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TOTAL PHOSPHORUS IN ESTONIAN LAKES

Abstract. The total phosphorus content of the surface water of 95 small Estonian lakes was determined during the period 1978—1990. In the case of 23 investigated mesotrophic lakes the range of total phosphorus was 14—30 mg P/m^3, the average was 16 mg P/m^3; for eutrophic lakes (56) the range was 20—56 mg P/m^3 with the average value 30 mg P/m^3; total phosphorus for hypertrophic lakes (16) ranged from 54 to 171 mg P/m^3, with the average of 86 mg P/m^3. There was a clearly decreasing trend in the phosphorus concentration during the period 1978—1990. In the years 1984—1990 (except the year 1987) the phosphorus level was about two times below its levels of 1978 and 1981. The decreasing trend in the phosphorus content was well revealed in the majority of intensively studied lakes. The decrease in phosphorus concentrations is probably connected with the rich-in-water period which started in the late 1970s.

Key words: lakes, total phosphorus, trophic state, changes.

Phosphorus and nitrogen are the two elements widely accepted as the key chemical factors determining the productivity of lakes and, accordingly, controlling the degree of eutrophication. Phosphorus, in particular, has attracted attention in the research of eutrophication. As there is now a general agreement that phytoplankton is phosphorus-limited in the majority of lakes, the management of eutrophication is based mainly on phosphorus control.

Most studies conducted in Estonia on phosphorus up to the 1970s dealt with the determination of phosphate ions (Riikoja, 1940; Eesti järved, 1968; Võrtsjärv, 1973) in Estonian lakes. Our hydrochemistry team of the Institute of Zoology and Botany of the Estonian Academy of Sciences has been studying total phosphorus concentrations in Estonian lakes since 1978. The aim of this paper is to give a regional survey of total phosphorus concentrations of surface waters in small lakes of Estonia during the period 1978—1990.

Material and Methods

The lakes under study are located mainly in South-East and South Estonia, only those of Vooremaa are situated in the eastern part of the republic in the Jõgeva District. The number of the lakes studied each year ranged between 18 and 44. One group of lakes (17) was studied during 6—9 years, another (44) during 2—5 years, and the rest of the lakes (34) only during one year. The lakes were sampled three times in 1978: in the water circulation periods in spring (May) and autumn (September) and in the summer stagnation period (July). In 1979 the lakes were sampled only in May. From 1981 to 1990 the lakes were sampled on an average five times (from 4 to 8) after the ice-out (in most years early May, only in 1989 and 1990 early April) until late August or early September. Water samples were collected from the surface water. A total of 1373 analyses were made. Total phosphorus was determined after persulfate oxidation with the colorimetric method using ascorbinic acid and ammonium molybdate (Reports ..., 1977).

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As some lakes were studied intensively during several years while others were sampled only a few times during one year, the quality of the data is variable and it is difficult to compare them; therefore, all the data were processed by the analysis of variance. The effect of the lake, the effect of the observation year (1978 ... 1990), and the effect of the observation month (May ... September) were selected as factors. All data values were transformed to their logarithms prior to statistical analysis.

Results and Discussion

Table 1 shows the total phosphorus content of the surface water of 95 small Estonian lakes during the period 1978—1990. The trophic state of the lakes studied ranged from mesotrophic to hypertrophic. The lakes were classified using three most essential parameters of the trophic state (total phosphorus, chlorophyll *a*, and water transparency) developed by us (Милиус et al., 1987). The studied lakes were ranked from the lowest trophic state to the highest. Considering all three parameters, the lowest trophic state was found in L. Nohipalu Valgjärv and the highest in L. Pappjärv. The total phosphorus values in Table 1 represent the arithmetical and geometrical mean values, the latter from the analysis of variance. Since in our earlier papers (Milius et al., 1987; 1988, 1989; Kõvask, Milius, 1989; Кываск, Милиус, 1989) the arithmetical mean values of phosphorus concentrations were published for several lakes, we now considered it advisable to present, together with the geometrical mean values calculated from the analysis of variance, also the arithmetical mean values. The range of the observed arithmetical mean values of phosphorus was somewhat different (13—212 mg P/m^3) from the geometrical mean values (14—171 mg P/m^3).

