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CONTENT AND DISTRIBUTION OF PHOSPHORUS AND NITROGEN IN THE COASTAL WATERS OF WEST ESTONIA

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Abstract. The shallow semiclosed sea area between continental Estonia and its western islands was studied. The main inflow of fresh water, $865 \cdot 10^6$ $m^3 \cdot yr^{-1}$, from the Kasari River falls into the inner part of Matsalu Bay, with the P load 100 $t \cdot yr^{-1}$ and N load 2000 $t \cdot yr^{-1}$. The semiclosed central part of Haapsalu Bay receives municipal and industrial sewage waters. The influence of nutrient discharge from land was more obvious and harmful in the semiclosed inner parts of the bays where nutrient uptake by water vegetation occurred in the growth period. Intensive production of organic matter and accumulation of nutrients lead to a constant eutrophication process in the coastal areas of West Estonia.

Key words: Baltic Sea, coastal waters, salinity, phosphorus, nitrogen.

INTRODUCTION

The coastal region of West Estonia is a peculiar part of the Baltic Sea with very variable hydrological conditions and a high biological productivity. Its most interesting area is Matsalu Bay, which is part of the Matsalu Wetland of international importance. The coastal area of West Estonia is also a significant recreation region, the town of Haapsalu being a well-known health resort with curative mud baths.

The aim of this research was to observe the concentration and distribution of nutrients in the water of the coastal zone as affected by human activity. The investigation is part of a complex study of the hydrochemical and hydrobiological regime of the coastal waters of West Estonia, carried out by the Department of Marine Biology of the Institute of Zoology and Botany, Estonian Academy of Sciences.

STUDY AREA

The sea area between continental Estonia and its western islands belongs, according to the Baltic Marine Environmental Protection Commission, to the Baltic subregion "The Gulf of Riga" (Baltic. . ., 1990). It is a shallow area (mean depth 4.9 m, maximum depth 22 m) with a specific hydrological regime of an archipelago zone where water exchange with the open Baltic (Fig. 1) is restricted. There are numerous straits between the islands, from which this sea area has got its name — Väinameri, i.e. the Sea of Straits. About 85% of the water exchange of the Väinameri passes through the straits of Suur Väin and Hari Kurk. In the annual budget the amount of water inflow through the strait of

Suur Väin into the Väinameri exceeds the outflow through Hari Kurk into the entrance area of the Gulf of Finland (Мардисте, 1974). This means that the Väinameri is affected by water from the Gulf of Riga. The main fresh-water inflow to this area, about $865 \cdot 10^6\ m^3 \cdot yr^{-1}$ from the Kasari River, falls into the eastern part of Matsalu Bay through a dredged canal, which collects also the waters of other rivers. The discharge of the Kasari River makes up about 91% of the total fresh-water inflow to Matsalu Bay and exceeds the amount of water in this bay about 8 times (Eipre & Pärn, 1982; Mardiste & Kaasik, 1985; Ресурсы ..., 1972). Some of the small rivers (Taebla, Võnnu, Uuemõisa, and others) bring rich-in-nutrients fresh water into the eastern part of Haapsalu Bay. It is a very shallow area (depth mostly below 1 m) consisting of semiclosed regions partly separated by peninsulas. The main fresh-water inflow to Haapsalu Bay comes through its easternmost part. The water exchange between the eastern and central parts of Haapsalu Bay is limited. The central part of Haapsalu Bay receives municipal (25%) and industrial (55% from the food-processing industry) sewage waters (Velner et al., 1980) from the town of Haapsalu (13 000 inhabitants). Besides, a few small rivers, streams, and ditches fall into the Väinameri.

The water temperature of the Väinameri varies in a wide range during the year. The mean water temperature is from —0.2 to —0.3°C in the coldest month, February, and from 17.5 to 18.5°C in the warmest month, July (Mardiste, 1970). The vertical gradient of water temperature is, as a rule, small but may be considerable in some cases due to strong western currents from the open Baltic. The duration of the ice cover is long, lasting usually from the second half of November till the end of April.

