increase in the Baltic Sea (e.g. Perttilä et al. 1980b, Nehring 1984).

Oxygen. There were no significant changes in the wintertime oxygen level. On the basis of the summer results it seems that the average oxygen saturation level somewhat decreased in all coastal waters. The decreased bottom values might be explained with increased decomposition caused by increased production. According to Lassig et al. (1980) and Huttunen et al. (1985), however, no

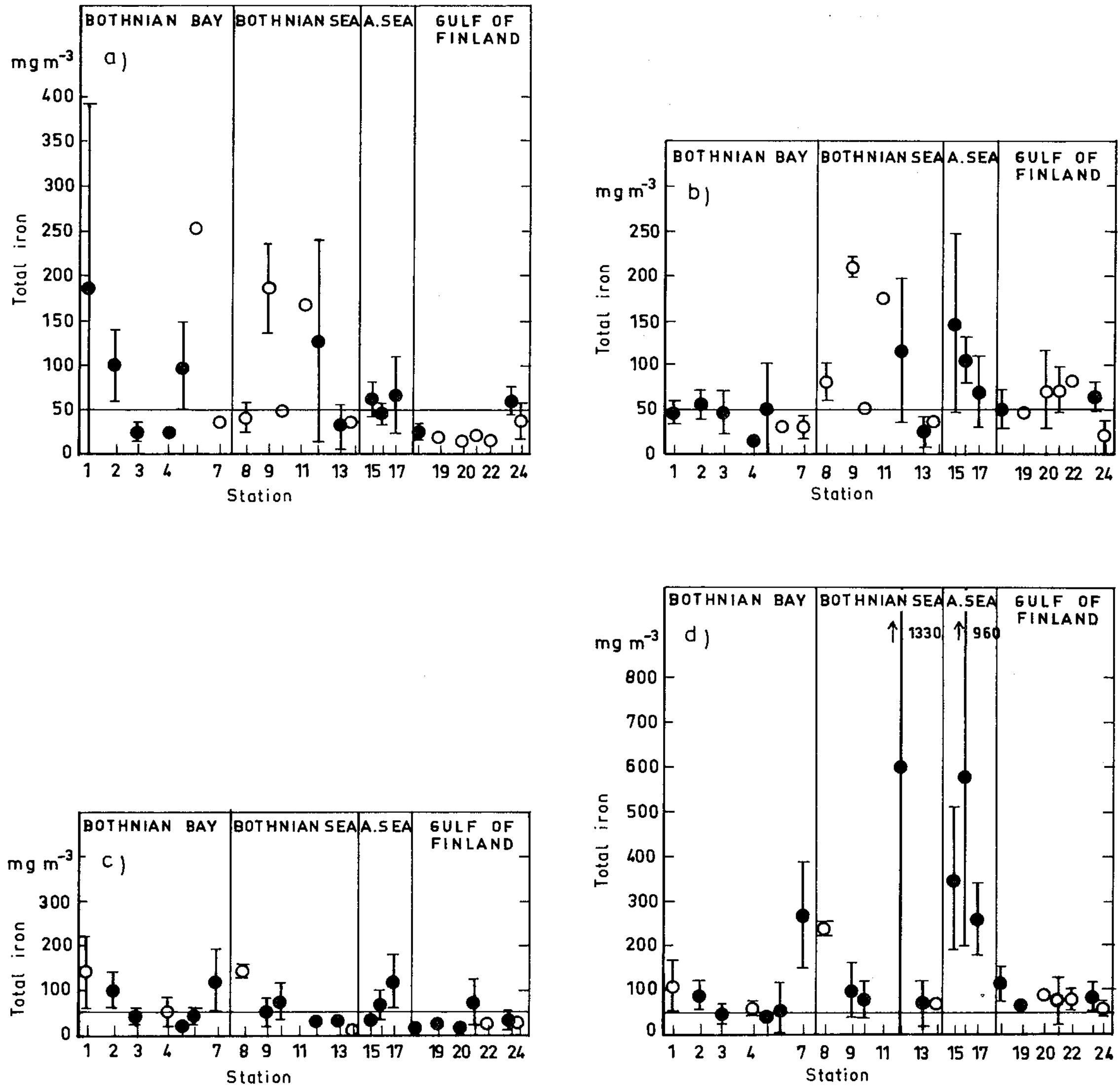

Fig. 7. Distributions of total iron.

clear trend has been observed in the primary production values measured in the non-loaded coastal waters. Off the city of Helsinki, an increasing trend has been observed (Pesonen 1980). Signs of eutrophication have been noticed also in the littoral and pelagial algal communities in the Gulf of Finland and in the Archipelago Sea (Kangas et al. 1982, Kononen and Niemi 1984, Kippo-Edlund and Niemi 1985).

