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SHORT-TERM EFFECT OF THE SEWAGE TREATMENT PLANT ON THE PHYTOPLANKTON IN KURESSAARE BAY

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Abstract. The response of the late summer phytoplankton biomass and species composition in shallow and eutrophied Kuressaare Bay on the southern coast of Saaremaa Island, Estonia, to the launching of the sewage treatment plant is reported. Compared with earlier results, obvious changes have taken place in the inner part of the study area, which was directly affected by domestic and industrial sewage waters until autumn 1991. The total biomass of phytoplankton has dropped from 13.4–32.0 to 0.3–2.2 mg l^{-1}. Changes were observed in the species composition of Cyanophyta and Chlorophyta. Dinophyta and Bacillariophyta showed interannual fluctuations without any clear trend.

Key words: Kuressaare Bay, late summer phytoplankton biomass and composition, sewage treatment plant, eutrophication.

INTRODUCTION

Ecological changes related to eutrophication of coastal waters of the Baltic Sea have been well documented during the recent decades. It is reported that, from local perspective, reductions in loads of nutrients thanks to building sewage treatment systems may give rapid results in terms of an improved coastal environment (Wulff & Niemi, 1992).

Investigation of the amount and species composition of phytoplankton is one of the most frequently used biological methods for monitoring water quality. Changes in phytoplankton community after taking restorative measures have been well investigated in marine environment (Viljamaa, 1978, 1988) but also in limnic environment (Ahlgren, 1978; Feuillade &

Druart, 1994). Obvious alterations in phytoplankton have been observed in such researches mainly after several years have passed since the restorative measures were taken.

The aim of the present study was to compare the phytoplankton biomass and species composition in Kuressaare Bay before and after the sewage treatment plant was put into operation. It was kept in mind that the plant has been in operation for a short time as yet.

STUDY AREA

Kuressaare Bay is a part of the West-Estonian Archipelago Biosphere Reserve. According to the Baltic Marine Environmental Protection Commission it belongs to the Baltic subregion 'The Gulf of Riga' (Baltic..., 1990).

Kuressaare Bay is situated on the southern coast of Saaremaa Island. The bay is semi-enclosed and shallow, mean depth 3.6 m, maximum depth 7 m. The bottom of the bay is mainly covered with soft sediments and bottom vegetation is rich (Trei, 1982; Трей, 1984; Kukk, 1993). As the hydrological regimes in different parts of Kuressaare Bay differ, they will be discussed separately: the inner part (site 7 in Fig. 1), the transition area (site 9), and the open part (all the other sites).

Kuressaare Bay functioned as a recipient of a large amount of untreated domestic and food industry sewage coming from the town of Kuressaare: the annual loads were 1000 t BOD_7, 100 t N, 10 t P (HELCOM, 1991) up to autumn 1991, when the sewage treatment plant was completed. Before World War II the bay was largely used as a recreational area. At present the bay is regarded as an anthropogenic eutrophied area (HELCOM, 1991).

MATERIAL AND METHODS

The material presented here was collected at the end of August at eight to ten stations in 1976, 1978, and during the period 1992–94, and at two stations in 1985 (Fig. 1). An overview of the depths and location of the sampling sites is presented in Table 1. Altogether 50 phytoplankton samples were taken.

The qualitative samples of phytoplankton were collected with a phytoplankton net (mesh size 70 μm) from the entire column of water. The quantitative samples were taken from a depth of 1 m with a one litre Mayer bottle. The phytoplankton samples collected in 1992–94 were preserved with acid Lugol solution for taxonomic identification and counting. The quantitative samples were analysed according to the Utermöhl (1958) technique. In order to get a statistically acceptable estimation, the number of units in a sample was counted to at least a total of 500 units. Cell numbers were converted to biomass by stereometrical formulae as described by Edler (1979). Diatom frustules were cleaned with concentrated HCl and H_2SO_4. The cleaned material was mounted in Hyrax.