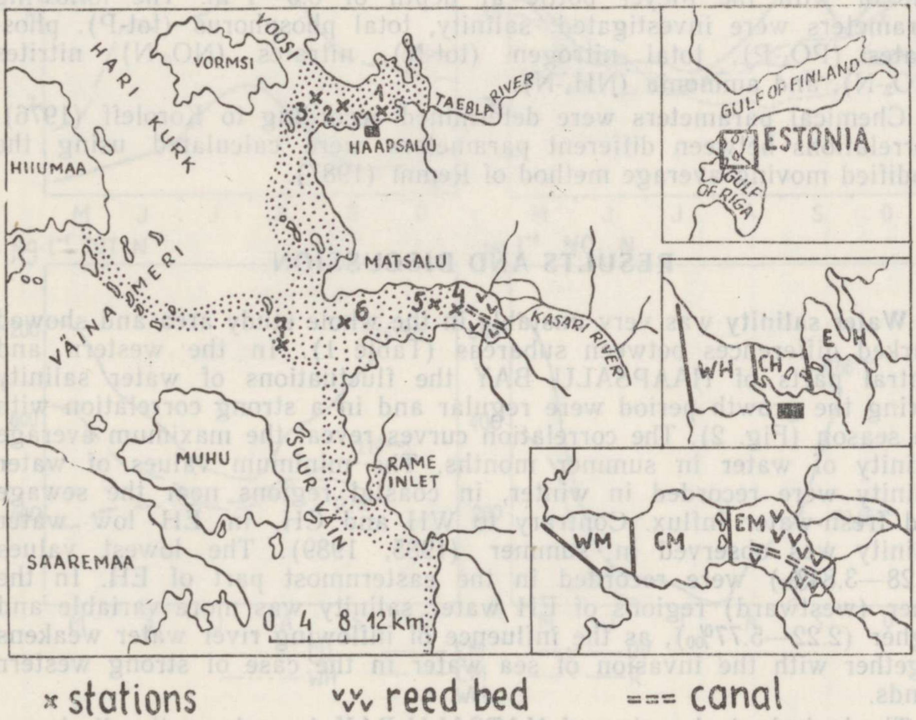

Fig. 1. Study area (dotted), its division, and location of recurrent sampling stations.

MATERIAL AND METHODS

The investigations were carried out in the eastern coastal waters of the Väinameri and on the section from Matsalu Bay to Hiiumaa Island. The indented coastline forms a number of bays in the area among which the largest are Haapsalu Bay and Matsalu Bay. Both were investigated in detail. Observations were carried out also in the semi-closed and unpolluted Rame Inlet. The overwhelming part of the study area is shallow, the depth is frequently less than 1 m, reaching 10 m only at a few stations.

The bays and their separate parts have different hydrological regimes and impact of human activity, therefore they will be discussed separately. They are denoted as follows: WH — the western part of Haapsalu Bay, CH — the central part of Haapsalu Bay, EH — the eastern part of Haapsalu Bay, WM — the western part of Matsalu Bay, CM — the central part of Matsalu Bay, EM — the eastern part of Matsalu Bay, and R — the Rame Inlet. Data on the waters of the open coastal area and the central part of the Väinameri between continental Estonia and islands without bays are discussed together and this region is called the open coastal area of the Väinameri (OV).

Investigations in separate areas were carried out in the following years: Haapsalu Bay — 1976 . . . 1979, 1985, Matsalu Bay — 1977 . . . 1987, Rame Inlet — 1981 . . . 1983, and open coastal area of the Väinameri — 1981 . . . 1983, 1986 . . . 1987. In the discussion of the distribution of nitrogen compounds in the water of Haapsalu Bay and the water quality of the eastern part of Haapsalu Bay, data from the years 1989 . . . 1990 are referred to. These data were not included in the statistical calculation together with other data.

The water samples were taken with the Ruttner type plastic bathometer or with the Meyer bottle at depth of 0.5—1 m. The following parameters were investigated: salinity, total phosphorus (tot-P), phosphates (PO_4-P), total nitrogen (tot-N), nitrates (NO_3-N), nitrites (NO_2-N), and ammonia (NH_4-N).

Chemical parameters were determined according to Koroleff (1976). Correlations between different parameters were calculated using the modified moving average method of Remm (1987).

RESULTS AND DISCUSSION

Water salinity was very unstable in the whole study area and showed marked differences between subareas (Table 1). In the western and central parts of HAAPSALU BAY the fluctuations of water salinity during the growth period were regular and in a strong correlation with the season (Fig. 2). The correlation curves reveal the maximum average salinity of water in summer months. The minimum values of water salinity were recorded in winter, in coastal regions near the sewage and fresh-water influx. Contrary to WH and CH, in EH low water salinity was observed in summer (1985, 1989). The lowest values (1.28—3.84‰) were recorded in the easternmost part of EH. In the other (westward) regions of EH water salinity was more variable and higher (2.22—5.77‰), as the influence of inflowing river water weakens together with the invasion of sea water in the case of strong western winds.

The hydrological regime of MATSALU BAY depends on the discharge of rivers (mainly the Kasari River) and on the direction and speed of the wind. The discharge of the Kasari River is very variable during the year, with floods in spring and autumn and low water in summer. The mean discharge of the Kasari River makes up about 32% of the mean annual discharge at a medium precipitation level in March—April, 32% in May—October, and only 7% in June—August (Eipre & Pärn, 1982). This affects notably the seasonal and spatial dynamics of water salinity in Matsalu Bay. The greatest seasonal fluctuations of water salinity were observed in EM and CM (Fig. 2). The curves of mean water salinity show maximum values in July—August. In WM the water exchange with the open area of the Väinameri is good and therefore water salinity here is higher and more stable. In winter hydrological conditions are greatly different from those of the growth period. In EM fresh water had practically gathered under the ice cover. In CM and WM stratification had taken place with a thin layer of low-salinity water under ice flowing out of the bay. For example, on March 26, 1987, when the thickness of the ice cover reached 90—95 cm, the salinity of the upper water layer (10—20 cm) was between 0.82—0.86‰ in CM and 1.31—2.75‰ in WM (Table 2), where fresh water was more thoroughly mixed with seawater. The water salinity of the near-bottom layer varied between 5.72—5.75‰ and 5.63—5.97‰, respectively.

The salinity of water in the RAME INLET was more stable in the growth period; however, no regular seasonal fluctuations were observed.