In general, no great changes have been observed in the total loading of oxygen-consuming substances into Finnish coastal waters in the 1970's. The amount of organic loading from industry and municipalities has decreased (Enckell-Sarkola et al. 1984, Finnish-Soviet Working Group 1984).

Total phosphorus. An increase was found between the two periods in summer. The rise in the surface layer was 2—5 mg m^{-3} in the Bothnian Bay, 5—7 mg m^{-3} in the Bothnian Sea 2—4 mg m^{-3} in the Archipelago Sea and 6—9 mg m^{-3} in the Gulf of Finland. Near the bottom the rise was usually somewhat greater.

Between the winter periods, however, concentrations of phosphorus decreased in the coastal

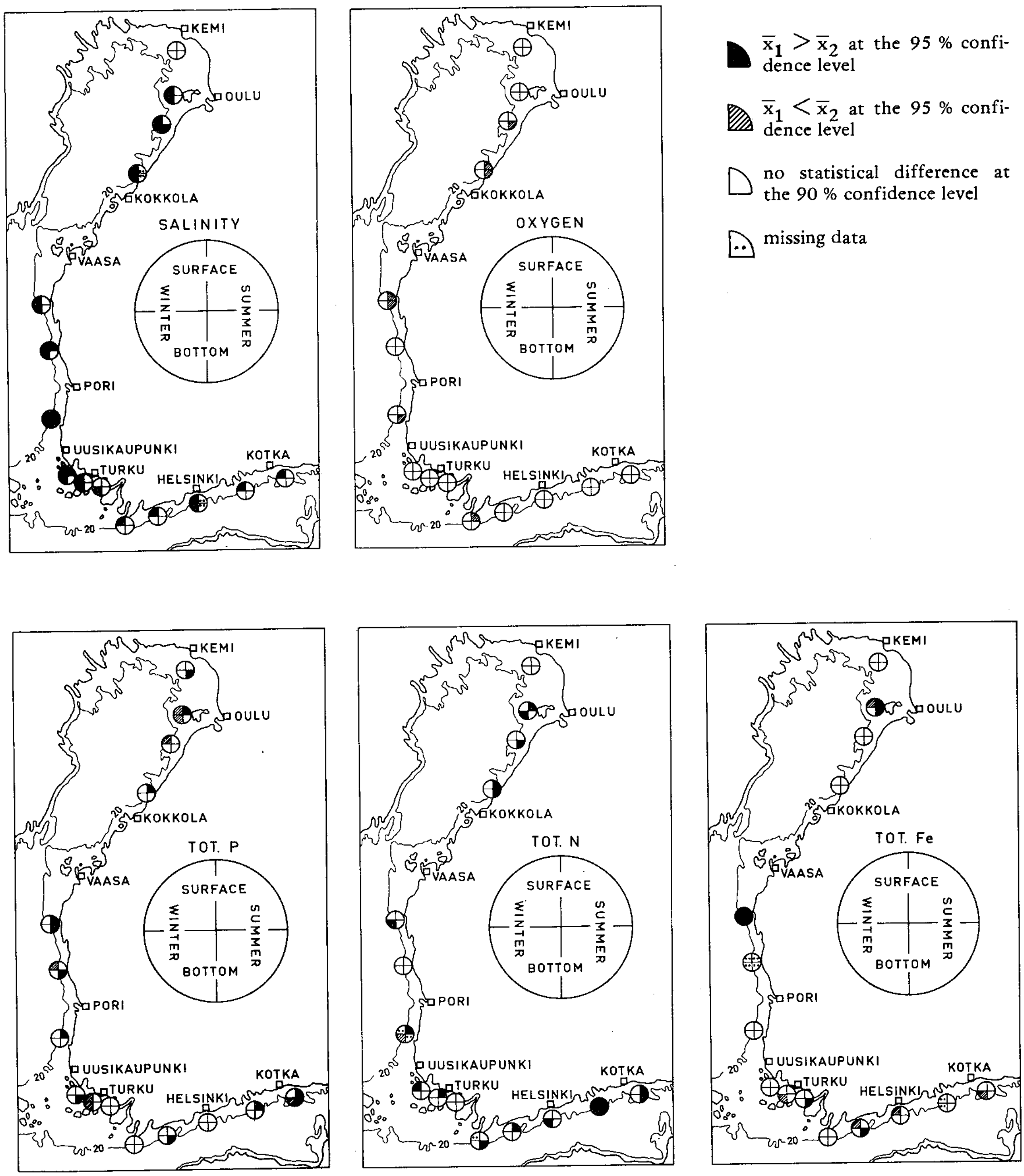

Fig. 8. Mean values of salinity, oxygen, total phosphorus, total nitrogen and total iron in 1976–1980 ($\overline{x}_1$) compared with the corresponding mean values in 1966–1970 ($\overline{x}_2$).

waters of the Gulf of Bothnia, the magnitude of the decrease varying from 3 to 9 mg m^{-3} in the surface layer and from 0 to 14 mg m^{-3} in the bottom layer. In the Gulf of Finland the changes were generally small.

The summertime increase of total phosphorus was apparently mainly due to the increase in the Baltic Sea. The decrease in the wintertime concentrations was probably partly caused by a decrease in the direct phosphorus load from the land during the 1970's (Enckell-Sarkola et al. 1984), and in the load from the rivers Oulujoki, Kokemäenjoki and Kymijoki (Pitkänen 1985). Increased accuracy of the analytical procedure is probably one reason for the decreasing trends.

Total nitrogen. The concentration of total nitrogen increased at most sampling stations between the summer periods 1966—1970 and 1976—1980. The trend was clearest in the Bothnian Bay and in the Gulf of Finland where the nitrogen level rose by 70—130 mg m^{-3} and 30—180 mg m^{-3} respectively depending on the station and depth. In the Archipelago Sea increases of 30—140 mg m^{-3} were observed. In the Bothnian Sea the change was uncertain partly because of lacking information.