The Utermöhl technique could not be used for counting the phytoplankton samples of 1976, 1978, and 1985 because we had no inverted microscope. The quantitative samples were treated using the sedimentation technique and counted with the help of the Goryaev chamber.

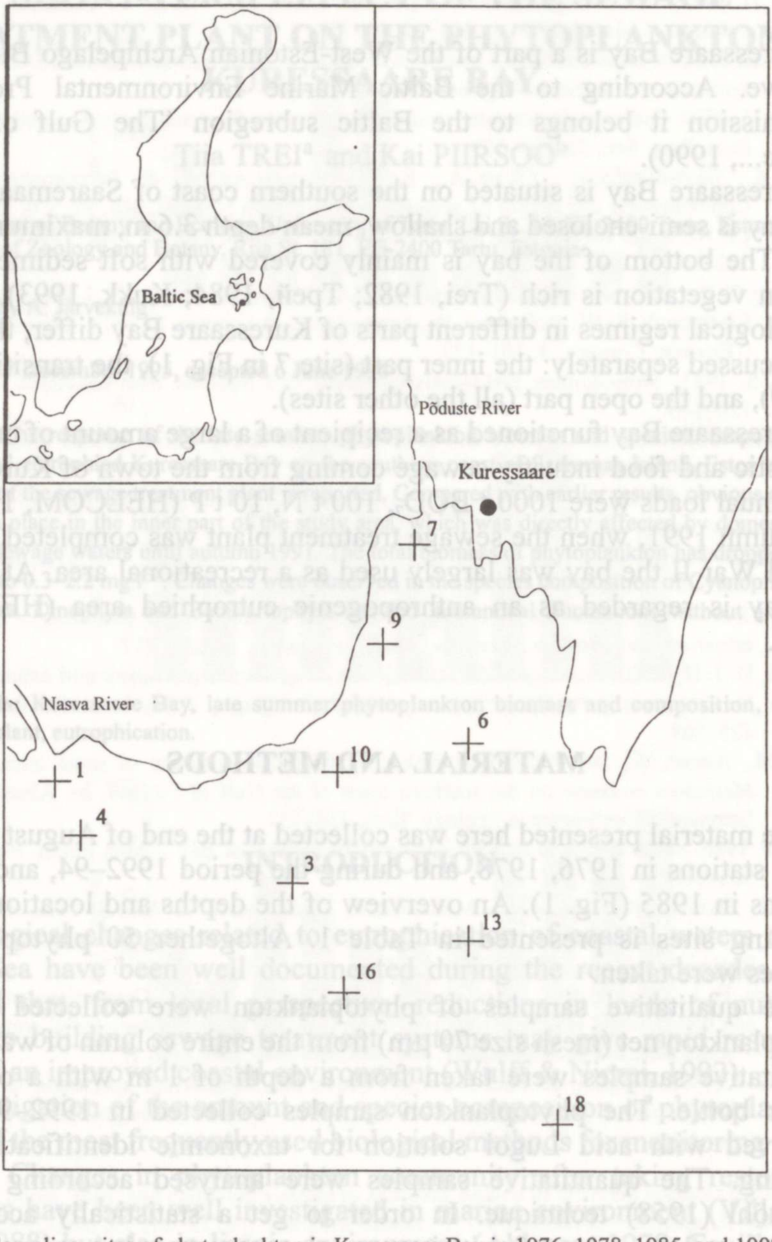

Fig. 1. Sampling sites of phytoplankton in Kuressaare Bay in 1976, 1978, 1985, and 1992–94.

Table 1

Depths and coordinates of phytoplankton sampling sites

Sampling site	Depth, m	Longitude	Latitude
1	3	22°24′00″	58°12′40″
3	3	22°26′45″	58°12′15″
4	3	22°23′45″	58°13′00″
6	4	22°28′45″	58°13′13″
7	2	22°28′00″	58°14′00″
9	2	22°27′30″	58°13′50″
10	2	22°27′00″	58°13′00″
13	7	22°28′33″	58°11′59″
16	7	22°27′09″	58°11′32″
18	3	22°29′37″	58°10′53″

Total phosphorus (tot-P) was analysed according to Koroleff (1982) in the Department of Hydrobiology of the Institute of Zoology and Botany by Malle Viik. Salinity was determined by titration against $AgNO_3$ and calculated according to Grasshoff and co-authors (1982). Water for the chemical analyses was taken from a depth of 1 m.