As one can see from Table 1, the difference between the arithmetical and geometrical mean values is insignificant in the case of some lakes (Inni, Saagjärv, Peitlemäe, Tillijärv, Rõikajärv) with the arithmetical mean being slightly smaller than the geometrical mean. In some cases, however (lakes Viisjaagu, Rõuge Suurjärv, Kisejärv, Liinjärv), this difference is quite noticeable, the arithmetical mean being considerably bigger than the geometrical mean. The difference between the arithmetical mean and the geometrical mean calculated from the analysis of variance is due to the fact that the arithmetical mean shows the mean phosphorus of the lake in the year under study and it depends on the frequency and time (month) of sampling. The geometrical mean calculated from the analysis of variance shows the phosphorus content of the lake during a certain period independent of the year or sampling times. Thus, the table gives information about the exact phosphorus content of the year (or years) studied, which was obtained from analysis (arithmetical mean), and the prognosticated phosphorus content for the 1980s (geometrical mean). The difference arising between the arithmetical and geometrical means results from the decreasing trend of the phosphorus content during the period.

In the case of 23 investigated mesotrophic lakes the range of total phosphorus was 14—30 mg P/m^3, the average was 16 mg P/m^3; for eutrophic lakes (56) the range was 20—56 mg P/m^3 with the mean value 30 mg P/m^3; total phosphorus for hypertrophic lakes (16) ranged from 54 to 171 mg P/m^3, with the average of 86 mg P/m^3.

Changes in the phosphorus concentrations of the surface water of the 95 lakes studied during the years 1978—1990 are presented in Table 2 and illustrated in Fig. 1. The whole observed range of phosphorus was from 19.9 to 51.6 mg P/m^3. The phosphorus concentration trend was clearly