According to the winter results the direction of change was in general increasing, but less steep and more unreliable than the trend of the summer periods.

In addition to the increased nitrogen level of the open sea the increased concentrations in the coastal waters may result from the somewhat increased nitrogen loading from the land during the 1970's (Enckell-Sarkola et al. 1984, Finnish-Soviet Working Group 1984). It also seems possible that the loading of inorganic nitrogen from the atmosphere has increased during the 1960's and the 1970's (Järvinen and Haapala 1980).

Nitrogen fixation by blue-green algae may have intensified as a result of a decrease in the N:P — ratio (Table 4, Rinne at al. 1979, Niemi 1979, Lassig et al. 1980, Hällfors et al. 1982). The significance of nitrogen fixation in the Gulf of Bothnia, particularly in the Bothnian Bay, is negligible (Rinne et al. 1981), and is insufficient to explain the increased level in concentration.

Inorganic nutrients. Changes in the levels of phosphate and nitrate concentrations between 1966—1970 and 1979—1980 were in the main similar to those observed for the total values (Tables 4 and 5). The wintertime phosphate-phosphorus concentrations increased, however, in the coastal waters of the Bothnian Sea and the Gulf of Finland. The clearest increases were recorded in the coastal waters of the Gulf of Finland. Concentrations of nitrate-nitrogen increased in the Bothnian Bay also in late summer. The level rose from 10—20 mg m^{-3} in the late 1960's to 20—60 mg m^{-3} in the late 1970's.

The decrease in the concentrations of nitrate in the Archipelago Sea cannot be explained on the basis of changes in the loading or changes in the open sea level of this nutrient.

