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CHLOROPHYLL *a* IN ESTONIAN LAKES

Chlorophyll *a* has been recognized as the simplest useful estimate and a good indicator of the phytoplankton biomass. Being the first link in the trophic chain, phytoplankton readily reacts on changes in the nutrient contents of a waterbody. The chlorophyll *a* content gives direct information about the trophic state of a waterbody and is applied as an index of the trophic state (Carlson, 1977; Walker, 1979; Милиус, 1983).

There were no chlorophyll investigations on Estonian lakes up to the first half of the 1970s. Our hydrochemistry group of the Institute of Zoology and Botany of the Estonian Academy of Sciences began studies of chlorophyll *a* concentrations on the small lakes of Estonia beginning from 1974. In the years 1974—1977 only 2—4 lakes were examined; the survey of this work has been published in (Milius, Pork, 1977a, b; Milius, Kõvask, 1977; Милиус, Кываск, 1978; 1979; 1980). Since 1978 the studies were performed on more than 20 lakes a year. A part of the results of chlorophyll data from the years 1978—1979 have already been published (Милиус, 1981; Kõvask, Milius, 1982). The aim of this paper is to give a regional survey as well as the trends of change in the chlorophyll *a* content in the surface water of the small lakes of Estonia during the period 1978—1990.

Material and methods

The 95 lakes studied are mostly located in the South-East and South Estonia; only a few lakes are situated in the eastern part of the Republic, in the Jõgeva district. The list of lakes examined in the order of their increasing trophic state is given in Table 1. The number of the lakes studied each year ranged between 18 and 44 (Table 2). 17 lakes were studied during 6—9 years (Table 3), 60 lakes during 2—5 years and 18 lakes only during one year. Between 1978—1979, studies 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 4 to 8 times (5 times on an average) after the ice-out until late August or early September. Water samples were collected from the surface water. A total of 1568 analyses were made. Chlorophyll *a* (chl) concentrations were determined according to the method of Talling (1969). Water was filtered through the Whatman GF/C filter paper. Chl was extracted with methanol and values were calculated by using the Marker equation (Marker, 1972).

In order to obtain a better survey of the data collected in various years and at different frequencies, the initial data were processed with the analysis of variance in which the effects of the lake, observation year and observation month were selected as factors.

