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YEARLY CHANGES IN TOTAL PHOSPHORUS AND CHLOROPHYLL *a* CONCENTRATIONS IN ESTONIAN LAKES

Abstract. Ninety-five small lakes (mesotrophic, eutrophic, and hypertrophic type) of Estonia were studied for the content of total phosphorus and chlorophyll *a* and their changes during 1978—1990. It was proved statistically that the content of total phosphorus decreased during the observation period. The content of chlorophyll *a* changed in an undulatory mode, with maxima in the late 1970s and early 1980s and in 1987—1988, and with minima in 1984 and 1990. The relationship between chlorophyll *a* and total phosphorus was highly significant ($r=0.80$) under long-term study.

Key words: lake, total phosphorus, chlorophyll *a*, trophic state, yearly changes.

Phosphorus is generally considered to be a growth limiting and the most easily controllable nutrient involved in algal productivity in lakes. Chlorophyll *a* is a good indicator of the phytoplankton biomass. As chlorophyll *a* and the total phosphorus concentration give direct information about the trophic state of lakes, these parameters are used as indices of the trophic state (Carlson, 1977; Walker, 1979; Милиус, 1983, 1984).

The hydrochemistry group of the Institute of Zoology and Botany of the Estonian Academy of Sciences has been studying total phosphorus and chlorophyll *a* concentrations in small lakes of Estonia. The aim of this paper is to follow changes in total phosphorus and chlorophyll concentrations over the period of 13 years.

Material and Methods

Measurements of total phosphorus and chlorophyll concentrations were made on the surface waters of 95 small Estonian lakes during 1978—1990. The lakes studied are mostly in South-East and South Estonia; only a few lakes 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 (Table). Seventeen lakes were studied during 6—9 years, 60 lakes during 2—5 years, and 18 lakes only during one year. Between 1978—1979, observations were performed three times a year: during the water circulation period in spring (May) and autumn (September) and at the peak of summer stagnation (July). In 1980 the lakes were sampled only twice: in July and September. From 1981 to 1990 the lakes were sampled four to eight times (on an average five times) after the ice-out until late August or early September. Total phosphorus (P) was determined with the colorimetric method using ascorbic acid and ammonium molybdate after persulphate oxidation of the sample (Reports ..., 1977). The chlorophyll *a* (chl) concentration was determined according to the method of Talling (1969). Water was filtered through

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Geometrical mean values of total phosphorus and chlorophyll *a* concentrations in Estonian small lakes grouped according to trophic state

Year	Number of lakes	Number of samples		Total phosphorus, mg P/m³±S. E.			Chlorophyll *a*, mg/m³±S. E.		
		P	chl	Mesotrophic	Eutrophic	Hypertrophic	Mesotrophic	Eutrophic	Hypertrophic
1978	25	83	83	28.8±2.7	40.9±2.3	114.2±12.9	3.9±0.3	8.6±0.7	14.9±4.5
1979	22	22	75	21.9±2.4	33.7±2.3	99.0±15.0	4.4±0.4	9.3±0.8	25.0±7.4
1980	21		59				2.9±0.3	9.3±0.9	22.6±6.2
1981	44	201	206	31.2±2.7	48.3±2.5	104.7±9.3	3.9±0.9	8.9±0.5	24.3±5.0
1982	30	154	152	21.9±1.9	35.1±1.8	94.2±7.6	2.7±0.2	7.2±0.5	17.3±3.0
1983	28	138	138	14.3±1.3	35.0±1.9	89.8±7.3	2.3±0.2	6.0±0.4	18.7±3.3
1984	18	73	118	12.1±1.1	22.5±1.4	98.0±8.7	2.2±0.2	4.7±0.4	18.5±3.6
1985	18	125	140	12.2±1.1	23.0±1.2	67.4±5.4	3.5±0.3	6.5±0.5	18.3±3.1
1986	19	94	93	11.8±1.0	21.4±1.2	57.5±4.7	2.9±0.2	6.4±0.5	20.4±3.7
1987	20	101	98	15.6±1.8	29.8±1.6	109.8±10.6	4.3±0.6	11.0±0.9	28.7±7.0
1988	20	123	120	10.2±1.2	22.7±1.2	80.4±7.7	3.6±0.5	9.9±0.7	29.4±7.2
1989	20	138	139	12.8±1.5	25.7±1.4	60.9±5.8	2.8±0.4	8.9±0.7	14.1±3.4
1990	20	120	120	9.1±0.8	19.6±1.0	44.2±4.2	2.4±0.2	5.4±0.3	14.7±3.5

the Whatman GF/C filter paper. Methanol was used to extract chl and chl values were selected using Marker's equation (1972). The whole material includes 1568 chl and 1373 P analyses. No P measurements were made in 1980, and in 1979 P measurements were made only in May.