RESULTS

1. Environmental factors

1.1. Salinity

There is a clear salinity gradient from the mouth of the Põduste River towards the open sea (Fig. 2*a*). The highest gradient was observed in August 1993 when salinity varied from almost fresh water near the river mouth to 5.8‰ in the open area. In the outer part of the bay few differences in surface salinity were found between different sampling sites. During the last two decades a decrease in the late summer surface salinity by 0.6–1.0‰ has been observed at different sampling sites in the outer part of Kuressaare Bay. Differently from the Põduste River, near the mouth of the Nasva River no clear influence of fresh water on water salinity was observed. This is probably due to the opened location of the latter. Salinity correlated negatively with the tot-P ($R = -0.799$; $p = -0.0003$).

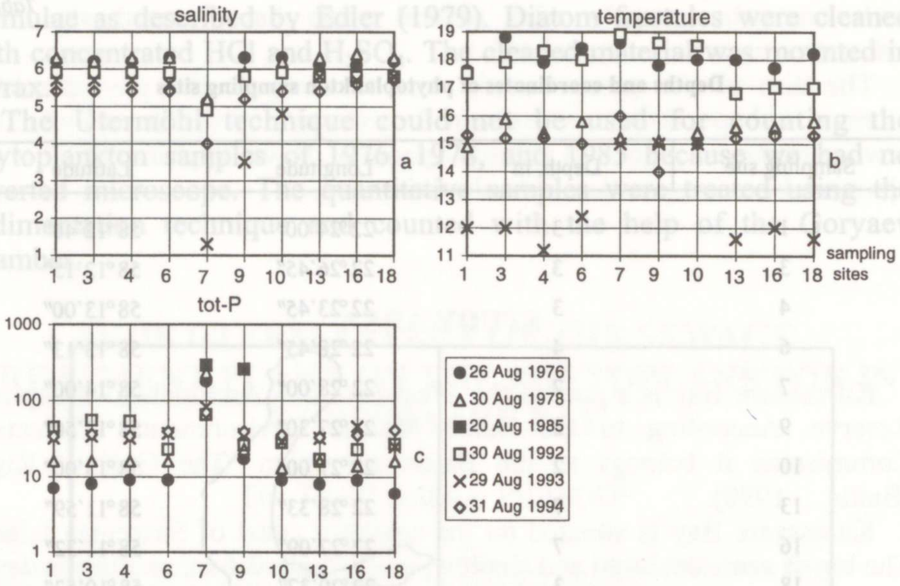

Fig. 2. Salinity (‰), temperature (°C), and tot-P (µg l^{-1}) at a depth of 1 m in ten sampling sites in Kuressaare Bay in 1976, 1978, 1985, and 1992–94.

1.2. Temperature

Water temperature is controlled by the seasonal and interannual climatological fluctuations. The highest values of surface temperature were recorded in Kuressaare Bay in the late summers of 1976 and 1992 (Fig. 2*b*) (mean values 18.1 and 17.9°C, respectively). In 1978 and 1994 the water temperatures were about 3°C lower (mean 15.5 and 15.4°C, respectively). The late summer water temperature was especially low in 1993, when it varied from 11.2 to 15°C (mean 12.8°C). In the inner part of the bay the surface temperature was regularly somewhat higher due to its protected location.

1.3. Tot-P

The most obvious changes in the tot-P values have taken place in the inner part of the bay at the sampling site 7 near the mouth of the Põduste River (Fig. 2*c*). In 1976, 1978, and 1985 the tot-P values were respectively 179, 233, and 290 µg l^{-1} but in 1992–94 only 66, 83, and 70 µg l^{-1}. This means that tot-P has declined two to three times after the sewage treatment plant was put into operation. The values of tot-P remained somewhat higher at site 7 also after the introduction of the sewage treatment systems.