Table 1

Total phosphorus concentrations (mg P/m^3) in small Estonian lakes

Lake	Lake catalogue № *	Year	Number of samples	Arithm. mean ± S. E.	Geom. mean ± S. E.
1	2	3	4	5	6
Nohipalu Valgjärv	1297	1978—79; 1982—83	22	21.6± 3.2	14.1± 0.7
Väike-Palkna	1517	1981	2	27.5± 2.5	19.3± 2.3
Piigandi	1084	1979; 81—86; 1990	38	17.4± 2.3	15.3± 0.7
Inni	1200	1987—90	23	12.5± 1.2	14.4± 0.8
Hino	1555	1979	1	30.0	21.8± 3.8
Peitlemäe	1054	1987—89	17	14.1± 1.3	15.2± 0.9
Roksi	1170	1987—89	18	13.1± 0.9	14.6± 0.8
Pulli	1552	1979; 1981	4	35.0±14.3	19.8± 1.9
Saagjärv	1047	1987—89	18	13.3± 1.2	14.4± 0.8
Udsu	1177	1978; 1981—86	30	18.0± 1.6	17.1± 0.8
Uiakatsi	1238	1979; 81—86; 1990	39	18.1± 2.1	15.9± 0.7
Koorküla Valgjärv	1180	1978; 81—86	30	17.1± 1.4	16.7± 0.8
Virtsjärv	1178	1987—89	18	14.6± 1.1	16.3± 0.9
Tillijärv	835	1984	4	13.0± 3.7	13.6± 1.3
Saadjärv	653	1978—79; 81—86	35	23.3± 2.5	17.7± 0.8
Viisjaagu	924	1979; 81—83	19	29.3± 5.0	18.4± 1.0
Tõrva Vanamõisa	1000	1984—86	16	12.6± 1.8	14.8± 0.8
Rõuge Suurjärv	1403	1981	3	40.3± 9.4	24.4± 2.6
Kisejärv	1532	1981	3	46.0±21.9	21.9± 2.3
Kooraste Kõverjärv	1232	1981	4	41.5±12.0	21.5± 2.0
Tõugjärv	1400	1981	3	33.0± 9.0	19.0± 2.0
Liinjärv	1404	1981	3	49.7±11.3	29.7± 3.1
Rõikajärv	834	1984	4	14.0± 3.7	14.6± 1.4
Prossa	568	1981	3	46.3±19.1	23.8± 2.5
Kooraste Suurjärv	1236	1979; 81; 90	13	30.2± 7.1	22.1± 1.3
Jõksi	1224	1979; 81—83; 85—86; 90	35	21.4± 2.1	19.9± 0.9
Agali	847	1978; 81—83; 85—86	34	28.7± 2.6	24.7± 1.1
Rõuge Ratasjärv	1401	1981	3	39.3±11.3	23.3± 2.5
Nõo Suur-Karujärv	935	1979	1	28	20.3± 3.5
Tsolgo Pikkjärv	1282	1982—83	9	31.9± 2.7	28.5± 1.9
Tuuljärv	1413	1979	1	42	30.5±10.8
Pühajärv	1053	1978; 1981; 86—90	36	24.1± 2.5	23.9± 1.1
Kääriku	1059	1987—89	18	18.3± 0.9	20.7± 1.2
Jaanuse	1038	1987—89	18	22.3± 2.3	24.1± 1.4
Paidra	1284	1982—83	9	28.1± 2.7	25.3± 1.7
Nõuni	1013	1978; 81—82; 90	19	29.2± 3.5	22.7± 1.2
Pikrejärv	1171	1978; 87—89	21	25.0± 3.6	23.3± 1.3
Rõuge Valgjärv	1405	1981	5	59.6± 7.0	35.3± 3.0
Kavadi	1437	1979; 81	3	44.7± 6.2	27.2± 2.9
Kooraste Pikkjärv	1230	1984; 90	10	17.9± 1.6	24.7± 1.6
Kirikumäe	1447	1981	3	60.3±22.3	31.8± 3.3
Karijärv	843	1979; 81—82	10	48.0±13.9	31.0± 2.0
Vaskna	1443	1979	1	52	37.8± 6.6
Vissi	727	1979	1	47	34.1± 6.0
Kasaritsa Verijärv	1381	1979; 81—82; 90	15	35.4± 4.8	31.3± 2.1
Tornijärv	1057	1983	5	24.2± 3.5	22.1± 1.9
Kaussjärv	1402	1981	5	46.6± 8.3	25.9± 2.3
Vagula	1261	1978; 90	9	35.2± 7.2	37.9± 2.6
Kuremaa	554	1981	6	58.3±10.9	31.5± 2.5
Lavatsi	851	1978; 81—86	43	36.9± 3.3	29.2± 1.2
Vasula	753	1978; 79; 81	10	54.0± 9.3	32.2± 2.1
Kiidjärv	1107	1978; 81	7	62.0± 4.3	39.7± 3.0
Kasaritsa Valgjärv	1380	1979; 81—82; 90	13	35.5± 6.0	32.6± 1.9
Holstre	904	1984	4	35.8± 3.8	43.3± 4.2
Erastvere	1228	1979; 81—83; 90	21	43.4± 3.7	38.5± 2.0
Partsi Kõrtsijärv	1128	1978	3	52.0± 4.6	36.8± 3.9
Otepää Valgjärv	1077	1978	3	50.3± 8.8	34.4± 3.7
Vidrike	1203	1984; 90	11	33.0± 3.5	43.8± 2.8

* Kask, 1964.