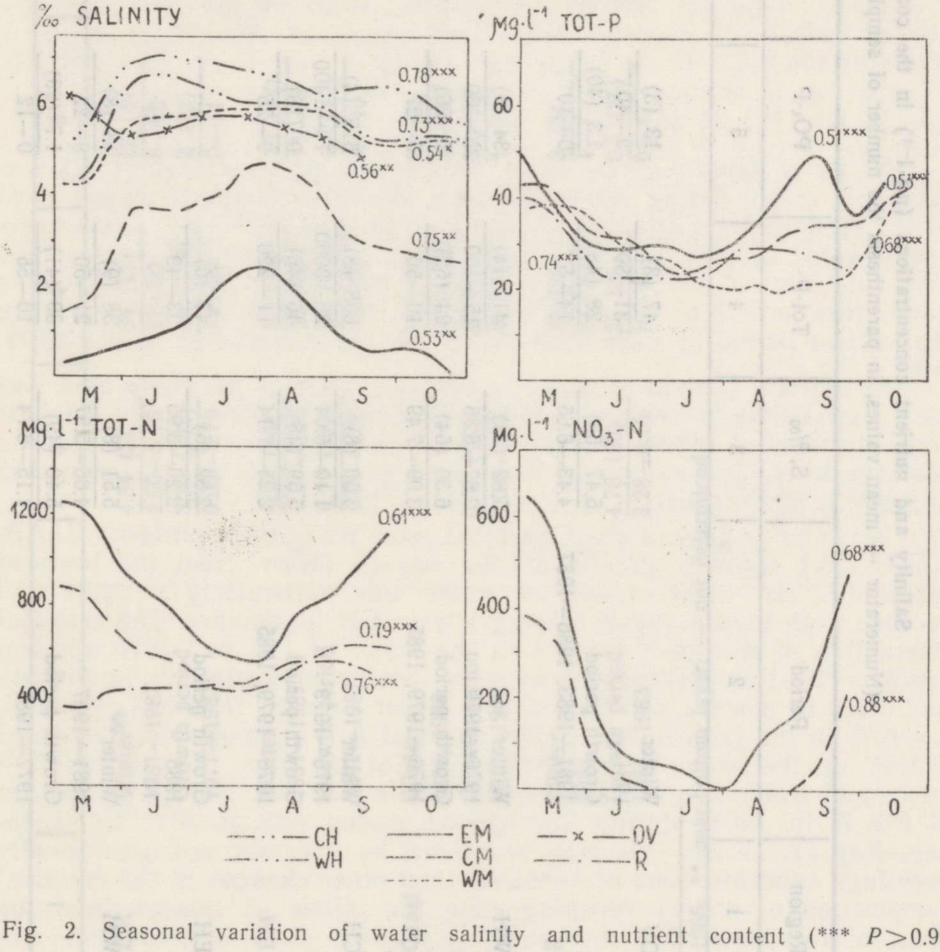

Fig. 2. Seasonal variation of water salinity and nutrient content (*** $P>0.99$, ** $P>0.95$, * $P>0.90$).

Table 1

Salinity and nutrient concentrations ($\mu g \cdot l^{-1}$) in the coastal waters of West Estonia
(Numerator — mean values, in parenthesis the number of samples; denominator — variation ranges)

Region	Period	S, ‰	Tot-P	PO_4-P	Tot-N	NO_3-N	NO_2-N	NH_4-N
1	2	3	4	5	6	7	8	9
OV	Winter 1981	—	47 (3) 31—80	13 (3) 2—40	686 (3) 590—850	353 (3) 315—410	6 (3) 5—8	49 (3) 0—130
	Growth period 1981—1983, 1986—1987	5.47 (53) 4.43—6.65	28 (48) 14—52	1.3 (40) 0—10	355 (41) 170—670	19 (39) 0—90	1 (39) 0—6	5.7 (39) 0—32
WH	Winter 1976—1979	5.82 (14) 2.87—6.86	41 (14) 15—100	34 (8) 20—60	—	—	—	—
	Growth period 1976—1979, 1985	6.30 (64) 3.99—7.49	24 (62) 10—50	7 (26) 0—27	372 (5)* 330—440	—	—	—
CH	Winter 1976—1979	3.50 (8) 1.10—6.04	698 (8) 26—3000	512 (4) 70—1400	—	—	—	—
	Growth period 1976—1979, 1985	5.59 (48) 2.25—7.14	46 (45) 11—220	9 (18) 0—25	582 (5)* 300—730	—	—	—
EH	Growth period 1985	2.82 (6) 2.26—3.95	43 (6) 33—49	—	780 (6) 620—870	—	—	—
WM	Winter** 1981—1987	5.51 (8) 4.66—5.97	38 (9) 21—50	18 (8) 9—22	1099 (8) 990—1280	538 (8) 520—1030	20 (8) 10—27	15 (8) 0—125
	Growth period 1977—1987	5.40 (49) 1.15—6.74	30 (41) 10—55	1.7 (23) 0—12	375 (28) 210—670	26 (27) 0—195	0 (15) 0	1.8 (21) 0—14