The ratio of nitrate to phosphate concentrations (w/w) decreased in all areas except the coastal waters of the Bothnian Bay where the ratio clearly increased. These changes were mainly due to

Table 4. The average surface level of nitrate nitrogen (mg m^{-3}), phosphate phosphorus (mg m^{-3}) and the ratio (w/w) of these two variables in the late winters 1966—1970 and 1979—1980.

Coastal area (see Fig. 1)		Station	NO_3-N (mg m^{-3})		PO_4-P (mg m^{-3})		NO_3-N/PO_4-P	
			66—70	79—80	66—70	79—80	66—70	79—80
Bothnian Bay	I	1	62	80	5	8	12	10
		2	80	100	8	7	10	14
	II	3	94	87	7	4	13	22
		4	84	95	3	2	27	43
Bothnian Sea	II	9	52	47	8	8	6.5	5.9
		11	41	38	4	7	10	5.4
		13	57	46	6	7	9.5	6.6
Archipelago Sea		15	102	77	16	15	6.4	5.1
		16	154	118	18	17	8.6	6.9
		17	309	210	16	20	19	11
Gulf of Finland	I	18	55	88	19	21	2.9	4.2
		19	65	102	18	30	3.6	3.4
		20	72	76	20	26	3.6	2.9
	II	22	93	121	16	29	5.8	4.2
		23	138	200	19	35	7.3	5.7

Table 5. The average level of phosphate phosphorus ($mg\ m^{-3}$) and nitrate nitrogen ($mg\ m^{-3}$) in the different coastal water areas in the late summers 1966—1970 and 1979—1980. The range of the mean values in each sea area is presented.

Coastal area (see Fig. 1)		NO_3-N ($mg\ m^{-3}$) 66—70	NO_3-N ($mg\ m^{-3}$) 79—80	PO_4-P ($mg\ m^{-3}$) 66—70	PO_4-P ($mg\ m^{-3}$) 79—80
Bothnian Bay	I	18—20	56[1)]	2—4	4[1)]
	II	7—10	21—50	0	1—6
Bothnian Sea	II	4—7	1—10	0	1—3
Archipelago Sea		1—3	6[2)]	1—3	2—6
Gulf of Finland	I	1—4	1—4	1	3[3)]
	II	2—6	2—3	1—3	3—7

[1)] only station 2
[2)] only station 16
[3)] only station 18

changes in the open sea, but probably also to changes in the N:P — ratio of loading especially in the Archipelago Sea where the N:P — ratio of loading clearly decreased during the 1970's (Enckell-Sarkola et al. 1984).

The increase of the ratio was very clear in the coastal waters of the Bothnian Sea and in the Archipelago Sea. In the late 1970's the nutrient ratio was close to ideal for primary production, if the N:P — ratio 6—7:1 by weight (Redfield et al. 1963, Sen Gupta and Koroleff 1973) is considered optimum for algae in the Baltic Sea. The somewhat increased summer level of phosphate seems to be in accordance with this observation (Table 5), but this may also be due to the change in the analytical procedure.

Free inorganic nitrogen was present at all stations in both of the late summer periods. Especially the concentrations of ammonium were relatively high, probably due to loading at some of the stations. It was not possible to take into account the effect of ammonium on the nutrient ratio because the analytical method had changed.

Iron. A slightly but rather unreliably rising trend was observed in the iron level in the late summer samples between the two periods. This was probably connected with a minor increase in the iron concentrations observed in the data of the rivers discharging into the Finnish coastal waters in the 1970's. In the late winter values, the direction of change in the coastal waters was in general slightly decreasing.

At station no. 9 in the Bothnian Sea a clear increase in the iron level was evident, particularly in the bottom layer both in winter and summer. It is possible that the great quantities of industrial wastes containing iron, which are discharged off the city of Pori, have increased the level of iron in this part of the Bothnian Sea, although the iron load has decreased during the 1970's (Voipio and Niemistö 1975, Pitkänen 1979, Häkkilä 1981, 1983, Tulkki et al. 1983).

4. CONCLUSIONS

At the coastal sampling stations the water quality reflected in the first place the conditions prevailing in the open sea. The north-eastern Bothnian Bay, the archipelago in the Quark, the inner Archipelago Sea and the coastal waters of the eastern Gulf of Finland, however, clearly differed from the outer areas and more open waters of the corresponding sea areas. This can be explained by a restricted mixing with river and waste waters being discharged into these coastal waters.