In order to explain year-to-year changes in P and chl concentrations, all initial data values were transformed to their logarithms and processed with the analysis of variance. The effect of the lake, observation year and month were taken into account as factors. The analysis of variance was selected since it enables to compare data collected in various years and at different frequencies.

Results and Discussion

The trophic level of the lakes under study was classified according to three main parameters of the trophic state (P, chl, water transparency). Our results show that 24% of the lakes investigated are mesotrophic (23 lakes), 59% eutrophic (56 lakes), and 17% hypertrophic (16 lakes).

Changes in the P concentrations of the surface water of the 95 lakes studied during the years 1978—1990 are presented in the Table and illustrated in Fig. 1. The whole range of phosphorus observed was from 19.9 to 51.6 mg P/m³. The concentration of P showed a clearly decreasing trend during the years under study (at the probability level 0.002). The highest mean concentration was found in 1981 and the lowest in 1990, with a certain increase in 1987. The same decreasing trend in the P concentration was well revealed in all trophic types (at the probability level 0.001 for the mesotrophic type, 0.004 for the eutrophic, and 0.007 for the hypertrophic type, Fig. 2). The variation of the P content was the greatest in the hypertrophic type. Maximum mean P concentrations were recorded in 1978 and 1981; by 1984 the concentration had gradually decreased in mesotrophic and eutrophic lakes, while in the hypertrophic type a marked decrease occurred in 1985—1986. All lake types had undergone a distinct increase in P values by 1987, followed again by a decrease down to minimum values by 1990. The difference between the maximum and minimum values was about twofold in all lake types (Table).

In the chl content of the surface water of the 95 lakes studied no unidirectional changes took place during 1978—1990 (Fig. 3). The chl content varied within a broad range from 5.3 to 10.8 mg/m³. Changes in chl concentrations were fluctuating with maxima in 1979—1981 and 1987—1988, and with minima in 1984 and 1990.

Such undulatory changes have been characteristic of mesotrophic, eutrophic, and hypertrophic lakes (Fig. 4). In mesotrophic and eutrophic types the chl content showed maximum values in the late 1970s and early 1980s, and after a temporary and gradual decline, a minimum in 1984; another, higher maximum was reached in 1987—1988, after which the chl content decreased again. The variation of the chl content was the greatest in the hypertrophic type. The chl content also changed in an undulatory mode, but with maxima in 1979—1981 and 1987—1988 and with minima in 1982—1986 and 1989—1990.

Though the concentration of chl shows wavelike changes, there appears a similarity with the P trend: the maximum values of the late 1970s and early 1980s are followed by a decrease; the minimum occurs in 1984—1986. The course of P and chl trends is changed in 1987 by a rise in the P content, which is 1.3—1.4-fold in mesotrophic and eutrophic lakes and even 1.9-fold in hypertrophic lakes. This brings

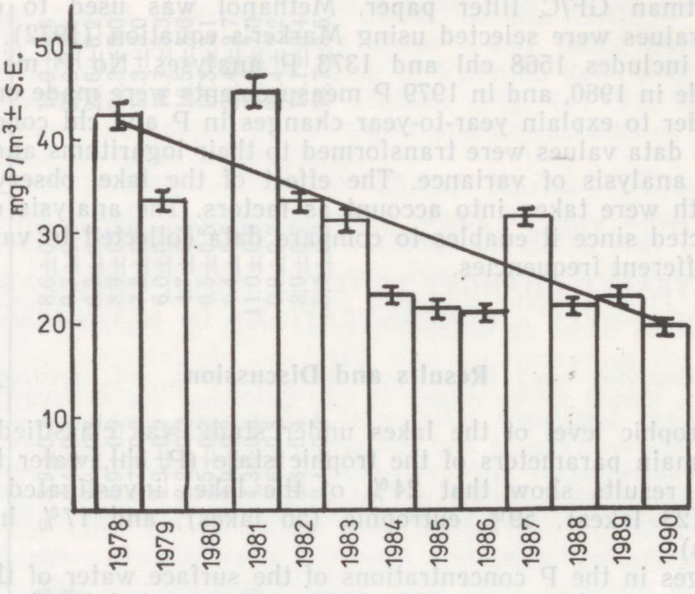

Fig. 1. Trend of total phosphorus concentration in Estonian lakes during 1978—1990.