1	2	3	4	5	6	7	8	9
CM	Winter** 1981—1987	4.34 (5) 2.50—5.75	34 (15) 21—50	13 (4) 8—22	1348 (4) 1180—1600	649 (4) 580—770	16 (4) 7—20	30 (4) 0—55
	Growth period 1977—1987	3.30 (132) 0.05—5.70	34 (119) 14—65	2 (72) 0—14	615 (86) 320—1280	115 (78) 0—700	0.4 (71) 0—11	1.5 (67) 0—9
EM	Winter 1981—1987	0.07 (14) 0.04—0.25	87 (18) 22—350	39 (12) 11—65	2225 (11) 780—2800	1111 (11) 600—1820	10 (12) 3—37	30 (11) 0—98
	Growth period 1977—1987	0.97 (160) 0.04—3.96	34 (135) 13—90	3 (112) 0—40	905 (120) 310—1820	230 (115) 0—1110	3.4 (112) 0—23	2.4 (106) 0—32
Canal	Winter 1986, 1988	—	147 (3) 115—180	82 (3) 80—85	3880 (3) 2160—6720	2511 (3) 1620—3400	14 (3) 7—20	176 (3) 70—310
	Growth period 1977—1987	0.05 (18) 0.04—0.12	67 (26) 40—115	30 (22) 1—70	1439 (24) 670—2630	786 (23) 24—1520	7 (22) 0—21	8.4 (19) 0—44
R	Winter 1981	—	25 (3) 21—30	3 (3) 1—7	910 (3) 610—1410	509 (3) 400—680	21 (2) 8—33	64 (2) 25—105
	Growth period 1981—1983	4.78 (23) 3.28—6.16	25 (35) 19—45	0.5 (25) 0—4	440 (34) 270—580	2 (16) 0—6	0 (16) 0	4.5 (16) 0—21

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* 1985; ** near-bottom layer; — not determined.

Table 2

Nutrient content ($\mu g \cdot l^{-1}$) in stratified winter water of Matsalu Bay (March 26, 1987)
(Numerator — mean values, denominator — variation ranges)

Parameter	WM		CM	
	surface	near bottom	surface	near bottom
Number of samples	5	5	2	2
S, ‰	2.21 1.31—2.79	5.82 5.63—5.97	0.84 0.82—0.86	5.74 5.72—5.75
Tot-P	95 84—114	43 39—50	116 115—117	46 39—53
PO_4-P	49 44—60	17 13—22	80 78—81	17 12—22
Tot-N	3380 2950—3650	1070 990—1170	3640 3430—3850	1200 1180—1220
NO_3-N	2560 2420—2640	570 520—620	2285 2580—2590	620 580—660
NO_2-N	19 13—26	24 21—27	16 13—19	20 19—20
NH_4-N	165 125—220	22 1—90	200 180—225	40 25—55
Inorg. P:tot-P, %	52	40	68	37
Inorg. N:tot-N, %	81	58	71	57

The water salinity in the open coastal area of the VÄINAMERI was relatively stable during the period from May to September, though most of the stations were situated along the narrow coastal area. A markedly lower water salinity (2.54‰) was measured only once (in September). Our data showed that the mean salinity of water in OV (5.47‰) was quite close to that of the open area of the Gulf of Riga (5.96‰) during the ice-free period by data from 1977—1981 (Андрушайтис et al., 1987).

The nutrient content of water in different parts of the study area was very variable both regionally and seasonally (Table 1). The highest concentrations of nutrients were recorded in the water of Haapsalu and Matsalu bays. The reason is that the main inflow of allochthonous biogens to coastal waters of West Estonia passes through these bays.

The water quality of the CENTRAL and WESTERN parts of HAAPSALU BAY depends greatly on the sewage inflow from the town of Haapsalu. The tot-P content of water was particularly variable and reached high values (up to 220 $\mu g \cdot l^{-1}$) in CH in summer. The seasonal fluctuation of the tot-P content in the water of CH and WH was not regular. Tot-P concentrations of water decreased westwards in the bay and were in a weak correlation with water salinity ($R=0.34$, $P>0.95$, $n=107$) in the growth period. The seasonal and regional distributions of PO_4-P in the water were irregular. Notable was the high PO_4-P content of water at some stations of WH in summer. A high percentage of PO_4-P in tot-P during the growth period was peculiar for Haapsalu Bay (Table 3). This may be caused by irregular and occasionally very high concentrations of nutrients (and other changes in the chemical composition of water) resulting from the inflow of sewage from the town of Haapsalu. The mechanical treatment plant of Haapsalu was out of order in winter 1978. Further, dying out and disappearance of benthic algae in CH were recorded in the following summers (Трей, 1984). Vegetation reappeared in CH by the late 1980s. Despite that, a very great proportion (34%) of PO_4-P in tot-P was recorded in summer 1990.

In winter the water of Haapsalu Bay was rich in phosphorus, especially in CH where the tot-P content rose up to 3000 $\mu g \cdot l^{-1}$. As water exchange under the ice cover was limited, anoxic conditions were recorded; hence, the release of phosphorus from bottom sediments was possible. The portion of PO_4-P in tot-P was very great (Table 3).