1	2	3	4	5	6
Laanemetsa	1179	1987—89	18	30.7± 2.5	34.1± 2.0
Petajärv	1166	1978; 82—83; 85—86	23	40.0± 4.2	39.7± 2.0
Kurnakese	1037	1987—89	18	43.1± 7.2	42.9± 2.5
Kuningvere	588	1981	5	74.0±13.8	37.5± 3.2
Elistvere	651	1978	3	36.0± 2.0	25.5± 2.7
Pangodi	1006	1978; 81—83; 85—86; 90	35	35.4± 3.0	34.3± 1.6
Karsna	1275	1982—83	9	52.0±10.8	44.3± 3.0
Viljandi	828	1981	3	66.7±11.1	35.9± 3.8
Vellavere Külajärv	925	1978—79; 81—83	21	55.2± 5.1	39.4± 2.0
Kubija	1378	1981	9	29.6± 5.0	31.7± 2.2
Mäha	1048	1987—90	24	37.3± 2.2	44.9± 2.3
Väike-Juusa	1041	1987—89	18	34.1± 3.4	36.5± 2.1
Otepää Kärnjärv	1051	1987—90	24	30.5± 2.3	35.6± 1.9
Verevi	932	1978—79; 81; 83—89	45	50.3± 4.6	46.3± 2.0
Annejärv	1277	1982—83	9	60.4± 6.9	54.3± 3.7
Kaiavere	571	1978	3	61.0±12.0	41.9± 9.5
Saare	573	1981	5	63.6±14.1	33.0± 2.8
Pilkuse	1042	1987—89	18	40.7± 3.3	44.1± 2.5
Vana-Koiola	1249	1982—83	9	55.2± 4.1	50.4± 3.5
Kadastiku	1184	1987—89	18	42.6± 4.4	45.6± 2.6
Kaarepere Pikkjärv	569	1981	3	60.0±16.1	34.8± 3.7
Raigastvere	650	1978	3	49.7± 4.0	35.1± 3.8
Tamula	1262	1978; 90	9	50.4± 8.0	56.2± 3.9
Jääva	1173	1987—89	18	53.8± 7.3	55.2± 3.2
Juusa	1055	1981—83; 85—89	45	56.0± 4.2	55.0± 2.4
Lasva	1290	1982—83	10	78.8± 4.1	71.0± 4.7
Linaleojärv	1289	1987—89	18	79.4±13.5	71.8± 4.1
Holstre Linajärv	902	1984	4	55.0± 8.8	65.6± 6.3
Väike-Kodijärv	1010	1978	3	82.0±22.0	54.2± 5.8
Kodijärv	1009	1982—83; 85—86	20	55.6± 5.7	61.1± 3.2
Ruusmäe	1537	1979	1	222	161.3±28.1
Kokora Mustjärv	587	1981	6	140.0±25.2	75.1± 6.0
Laose Valgjärv	831	1984	3	148.7±43.0	161.0±17.4
Kriimani	948	1978; 80; 81—86	39	114.0± 9.0	101.3± 4.4
Kooraste Linajärv	1233	1979; 81—86; 90	36	110.0± 8.6	116.2± 5.2
Otepää Pikajärv	1078	1978; 82—86	29	139.1±14.4	137.4± 6.5
Pappjärv	1379	1979; 82—86; 90	33	211.9± 5.7	171.3± 7.9

Table 2

Range of arithmetically averaged values and geometrical mean values of total phosphorus concentrations (mg P/m^3) in small Estonian lakes

Year	Number of lakes	Number of samples	Arithm. Min.	Arithm. Max.	Geom. mean ±S. E.
1978	25	83	19.7	163.3	45.9±1.9
1979	22	22	15.0	270.0	37.1±2.0
1981	44	201	27.5	192.1	51.6±1.9
1982	30	154	17.0	465.8	37.1±1.4
1983	28	138	10.0	431.3	33.1±1.2
1984	18	73	8.5	174.5	27.3±1.1
1985	18	125	9.4	132.6	24.2±0.9
1986	19	94	9.6	92.0	22.2±0.9
1987	20	101	13.0	92.0	34.0±1.4
1988	20	123	9.2	79.0	24.7±1.0
1989	20	138	11.9	70.7	26.9±1.1
1990	20	119	9.2	109.5	19.9±0.8