Before the sewage treatment systems were launched the difference in the tot-P concentration between sampling station 9 and the outermost area was more or less regularly bigger than later. In the years 1992–94 this difference was insignificant.

A comparison of the tot-P concentrations in the outer part of the bay in the seventies and nineties shows that earlier values were lower. The tot-P value was particularly low in 1976 (mean 8 µg l^{-1}, SE ± 0.150, $n = 8$) but later it started to increase being 15 µg l^{-1} (SE ± 0.159, $n = 8$) in 1978. In the years 1992–94 the mean tot-P concentration was 34.3 µg l^{-1} (SE ± 0.389, $n = 24$) in the outermost sampling sites.

2. Phytoplankton

2.1. Total phytoplankton biomass

Data on phytoplankton biomass are presented in Fig. 3. During the late summers of 1976, 1978, and 1985, i.e. before the sewage treatment plant was put into operation, the total biomass of phytoplankton was luxurious in the inner part of the bay. At sampling site 7 the biomass was respectively 20.0, 32.0, and 13.4 mg l^{-1}. In 1976 this biomass peak was caused by the bloom of the blue-green algae *Lyngbya aestuarii* and *Planktothrix agardhii*. In 1978 the autotrophic dinoflagellate *Glenodinium foliaceum* formed 91% of the total biomass and in 1985 the centric diatom *Thalassiosira baltica* constituted 80% of the total biomass. In 1992–94 the phytoplankton biomass at the same site was respectively 2.2, 0.4, and 0.3 mg l^{-1}. A drastic decrease in the phytoplankton biomass had taken place in the inner part of the bay.

The phytoplankton biomass at sampling site 9 was very variable. It fluctuated between 0.2 and 16.1 mg l^{-1} without any clear trend during the observation years. This site acted as a transition area between the inner and the outer part of the bay.

In the open part of the bay the spatial variability of the total biomass was small in time (mean 0.25, SE ± 0.007, $n = 30$). The only exception

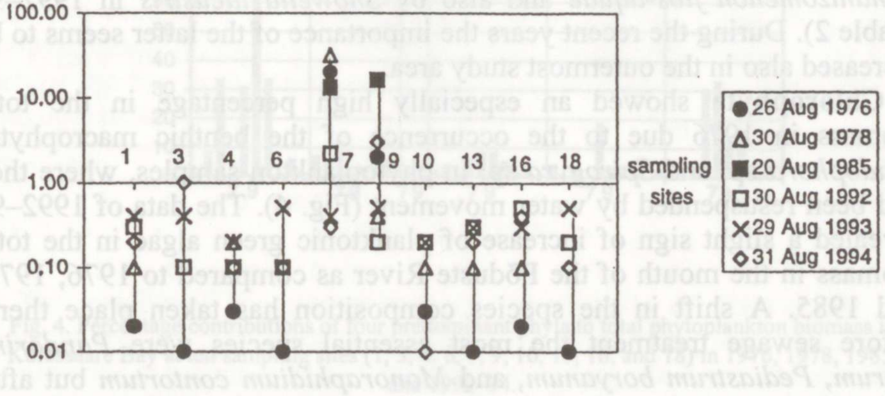

Fig. 3. Phytoplankton biomass (mg l^{-1}) at a depth of 1 m in ten sampling sites in Kuressaare Bay in 1976, 1978, 1985, and 1992–94.

was 1976, when the phytoplankton biomass was especially low (mean 0.02, SE ± 0.001, $n = 8$).

Total biomass correlated highly significantly with tot-P ($R = 0.650$, $p = 0.0003$) and phytoplankton abundance ($R = 0.790$, $p = 0.0003$).

2.2. Species composition

A total of 178 algal species were identified before the sewage treatment and 130 species after that. The predominant phyla were Cyanophyta, Dinophyta, Bacillariophyta, and Chlorophyta.