The concentration of tot-N was unevenly distributed, being higher in CH and decreasing towards the western part of the bay in summer 1985 (Table 1). The same tendency was noticed in the summers of 1989 and 1990 (during repeated research of Haapsalu Bay); the concentration of tot-N varied in wider limits: 370—1100 $\mu g \cdot l^{-1}$ ($n=16$) in CH and 210—500 $\mu g \cdot l^{-1}$ ($n=19$) in WH. NO_3-N occurred in the open water of CH and WH, its concentrations were from 11 to 85 $\mu g \cdot l^{-1}$. A considerable amount of NH_4-N, up to 45 $\mu g \cdot l^{-1}$, was observed in the water of CH and WH. The content of NO_2-N in the water was on the level of the analytical minimum throughout the central and western parts of the bay in the summers of 1989 and 1990.

The water of the EASTERN part of HAAPSALU BAY is enriched with allochthonous nutrients from rivers. The mean concentrations of biogens in the water of the Taebla River were 180 $\mu g \cdot l^{-1}$ tot-P, 75 $\mu g \cdot l^{-1}$ PO_4-P, 2800 $\mu g \cdot l^{-1}$ tot-N, 200 $\mu g \cdot l^{-1}$ NO_3-N, 20 $\mu g \cdot l^{-1}$ NO_2-N, and 90 $\mu g \cdot l^{-1}$ NH_4-N (in August 1985, 1989). Despite the inflow of allochthonous P, its concentration in the water of EH did not increase in summer and remained lower than in the water of CH at the same time. [The mean tot-P content was 44 $\mu g \cdot l^{-1}$ ($n=8$) in EH and 71 $\mu g \cdot l^{-1}$ ($n=16$) in CH, while PO_4-P was 2 $\mu g \cdot l^{-1}$ and 7 $\mu g \cdot l^{-1}$, respectively. The water of WH contained 29 $\mu g \cdot l^{-1}$ of tot-P ($n=19$ and 5 $\mu g \cdot l^{-1}$ of PO_4-P in the summers of 1985 and 1989]. The share of inorganic P in tot-P in the water of EH was notably small, which shows that allochthonous phosphates turn intensively into organic compounds.

Table 3

Percentage of inorganic P and N in their total content in the coastal waters of West Estonia

Region	Winter		Growth period	
	Inorg. P / Tot-P	Inorg. N / Tot-N	Inorg. P / Tot-P	Inorg. N / Tot-N
OV	33	59	6	7
WH	69	—	27	—
CH	73	—	22	—
WM	52* 45**	78* 52**	8	7
CM	53* 35**	62* 52**	8	15
EM	49	53	9	21
Canal	64	60	44	54
R	12	65	4	2

*surface layer; **near-bottom layer; — not determined.

The tot-N content of water was the highest in the eastern region of EH, 980 $\mu g \cdot l^{-1}$ ($n=5$), and decreased gradually to an average of 320 $\mu g \cdot l^{-1}$ ($n=19$) in WH. The tot-N distribution was in a strong linear correlation with water salinity throughout Haapsalu Bay ($r=-0.79$, $P>0.999$, $n=56$). Of inorganic N compounds only NH_4-N was observed in small amounts (1.7 $\mu g \cdot l^{-1}$ on the average) in the water of EH.

According to the mean discharge of the river water inflow (Eipre & Pärn, 1982) and our data on its chemical composition, average annual loads in MATSALU BAY are about 100 $t \cdot yr^{-1}$ tot-P. 40 $t \cdot yr^{-1}$ PO_4-P, 2000 $t \cdot yr^{-1}$ tot-N, and 1000 $t \cdot yr^{-1}$. NO_3-N. The nutrient load in the bay is very variable in different seasons, depending on wide-range changes both in the seasonal distribution of discharge and the nutrient content in the river water. The load of nutrients is the greatest in early spring, making up about 30—40% of the annual tot-P and tot-N loads; the lowest values occur in June—August (about 4%). The extremely great nutrient loading in March—April 1986 has been described in detail on the basis of the data from the Kasari River (Krõsanova et al., 1987; Крысанова & Луйк, 1989).

The data on nutrient concentrations in the water of Matsalu Bay reflect an uneven seasonal distribution of the nutrient inflow. The temporal variation of the tot-P content of water was statistically highly significant in all parts of the bay and had a medium correlation with seasons (Fig. 2). The curves of the mean tot-P content had steep declines in May and rose first in EM (in August) and last in WM (in October). The tot-P content was in a significant but weak linear correlation with water salinity ($r=-0.47$, $P>0.999$, $n=51$) according to simultaneously obtained data from three stations situated on the longitudinal section of the bay (near the influx of the connecting canal, in the middle part, and in the mouth of the bay). When treated with the