Table 3

Geometrical mean values of phosphorus concentrations (mg P/m³ ± S. E.) in small Estonian lakes

Lake	1978	1981	1982	1983	1984	1985	1986	1990	mean
Piigandi		22.9± 3.9	16.6± 3.2	14.5± 2.7	10.4± 2.0	12.9± 2.2	10.6± 1.9	9.9±1.8	14.5± 1.6
Uiakatsi		31.7± 4.4	24.7± 3.3	14.0± 1.9	19.0± 2.8	8.7± 1.1	9.3± 1.3	8.2±1.1	15.9± 1.5
Koorküla									
Valgjärv	19.5± 1.4	32.4± 2.4	25.1± 1.6	15.2± 1.0	14.5± 1.0	11.9± 0.8	9.6± 0.6		16.9± 0.9
Udsu	22.9± 1.9	33.8± 2.8	18.7± 1.3	15.9± 1.3	7.4± 0.6	13.1± 1.0	18.2± 1.4		17.0± 1.1
Saadjärv	37.0± 4.5	26.7± 3.3	27.4± 3.7	11.8± 1.6	11.0± 2.1	11.0± 1.4	11.6± 1.5		18.5± 1.8
Jõksi		23.9± 3.5	23.2± 3.6	25.9± 4.0		14.4± 2.1	12.5± 2.0	14.6±2.2	18.3± 1.9
Agali	33.6± 3.1	37.4± 3.1	37.4± 3.0	23.0± 1.9		15.9± 1.3	18.6± 1.6		26.2± 1.7
Lavatsi	51.9± 4.6	60.4± 4.5	26.9± 2.0	35.4± 2.7	24.2± 2.0	19.3± 1.5	22.3± 1.8		31.8± 2.0
Pangodi	45.1± 4.3	45.1± 4.1	40.4± 3.5	39.6± 3.4		31.4± 2.6	26.3± 2.3	16.1±1.4	33.1± 2.1
Petajärv	53.8± 6.1		50.8± 5.5	46.5± 5.1		29.9± 3.0	21.1± 2.2		38.1± 3.2
Verevi	37.3± 6.8	47.7± 8.0		70.4±11.8	25.4± 4.6	35.0± 5.1	27.9± 4.4		43.0± 4.0
Juusa		34.2± 3.8	59.8± 5.6	42.5± 4.1		62.9± 5.7	42.5± 4.1		49.0± 3.2
Kooraste									
Linajärv		116.6±11.3	97.9± 8.7	108.1± 9.6	125.6±11.5	85.3± 7.2	71.5± 6.3	108.5±9.4	113.6± 7.9
Kriimani	162.2±15.5	187.2±14.1	110.3± 8.3	79.0± 6.7	113.8± 9.6	74.7± 5.9	55.8± 4.7		118.6± 7.1
Otepää									
Pikajärv	158.3±17.2		179.3±17.7	107.4±10.6	167.2±17.1	106.4±10.0	84.1± 8.3		129.7± 9.7
Pappjärv			425.0±82.2	365.4±64.9	140.5±27.1	106.4±18.4	83.5±15.4	54.0±9.6	150.4±18.0