Cyanophyta dominated at the mouth of the Põduste River in 1976 (Fig. 4 and Table 2). There was an intensive bloom at sampling site 7 (Пийрсоо, 1979). It was caused by *Lyngbya aestuarii* and *Planktothrix agardhii*, which constituted about 53% of the total biomass. Near the mouth of the Nasva River the high percentage contribution of Cyanophyta to the total phytoplankton biomass was caused by *Nodularia spumigena* filaments (72.7%) at sampling site 1 and by *Anabaena lemmermannii*, *A. variabilis*, *Oscillatoria limosa*, and *Chroococcus limneticus* (in all 30%) at sampling site 4. At site 18 the high percentage of blue-greens in the total phytoplankton biomass was caused by *Anabaena lemmermannii*, *A. variabilis*, and *Oscillatoria* sp., at other sampling sites by *Aphanizomenon flos-aquae*.

In 1978 and in 1985 the blue-green algae formed an insignificant part of the total biomass in the whole study area (Fig. 4). In 1992–94 Cyanophyta did not form a high biomass (Fig. 4). Their contribution to the total phytoplankton biomass did not exceed 20% in Kuressaare Bay. In this period *Aphanizomenon flos-aquae* and *Snowella lacustris* were the dominant blue-green species at all sampling sites.

A comparison of the results of 1992–94 with those of 1976, 1978, and 1985 revealed some changes in the species composition near the mouth of the Põduste River. *Lyngbya aestuarii* and *Planktothrix agardhii*, but also *Oscillatoria princeps* and *O. limosa*, which occurred in 1976, 1978, and 1985, had disappeared almost completely and were replaced mainly by *Aphanizomenon flos-aquae* and also by *Snowella lacustris* in 1992–94 (Table 2). During the recent years the importance of the latter seems to be increased also in the outermost study area.

Chlorophyta showed an especially high percentage in the total biomass in 1976 due to the occurrence of the benthic macrophytes *Cladophora* sp. and *Spirogyra* sp. in phytoplankton samples, where they had been resuspended by water movement (Fig. 4). The data of 1992–94 revealed a slight sign of increase of planktonic green algae in the total biomass in the mouth of the Põduste River as compared to 1976, 1978, and 1985. A shift in the species composition has taken place there: before sewage treatment the most essential species were *Pandorina morum*, *Pediastrum boryanum*, and *Monoraphidium contortum* but after that *Oocystis lacustris*, *Scenedesmus ecornis*, *S. opoliensis*, and *Monoraphidium contortum* (Table 3).