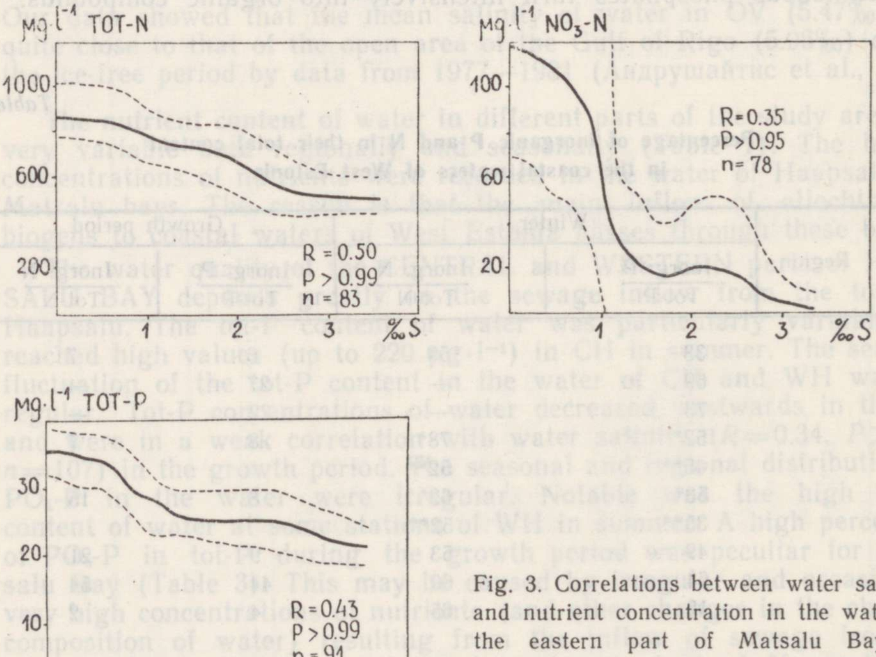

Fig. 3. Correlations between water salinity and nutrient concentration in the water of the eastern part of Matsalu Bay in summer (mean values of nutrients with confidence limits).

moving average method, all data revealed similar relationships between water salinity and tot-P content ($R=0.34$, $P>0.99$, $n=293$) throughout the bay. More detailed analyses of results from EM in summer showed a decline of the mean tot-P concentration in the region where water salinity ranged between the values 0.5—1.5‰ (Fig. 3), i.e. in the area near the influx of river water, where the bulk of P was accumulated by abundant benthic plants. The presence of numerous phytoplankton did not affect the results, since in the analyses of unfiltered seawater the tot-P concentration included the P contained in phytoplankton cells, too. In EM the turning of phosphates into organic P compounds is very intensive. The percentage of PO_4-P in tot-P in the water of EM was five times lower than in the water of the connecting canal (Table 3). Therefore, despite continuous addition of phosphates during the growth period, PO_4-P decreased to its minimum value in the water of EM in summer and underwent regular seasonal changes ($R=0.61$, $P>0.99$, $n=112$). The PO_4-P content in the water of the open area of CM and WM was low but was higher at some stations in the coastal zone. The spatial distribution of PO_4-P concentrations in the water throughout Matsalu Bay was irregular and was not correlated with the changes of water salinity.

In winter the water of Matsalu Bay was rich in phosphorus. Higher concentrations of tot-P were recorded under the ice cover in EM and in the surface layer of CM and WM (Tables 1, 2). Contrary to the vegetation period, in winter the percentage of PO_4-P in tot-P was big and comparatively stable in the surface water flowing from the canal into the outer part of the bay, being slightly smaller in the near-bottom water (Tables 2, 3)). This means that the water flowing out of the bay in winter contains large amounts of free phosphates.

Wide-range seasonal and spatial fluctuations of the N content in the different parts of Matsalu Bay were established. The water of EM revealed the greatest temporal changes of the tot-N content, which were in a medium correlation with seasons (Fig. 2). The correlation curve of the mean tot-N content showed high values in spring and autumn with a steep decline in midsummer. A similar regularity of tot-N variation, although not so extensive, was observed in the water of CM. The tot-N concentration in the water of WM was the most stable and did not depend on the season in the growth period.

The distribution of allochthonous nitrogen in the water of the bay depends greatly on the degree to which river water is mixed with seawater. The tot-N content of the water was in a strong negative linear correlation with water salinity, sampled from the longitudinal section of the bay ($r=-0.82$, $P>0.999$, $n=45$). The moving average method revealed a similar relationship between the tot-N content and water salinity throughout the bay ($R=0.72$, $P>0.99$, $n=231$). A more detailed analysis of data showed a considerable decrease in the tot-N content in the region where water salinity changed between 0.5—2.5‰, i.e. in EM (Fig. 3). This occurred mainly due to the consumption of inorganic N compounds by benthic vegetation. NO_3-N dominated among inorganic N. Its content was great in the inflowing river water during the whole vegetation period but in summer decreased to a minimum already in the water of EM. It has been proved that large amounts af allochthonous nitrates can be rapidly consumed by both assimilation and various reduction processes in shallow coastal waters (Schlungbaum & Nausch, 1988). In spring and autumn, on the contrary, very high concentrations of NO_3-N were recorded in the water of EM (Fig. 2). The relatively slight seasonal changes of the NO_3-N content in the water of WM were irregular. The content of other inorganic N compounds in the water of the canal and the bay during the growth period was small. The regional distribution of NO_2-N was in a highly significant correlation with water salinity, although the correlation index was weak ($R=0.51$, $P>0.99$, $n=197$). Higher concentrations of NO_2-N were observed only in the water with a salinity less than 1.2‰ in EM. The content of NH_4-N was slightly higher and more variable throughout the bay. The proportion of inorganic N in tot-N declined considerably in the water of EM and less in the outer parts of the bay (Table 3).