The effect of waste water discharges containing nutrients or susbtances consuming oxygen was usually not very clear at a distance of 5—15 km from the coast line, if good mixing circumstances prevailed. For example, only slight signs of purified waste waters of nearly one million inhabitants could be seen about 15 km off the city of Helsinki. Even the effects of the heavily loaded River Kokemäenjoki were quite small about 10 km off its estuary.

The variables studied were not specific for all industrial waste waters. It was possible, however, to detect some effects of chemical wood-processing industry off Pietarsaari, Kaskinen and Rauma in the Gulf of Bothnia. The effect of pigment industry in Pori and fertilizer industry in Uusikaupunki was apparent. The combined effect of river and waste waters was extensive in the north-eastern Bothnian Bay, in the inner Archipelago Sea and in the eastern Gulf of Finland.

The increase in nutrient concentrations reflected, to a considerable extent, changes in the concentrations of the Baltic Sea, but probably also changes in loading in the case of nitrogen. The effect of the hydrographical changes was clearly observable in the coastal waters of the Gulf of Finland, where a rise of salinity, phosphorus and nitrogen levels was evident between the late 1960's and the late 1970's. In the Gulf of Bothnia, the increase was more inconsistent, probably because of a less direct contact with the Baltic Proper. According to the winter data, phosphorus concentrations even decreased, which was in accordance with the simultaneously decreased loading from the land, but may also be due to the improved analytical procedure.

The observed decrease in the inorganic N:P — ratio is important especially in the Bothnian Sea and in the outer Archipelago Sea because the nutritional conditions became more favourable for nitrogen-fixing blue-green algae.

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TIIVISTELMÄ

Työssä tarkasteltiin ravinteiden sekä eräiden muiden veden kemiallista laatua kuvaavien tekijöiden keskimääräistä jakautumista Suomen rannikkovesissä. Lisäksi selvitettiin pitoisuuksien muuttumista vuosijaksojen 1966—1970 ja 1976—1980 välillä. Aineisto oli peräisin vesihallituksen ja Merentutkimuslaitoksen seurantatutkimuksista. Tilastolliseen käsittelyyn otettiin tiedot 24:ltä maalta tulevan kuorman välittömän vaikutuspiirin ulkopuolella sijaitsevalta havaintoasemalta.

Avoimien rannikkovesialueiden pitoisuudet olivat yleensä lähellä vastaaviin ulappa-alueiden pitoisuuksia. Perämeren koillisosassa, Merenkurkun saaristossa, Saaristomeren sisäosissa ja Suomenlahden itäosassa rannikon mataluus ja rikkonaisuus yhdessä joki- ja jätevesikuorman kanssa aiheuttivat vastaavista ulappamerialueista selvästi poikkeavan vedenlaadun. Maalta tulevan kuorman vaikutuksia todettiin lisäksi Kokkolan, Pietarsaaren, Kaskisten, Porin, Rauman, Uudenkaupungin ja Helsingin edustoilla sijaitsevilla asemilla.

Rannikkovesien kokonaistyppipitoisuudet nousivat vuosijaksojen 1966—1970 ja 1976—1980 välillä. Fosforin kohdalla nousua tapahtui vain loppukesän näytteissä. Kehitys johtui pääosin vastaavien pitoisuuksien kasvusta Itämeren pääaltaan pintakerroksessa. Typen kohdalla myös kuormituksen kasvu mahdollisesti kohotti pitoisuuksia. Pohjanlahden talviaikaisissa kokonaisfosforipitoisuuksissa todettu lasku liittynee osittain kuormituksen pienenemiseen. Myös analyysimenetelmän tarkentuminen on saattanut vaikuttaa tuloksiin.

Epäorgaanisen typen ja fosforin talviaikaisten pitoisuuksien suhde pieneni kaikkialla muualla paitsi Perämeren rannikkovesissä, jossa se kasvoi. Etenkin Saaristomerellä ja Selkämeren rannikkovesissä ravinnesuhde siirtyi ilmakehän typpeä sitovia sinileviä suosivaan suuntaan.

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