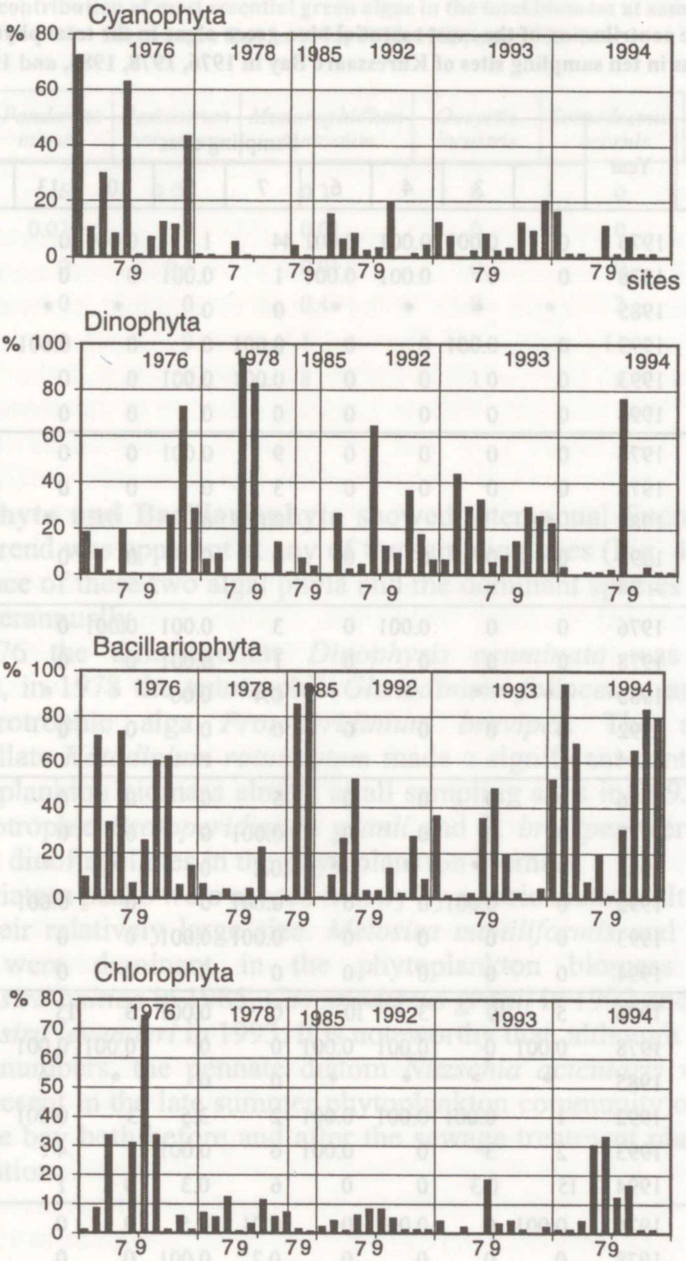

Fig. 4. Percentage contributions of four predominant phyla to total phytoplankton biomass in Kuressaare Bay at ten sampling sites (1, 3, 4, 6, 7, 9, 10, 13, 16, and 18) in 1976, 1978, 1985, and 1992–94.

Table 2

Percentage contribution of the most essential blue-green algae in the total phytoplankton biomass in ten sampling sites of Kuressaare Bay in 1976, 1978, 1985, and 1992–94

Species	Year	Sampling sites 1	3	4	6	7	9	10	13	16	18
Lyngbya aestuarii	1976	0	0.001	0.001	0.001	44	1	0.001	0	0	0
	1978	0	0	0.001	0.001	1	0.001	0	0	0	0
	1985	*	*	*	*	0	0	*	*	*	*
	1992	0	0.001	0	0	0.001	0	0	0.001	0	0
	1993	0	0	0	0	0.001	0.001	0	0	0	0
	1994	0	0	0	0	0	0	0	0	0	0
Planktothrix agardhii	1976	0	0	0	0	9	0.001	0	0	0	0
	1978	0	0	0	0	3	0	0	0	0	0
	1985	*	*	*	*	0.001	0	*	*	*	*
	1992 – 94	0	0	0	0	0	0	0	0	0	0
Oscillatoria limosa	1976	0	0	0.001	0	3	0.001	0.001	0	0	0
	1978	0	0	0	0	1	0.001	0	0	0	0
	1985	*	*	*	*	0.4	0.06	*	*	*	*
	1992 – 94	0	0	0	0	0	0	0	0	0	0
Oscillatoria princeps	1976	0	0	0	0	5	0	0	0	0	0
	1978	0	0	0	0	0.001	0	0	0	0	0
	1985	*	*	*	*	0.2	0	*	*	*	*
	1992	0	0.001	0	0	0.001	0	0	0.001	0	0
	1993	0	0	0	0	0.001	0.001	0	0	0	0
	1994	0	0	0	0	0	0	0	0	0	0
Aphani-zomenon flos-aquae	1976	5	10	3	10	0	0.001	3	13	5	10
	1978	0.001	0	0.001	0.001	0	0	0.001	0.001	0.001	0
	1985	*	*	*	*	0	0	*	*	*	*
	1992	1	0.001	0.001	0.001	2	3.5	13	0.001	0.001	1
	1993	2	3	0	0.001	6	0.001	1	4	0	13
	1994	15	0.3	0	0	6	0.3	0	1	1	0
Snowella lacustris	1976	0.001	0	0.001	0	0.01	0.5	0	0	0.001	0.001
	1978	0	0	0	0	0.2	0.001	0	0	0	0
	1985	*	*	*	*	0.003	0	*	*	*	*
	1992	3	15	8	8	0.001	0	10	0	2	4
	1993	10	3	0	3	0.001	2	2	7	10	7
	1994	1	0.3	1	0	4	0.001	7	0		0

* no data.