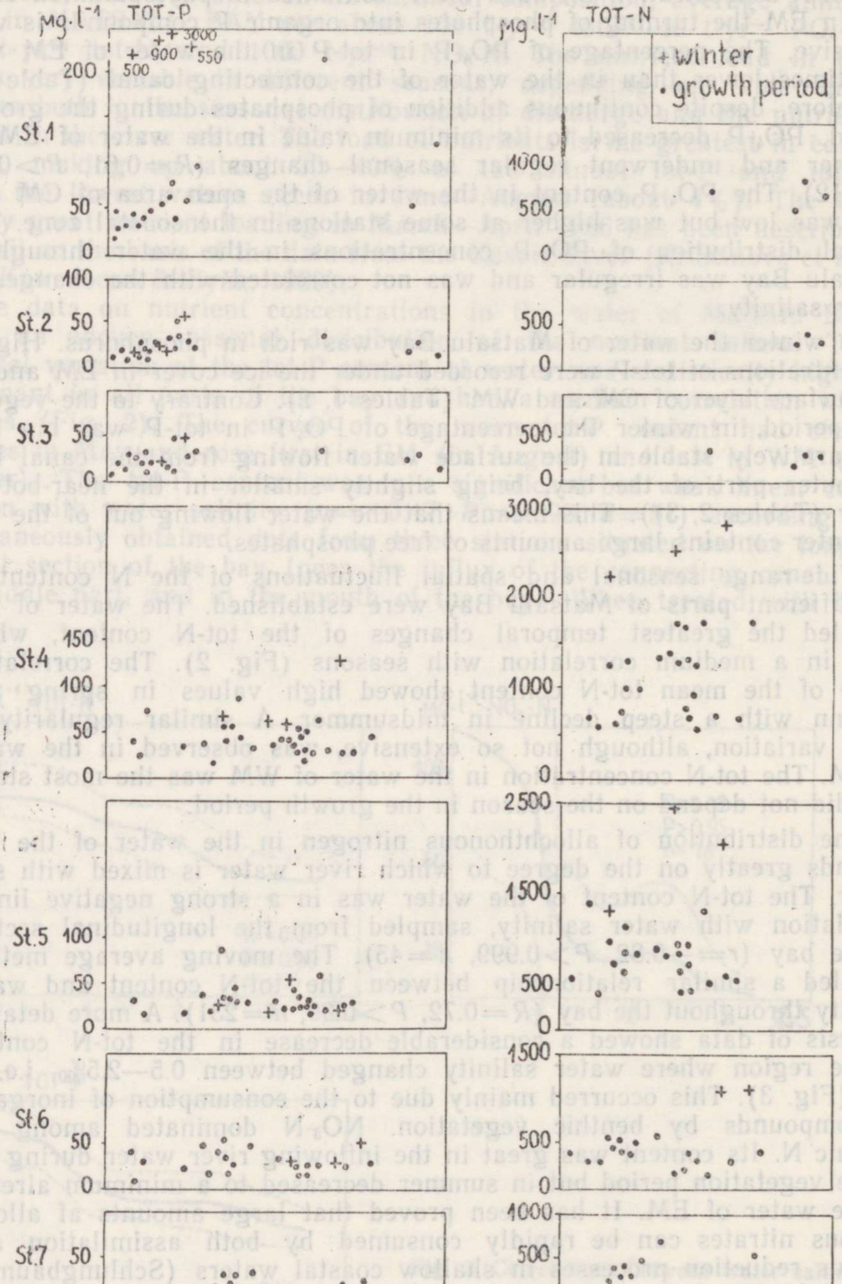

Fig. 4. Tot-P and tot-N concentrations in water at recurrent sampling stations.

In winter both the concentration of inorganic N and its relative importance rose in the water of the canal as well as the bay (Tables 1 and 3). The relative content of inorganic N was rather uniform throughout the bay and the canal. In the case of stratification (March 26, 1987) concentrations in the upper low-salinity water were higher than in the near-bottom layer. Among inorganic N compounds nitrates were predominant like in the growth period, while in winter water a notable increase in the NH_4-N content was recorded. Its allochthonous origin is concluded from the analyses of the water of the canal and different layers of the bay. The concentration of tot-N was also very high in the low-salinity water of the bay and the canal.

The water of the small shallow RAME INLET was poor in nutrients in the growth period, because the bottom was covered with rich vegetation and there was practically no nutrient inflow. Nevertheless, variation ranges for both tot-P and tot-N were narrow, seasonal fluctuations were statistically regular (Fig. 2). The contents of phosphates and nitrates were negligible during the growth period, the NO_2-N content was on the level of the analytical minimum. The NH_4-N concentration was notably high in the vegetation period. The scarce data available for winter showed that the water was poor in P, while the tot-N content was regionally very variable. The content of inorganic N compounds was rather big with nitrates predominating.

The nutrient content in the water of the open coastal area of the VÄINAMERI was very variable. No seasonal and regional regularities were observed in the distribution of nutrients in the water of OV. The level of tot-P and tot-N was similar to that of WH and WM. The concentrations of phosphates and nitrates were low, while nitrites were on the level of the analytical minimum in the water of OV. In the growth period the NH_4-N content was rather big in the water of some coastal stations. Great regional differences were observed in the winter water.