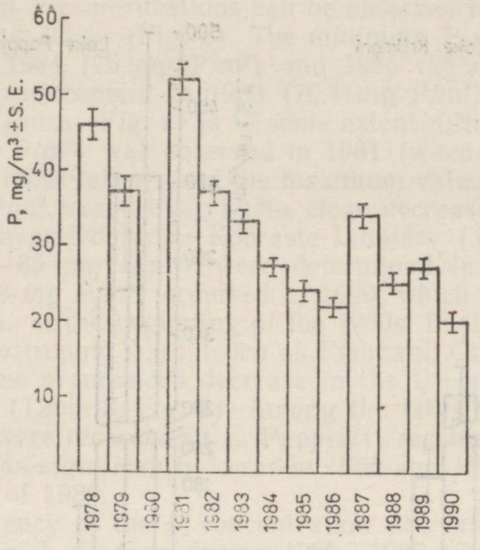

Fig. 1. Trend of total phosphorus concentration in small Estonian lakes during 1978—1990.

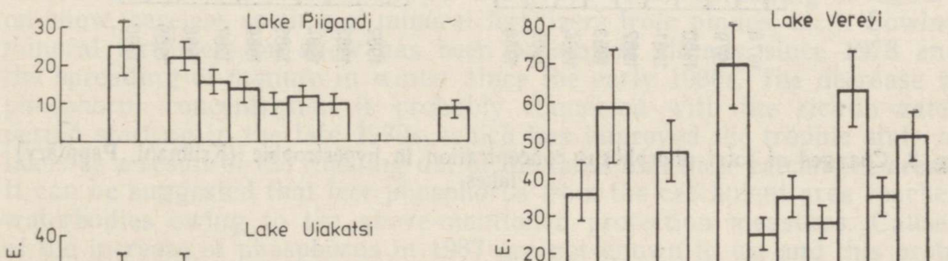

Fig. 2. Changes of total phosphorus concentration in mesotrophic (Piigandi, Uiakatsi) and eutrophic (Pangodi, Verevi, Juusa) lakes during 1978—1990.

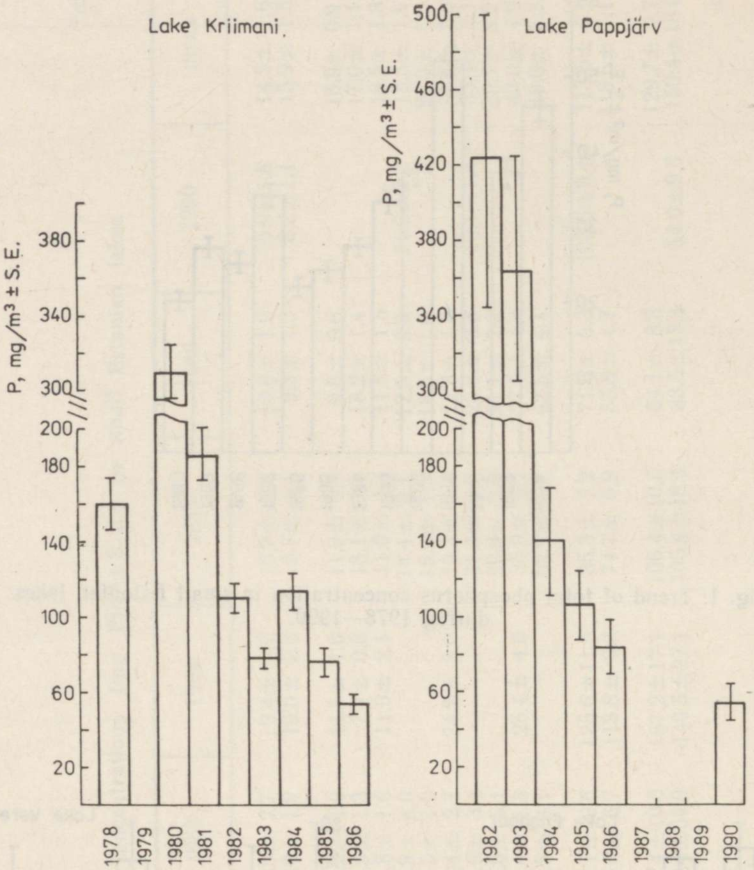

Fig. 3. Changes of total phosphorus concentration in hypertrophic (Kriimani, Pappjärv) lakes.

decreasing during the years under study. The highest mean concentration was found in 1981 and the lowest in 1990, with a certain increase in 1987. In the years 1984—1990 (except the year 1987) the phosphorus content was about two times below its contents in 1978 and 1981. Table 2 gives the maximum and minimum arithmetically averaged values of phosphorus for each year. The same tendency of the phosphorus concentration decrease was observed in the minimum and maximum averaged values during the years under study.