Table 3

Percentage contribution of most essential green algae in the total biomass at sampling site 7 in Kuressaare Bay in 1976, 1978, 1985, and 1992–94

Year	*Pandorina morum*	*Pediastrum boryanum*	*Monoraphidium contortum*	*Oocystis lacustris*	*Scenedesmus ecornis*	*Scenedesmus opoliensis*
1976	6	0.04	0.3	0	0	0.02
1978	0.03	0	0.01	0	0	0.01
1985	0	0.3	0.01	0	0	0
1992	0	0	0.4	0	2	4
1993	0	0	1	0	11	5
1994	0	0	8	1	5	18

Dinophyta and Bacillariophyta showed interannual fluctuations but no clear trend was apparent at any of the sampling sites (Fig. 4). Both the significance of these two algal phyla and the dominant species from them varied interannually.

In 1976 the dinoflagellate *Dinophysis acuminata* was the most important, in 1978 the autotrophic *Glenodinium foliaceum*, and in 1992 the heterotrophic alga *Protoperidinium brevipes*. The autotrophic dinoflagellate *Katodinium rotundatum* made a significant contribution to the phytoplankton biomass almost at all sampling sites in 1993. In 1994, the heterotrophic *Protoperidinium granii* and *P. brevipes* were the most important dinoflagellates in the phytoplankton biomass.

High diatom peaks were caused mostly by centric diatoms. It was partly due to their relatively large size. *Melosira moniliformis* and naviculoid diatoms were dominant in the phytoplankton biomass in 1976, *Thalassiosira baltica* in 1985, *Coscinodiscus granii* in 1992 and 1994, and *Thalassiosira levanderi* in 1993. It is noteworthy that, although it occurred in small numbers, the pennate diatom *Nitzschia acicularis* was nearly always present in the late summer phytoplankton community of the inner part of the bay both before and after the sewage treatment plant was put into operation.

DISCUSSION

The results of the phytoplankton investigation of Kuressaare Bay indicate that the most notable changes have taken place in phytoplankton community in the inner part of the bay at sampling site 7 near the mouth of the Põduste River. The late summer biomass dropped there from 13.4–32.0 mg l^{-1} before the sewage treatment to 0.3–2.2 mg l^{-1} after the sewage treatment. It means the decrease was about 60 times. This sharp decline was unexpected because the late summer measurements in 1992 were obtained only 11 months after the sewage treatment plant was put into operation. Some authors have mentioned that there are no changes in phytoplankton biomass after short-term (1–5 years) application of restorative measures. So, de Kloet et al. (1990) noted a lack of changes in the phytoplankton biomass as well as chlorophyll in the Loosdrecht Lakes (Holland) where reduction in external phosphorus loading had taken place three years ago. Similar lack of changes was reported by Feuillade & Druart (1994): five years after the successful reduction in nutrient loading in Lake Nantua (France) no changes in the maximum phytoplankton biomass had become evident. Daley & Pick (1990) observed no variations even after seven to eight years in the annual or maximum phytoplankton biomass. Cronberg (1982), on the contrary, marked a drastic decrease in the phytoplankton biomass from the start of restoration in Lake Trummen (Sweden). Thus, assuming that no gradual reduction in the phytoplankton biomass in Kuressaare Bay near the mouth of the Põduste River had occurred before the sewage treatment plant was taken into use (no data on phytoplankton between 1985 and 1992), only one explanation exists for this remarkable decline in the biomass in the innermost bay. It is a response to the reduction of nutrient load due to the launching of the sewage treatment systems. There was a high correlation between the biomass and tot-P concentrations.