The data of recurrent samples (Fig. 4) showed strong fluctuation in the tot-P and tot-N content at the stations of discharge areas (stations 1, 4) and more stable and lower levels in the water of the open parts of the bays. We cannot draw conclusions about temporal trends, since the observation period was too short and sampling irregular.

SUMMARY

Fresh water flows to the coastal waters of West Estonia mainly through Matsalu Bay. Therefore, the lowest water salinity in all the areas under study occurred in EM. The effect of fresh water reaches the open part of the bay during spring and autumn floods and is the smallest in midsummer due to the decrease of river water discharge. The influence of smaller rivers falling into EH is limited to the inner part of Haapsalu Bay in summer. The relatively higher water salinity in the open parts of Haapsalu Bay as compared to the water of the Väinameri is caused by the invasion of seawater from the entrance area of the Gulf of Finland. The water salinity of OV depends on currents in this sea area rather than on the direct inflow of fresh water. In winter fresh water accumulates under the ice cover in the shallow inner parts of the bays. In Matsalu Bay a thin layer of low-salinity water was observed flowing out of the bay.

The distribution of allochthonous nutrients in seawater depends on many factors among which hydrological and biological conditions are the most important. Variable high-value nutrient contents were observed in winter in the areas of low salinity. Nevertheless, the content of tot-P and tot-N did not correlate with water salinity throughout the study area in winter. The concentration of biogens in the water of shallow areas is influenced besides the amount of nutrient input also by interactions between water and sediments. Relatively stable and high rations of inorganic P:tot-P and inorganic N:tot-N throughout the sea area were typical of winter water.

The distribution of nutrients in shallow coastal waters during the growth period is complicated. The concentrations of tot-P and PO_4-P were in a significant but weak correlations with water salinity (Fig. 5) throughout the whole study area including Matsalu Bay, where the external supply was carried in by river fresh water. The distribution of P as an intensively recycling element did not depend on water movement only. As a result of the assimilation of PO_4-P by phytoplankton and benthic vegetation, the concentration of PO_4-P declined abruptly in the discharge area. The ratio of PO_4-P:tot-P was low in the water of the areas with abundant vegetation with the exception of CH and WH.

The nitrogen input was in excess with respect to the phosphorus content in the inflowing river water. The tot-N content correlated stongly with water salinity in the study area (Fig. 5). The content of NO_3-N (as dominating inorganic N), on the contrary, was in a weak and obviously nonlinear correlation with water salinity. A drop of the nitrate content was observed in the areas with abundant vegetation where in most cases the water salinity was low.

The inflow of allochthonous nutrients into Matsalu Bay varied seasonally and it was the smallest during the growth period. According to our data the load of P and N in the vegetation period makes up about 25—30% of their annual input. At the same time the assimilation of nutrients by water vegetation is active. Consequently, the outflow of inorganic P and N compounds from Matsalu Bay is small in the vegetation period. It forms about 20% of the annual input of biogens by

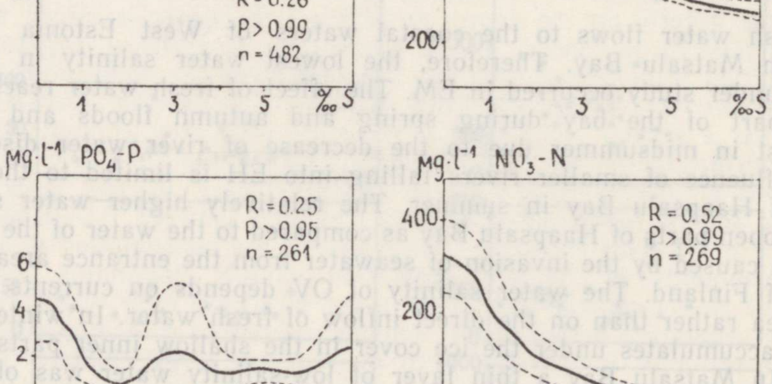

Fig. 5. Correlations between water salinity and nutrient content throughout the study area in the growth period (mean values of nutrients with confidence limits).

rivers according to mathematical calculations based on the data of water exchange and transfer of NO_3-N in Matsalu Bay (Фиштейн et al., 1987). Although a relatively small amount of nutrients is accumulated during the growth period, it has a decisive impact on the state of Matsalu Bay.

Inorganic P and N compounds, inflowing into Haapsalu Bay with river water, were mostly accumulated in EH in summer. In the water of CH and WH the biological turnover of discharged inorganic P and N was not complete and considerable amounts of PO_4-P and NH_4-N reached the open waters of Haapsalu Bay in summer.

The water quality of the open area of the Väinameri is established by the mixing of different water masses outflowing from several bays according to the system of currents typical of this sea area (Nõmmann, 1984; Паппел, 1983). Our data suggest that the tot-P and tot-N contents of the water of OV do not differ considerably from those of WM and WH.

Data of the level and distribution of nutrients allow of a conclusion that the influence of nutrient discharge from land is more obvious and harmful in the shallow semiclosed bay. The intensive production of organic matter and the accumulation of nutrients in the growth period leads to continuing eutrophication in the coastal areas of West Estonia.

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