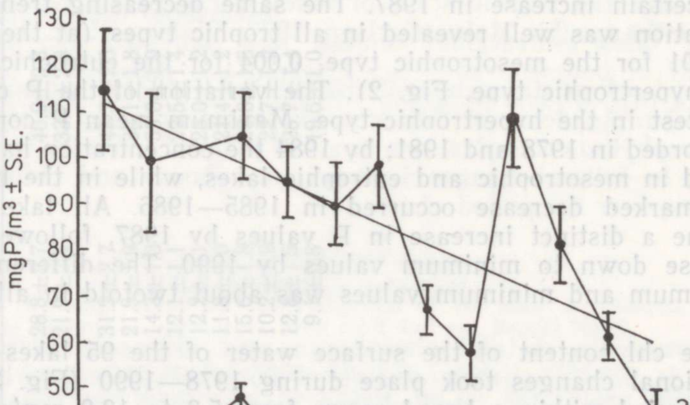

Fig. 2. Trend of total phosphorus concentration in mesotrophic (*1*), eutrophic (*2*), and hypertrophic (*3*) lakes during 1978—1990.

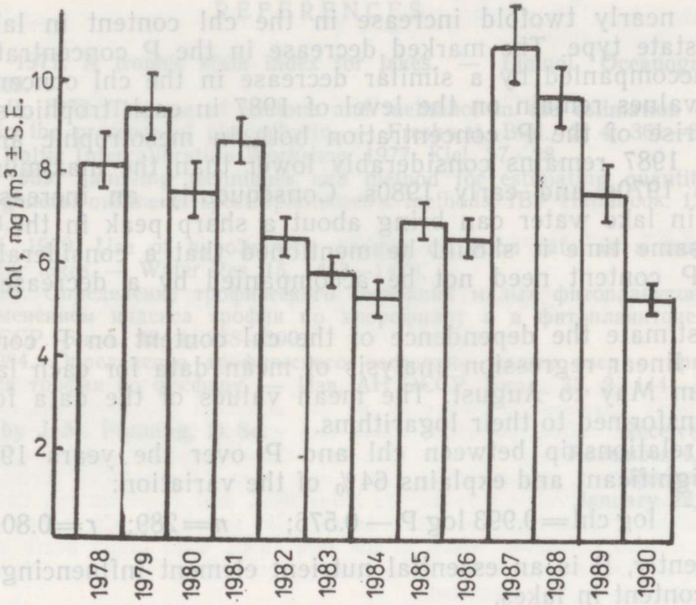

Fig. 3. Changes of chlorophyll *a* concentration in Estonian lakes during 1978—1990.

Fig. 4. Changes of chlorophyll *a* concentration in mesotrophic (*1*), eutrophic (*2*), and hypertrophic (3) lakes during 1978—1990.

about a nearly twofold increase in the chl content in lakes of each trophic state type. The marked decrease in the P concentration in 1988 is not accompanied by a similar decrease in the chl concentration: the latter's values remain on the level of 1987 in each trophic state type.

The rise of the P concentration both in mesotrophic and eutrophic lakes in 1987 remains considerably lower than the maximum values of the late 1970s and early 1980s. Consequently, an increase in the P content in lake water can bring about a sharp peak in the chl content. At the same time it should be mentioned that a considerable decrease in the P content need not be accompanied by a decrease in the chl content.

To estimate the dependence of the chl content on P concentrations, we used linear regression analysis of mean data for each lake in every year from May to August. The mean values of the data for the lakes were transformed to their logarithms.

The relationship between chl and P over the years 1978—1990 is highly significant and explains 64% of the variation:

$$\log \mathrm{chl} = 0.993 \log \mathrm{P} - 0.576; \quad n = 289; \quad r = 0.80.$$

Consequently, P is an essential nutrient element influencing changes in the chl content in lakes.

Since our lakes are located in agricultural landscape, agriculture is the greatest source of phosphorus pollution. The catchment areas of small lakes being small, an important role in their pollution is played by point pollution, especially from farms, municipal sewage, and saunas. Fertilizers from fields have a smaller effect but this can be multiplied by their improper use (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 spreading of manure in winter since the early 1980s. The decrease in the P concentration was probably connected with the rich-in-water period starting in the late 1970s, which improved the trophic state as a result of the flushing out of the lakes and their catchment areas. It can be suggested that less phosphorus reached waterbodies from the catchment area owing to the above-mentioned protection measures. The main factors which can influence yearly changes in chl concentrations are the weather conditions of the year (temperature, light, precipitation) and the biological availability of nutrient elements. The factors that caused the increase of P in 1987 and specific undulatory changes in chl concentrations are unknown to us, and would need further study.

Conclusion

The long-term study of 95 lakes in Estonia confirms the evidence of a clearly decreasing trend in the total P concentrations during the period 1978—1990.

The decreasing trend of total P was not accompanied by a similar decrease in the chl concentration, because the chl content changed in an undulatory mode, with maxima in the late 1970s and early 1980s and in 1987—1988, and with minima in 1984 and 1990. The dependence of the chl concentration on the total P concentration is highly significant ($r = 0.80$).

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