The decreasing trend in the phosphorus content was well revealed in most intensively studied lakes (Table 3, Figs. 2, 3). The maximum content of phosphorus was observed in 1981 which decreased twofold or more during the years studied. In mesotrophic lakes the phosphorus content amounted to 23—34 mg P/m^3 in 1981, but already by 1983 it had decreased down to 12—16 mg P/m^3, and the tendency of decrease continued up to 1986 and 1990 (Table 3, Fig. 2).

Also, when comparing the phosphorus values of eutrophic lakes in different years the same trend can be seen — from 37—60 mg P/m^3 in 1981 to 13—28 mg P/m^3 in 1986 (Table 3). Changes of phosphorus concentrations in hypertrophic lakes were the greatest. The maximum concentrations (160—425 mg P/m^3) were recorded in 1978 and 1981—1983, which had decreased down to 54—109 mg P/m³ in 1986 and 1990. No decreasing trend in P concentrations can be observed in the surface water of lakes Verevi and Juusa (Fig. 2). The minimum P values in L. Verevi were recorded in 1984 (25 mg P/m³) and 1986 (28 mg P/m³), and the maximum phosphorus content in 1983 (70.4 mg P/m³). The picture of P fluctuations in L. Juusa (Fig. 2) is to some extent different: the minimum P content (34 mg P/m³) was observed in 1981 (when the P content was the highest in the other lakes), and the maximum values in 1988 and 1985 (64 and 63 mg P/m³, respectively). No clear decrease in the P content was noted in the hypertrophic L. Kooraste Linajärv (Table 3). The minimum values (72—85 mg P/m³) were determined in 1985—1986, some higher values (109 mg P/m³) occurred in 1990, which indicated the same phosphorus level as at the beginning of the 1980s. In the remaining intensively studied hypertrophic lakes (such as Kriimani, Otepää Pikajärv, and Pappjärv) the same pronounced decrease in the P content was observed during the period (Table 3, Fig. 3). Among the lakes studied the highest P concentrations were recorded in L. Pappjärv, reaching 425 mg P/m³ in 1982; P content was significantly lower in 1986 and 1990 (5—8 times) as compared to that of 1982.

The same tendency of the P concentration decrease was observed in the surface water of L. Ladoga during 1980—1985 (Современное состояние..., 1987). The maximum mean values of phosphorus concentration (32—28 mg P/m³) were recorded in the spring and summer of 1980—1981; by 1984 and 1985 the concentration had decreased to 24 mg P/m³.

In Estonia the greatest source of phosphorus pollution is agriculture, since our lakes are affected by it or are located in agricultural landscape. As the catchment areas of small lakes are small, a great role in their pollution is played by point pollution, especially from farms, municipal sewage, and saunas. Fertilizers from fields have a smaller effect, but it can be multiplied by their improper use (such as the spreading of manure on snow, careless sowing of mineral fertilizers from planes, etc.). Sowing mineral fertilizers on snow has been prohibited already since 1978 and the spreading of manure in winter since the early 1980s. The decrease in phosphorus concentration is probably connected with the rich-in-water period starting in the late 1970s, which has improved the trophic state of lakes as a result of the flushing out of the lakes and their catchment areas. It can be suggested that less phosphorus from the catchment area reaches waterbodies owing to the above-mentioned protection measures. Causes of the increase of phosphorus in 1987 are not known to us, and this problem would need further study.

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