As to the outer part of the bay, the phytoplankton biomass did not vary remarkably either before or after the sewage treatment plant was put into operation except in 1976 when it was very low. Still, this value stays in the range of natural variability. As result of decline of the phytoplankton biomass in the inner part of the bay thanks to the treatment of sewage the split in the phytoplankton biomass values between the inner and outer part of the bay has decreased.

Concentrations of tot-P decreased near the mouth of the Põduste River in connection with the operation of the sewage treatment plant and thereby the discrepancy in tot-P values between the inner and outer parts of the bay decreased. However, in the open part of the study area the concentration of tot-P showed an increasing trend during the last two decades. As compared with 1976 the mean concentrations of tot-P had doubled in 1978. An upward trend of nutrients concentration had begun between 1976 and 1978 also in other Estonian semi-enclosed basins like Haapsalu and Matsalu bays (V. Porgasaar, pers. comm.). In the open part of Kuressaare Bay the mean tot-P concentrations were in 1992–94 twice as high as in 1978. Such an increase during a period of more than 15 years indicates most likely an overall eutrophication of Kuressaare Bay, which is a part of the Baltic Sea. Calculations by Larsson et al. (1985) suggest an increase in the total phosphorus loading by about eight times in the Baltic since the beginning of the 20th century due to human activities. In Pärnu Bay Tenson et al. (1993) reported on an average a 2-fold increase in the content of P, N, and Si during the last two decades.

The results of the investigation of phytoplankton composition were reserved and contradictory. Some alterations were found in the inner part of the bay in Cyanophyta. The main development pattern of the blue-greens community is the shift from *Lyngbya aestuarii*, *Plankthothrix agardhii*, *Oscillatoria limosa*, and *O. princeps* in 1976 to mainly *Aphanizomenon flos-aquae* and also *Snowella lacustris* in 1992–94. Piirsoo (1991) reported that *Lyngbya aestuarii*, *Plankthothrix agardhii*, and *Oscillatoria princeps* were indicators of eutrophic coastal waters in Estonia. Several authors (Horstmann, 1975; Niemi, 1976; Melvasalo & Viljamaa, 1977; Alasaarela, 1979) have noted that *Plankthothrix agardhii* occurs in the coastal waters and is a good indicator of eutrophication. Melvasalo & Viljamaa (1977) observed that *Aphanizomenon flos-aquae* has often been replaced by *Oscillatoria* spp. in areas polluted by domestic waste waters. In Kuressaare Bay the change in the species composition was the same: in connection with the diversion of local waste waters *Oscillatoria* spp. were replaced by *Aphanizomenon flos-aquae*.

It is important to mention that as compared with the results of 1976, 1978, and 1985, the importance of *Snowella lacustris* had risen in the outer part of Kuressaare Bay in 1992–94 (Table 2). It was often even predominant among the blue-greens. A similar phenomenon was reported by Wiktor & Plinski (1975): *Chroococcales* contribution in the total phytoplankton biomass increases in connection with eutrophication of small sea areas. No bloom of blue-greens was observed in Kuressaare Bay after the beginning of sewage treatment.

Green algae in the Baltic are of freshwater origin but up to now they have been accepted as common inhabitants especially near the discharge of river waters in shallow eutrophied bays. A slight sign of increase of green algae near the mouth of the Põduste River may be a consequence of the decline of water salinity in Kuressaare Bay during the last decades (Fig. 2*a*). The reason of changes in the species composition in the inner part of the bay is not known.

Dinophyta and Bacillariophyta showed interannual fluctuations both in the composition and in the proportion in the total biomass. This can only testify that *Nitzschia acicularis*, which occurred regularly in the late summer phytoplankton community in the inner part of the bay, holds the second place in the benches of the most pollution-tolerant species of *Nitzschia* according to Palmer (1969).

In conclusion, it is obviously too early to make predictions about the near future of Kuressaare Bay on the results presented here. However, the sharp decline in the phytoplankton biomass in the inner part of Kuressaare Bay is an obvious effect of the sewage treatment plant.

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