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Table 1

Chlorophyll *a* concentrations (mg/m³) in the small lakes of Estonia

Lake	Lake catalogue No.*	Year	Number of samples	Arithm. mean. ±S. E.	Geom. mean. ±S. E.
Nohipalu Valgjärv	1297	1977—1983	39	2.4±0.2	2.1±0.2
Väike-Palkna	1517	1980—81	4	2.2±0.2	1.9±0.4
Piigandi	1084	1979; 81—86; 1990	44	2.8±0.3	2.6±0.2
Inni	1200	1987—90	24	3.9±0.4	3.1±0.3
Hino	1555	1979	3	3.1±0.1	2.1±0.5
Peitlemäe	1054	1987—89	16	3.8±0.6	2.6±0.3
Roksi	1170	1987—89	17	4.4±0.4	3.3±0.4
Pulli	1552	1979—1981	8	3.2±0.6	2.4±0.4
Saagjärv	1047	1987—89	18	3.5±0.3	2.6±0.3
Udsu	1177	1978; 1981—86	34	3.1±0.3	3.1±0.3
Uiakatsi	1238	1979; 81—86; 1990	44	3.2±0.3	3.1±0.2
Koorküla Valgjärv	1180	1978; 81—86	34	3.8±0.5	3.5±0.3
Virtsjärv	1178	1987—89	18	4.6±0.4	3.5±0.4
Tillijärv	835	1984	7	2.7±0.6	3.4±0.5
Saadjärv	653	1975—1986	68	4.8±0.4	3.8±0.3
Viisjaagu	924	1979; 81—83	21	3.8±0.8	2.9±0.3
Tõrva Vanamõisa	1000	1984—86	20	4.5±0.5	4.5±0.5
Rõuge Suurjärv	1403	1980—81	5	3.8±0.8	3.0±0.5
Kisejärv	1532	1980—81	5	3.6±0.6	2.9±0.5
Kooraste Kõverjärv	1232	1980—81	4	4.2±0.5	3.3±0.6
Tõugjärv	1400	1980—81	5	6.0±1.5	4.4±0.8
Liinjärv	1404	1980—81	5	4.5±1.8	3.0±0.5
Rõikajärv	834	1984	7	5.0±1.4	5.7±0.9
Prossa	568	1980—81	5	5.5±1.2	4.2±0.8
Kooraste Suurjärv	1236	1979; 81; 90	15	5.3±0.6	4.8±0.5
Jõksi	1224	1979; 81—83; 85—86; 90	39	5.9±0.4	5.8±0.5
Agali	847	1978; 81—83; 85—86	35	5.2±0.4	5.1±0.4
Rõuge Ratasjärv	1401	1980—81	5	7.8±2.4	5.4±0.9
Nõo Suur-Karujärv	935	1979	3	9.8±2.2	7.1±1.6
Tsolgo Pikkjärv	1282	1982—83	9	5.5±1.4	5.1±0.7
Tuuljärv		1979	3	6.7±1.6	4.8±1.1
Pühajärv	1053	1978; 1981; 86—90	36	7.0±0.8	5.4±0.4
Kääriku	1059	1987—89	18	8.9±1.0	6.5±0.7
Jaanuse	1038	1987—89	18	8.3±0.9	6.0±0.7
Paidra	1284	1982—83	9	5.3±1.1	5.6±0.8
Nõuni	1013	1978; 81—82; 90	19	6.2±0.6	5.7±0.6
Pikrejärv	1171	1978; 87—89	21	8.5±1.1	6.0±0.6
Rõuge Valgjärv	1405	1980—81	7	5.5±0.9	4.4±0.7
Kavadi	1437	1979; 81	5	6.8±1.8	5.0±0.9
Kooraste Pikkjärv	1230	1984; 90	11	5.9±1.2	6.7±0.9
Kirikumäe	1447	1980—81	5	4.3±0.3	3.8±0.7
Karijärv	843	1979; 81—82	12	8.0±2.0	6.4±0.8
Vaskna	1443	1979	3	5.5±0.4	4.2±0.9
Vissi	727	1979	3	8.8±3.2	5.4±1.2
Kasaritsa Verijärv	1381	1979; 81—82; 90	17	6.4±1.6	6.2±0.7
Tornijärv	1057	1983	5	8.6±2.7	9.2±1.7
Kaussjärv	1402	1980—81	7	8.2±1.9	6.2±1.0
Vagula	1261	1978; 90	9	7.8±2.2	6.5±0.9
Kuremaa	554	1980—81	8	10.6±2.8	7.4±1.1
Lavatsi	851	1978; 80—86	59	10.4±0.9	9.4±0.7
Vasula	753	1978; 79; 81	12	11.0±1.5	8.3±1.0
Kiidjärv	1107	1978; 81	7	11.5±2.9	7.1±1.1
Kasaritsa Valgjärv	1380	1979; 81—82; 90	13	8.9±1.0	9.2±1.1
Holstre	904	1984	6	5.2±0.9	7.1±1.2
Erastvere	1228	1979; 81—83; 90	23	12.2±2.0	9.8±0.9
Partsi Kõrtsijärv	1128	1978	3	10.6±3.2	8.4±1.9
Otepää Valgjärv	1077	1978	3	11.8±2.7	9.7±2.2
Vidrike	1203	1984; 90	13	7.0±0.9	8.6±1.0
Laanemetsa	1179	1987—89	18	12.7±2.1	8.6±1.0

* *Kask, I.* 1964. Eesti NSV järvede nimestik. Tallinn

Table 1 continued

Petajärv	1166	1978; 82—83; 85—86	23	11.1±2.9	8.6±0.8
Kurnakese	1037	1987—89	18	13.3±2.1	8.8±1.0
Kuningvere	588	1980—81	8	13.4±1.8	10.3±1.5
Elistvere	651	1978	3	17.9±5.2	14.1±3.2
Pangodi	1006	1978; 81—83; 85—86; 90	36	13.9±1.8	11.8±1.0
Karsna	1275	1982—83	9	13.8±8.2	8.2±1.1
Viljandi	828	1981	3	16.5±4.3	**13.7±3.0**
Vellavere Külajärv	925	1978—79; 81—83	23	14.9±2.3	11.4±1.1
Kubija	1378	1980—81; 90	11	17.6±3.5	14.0±1.8
Mäha	1048	1987—90	24	13.5±1.2	11.1±1.1
Väike-Juusa	1041	1987—89	17	20.3±3.4	13.1±1.5
Otepää Kärnjärv	1051	1987—90	24	19.1±2.6	13.6±1.4
Verevi	932	1978—79; 81; 83—89	51	16.8±2.4	11.4±0.8
Annejärv	1277	1982—83	9	11.1±2.6	11.0±1.6
Kaiavere	571	1978	3	18.1±5.8	14.4±3.2
Saare	573	1980—81	7	21.4±2.2	17.5±2.7
Pilkuse	1042	1987—89	18	23.8±4.3	14.7±1.7
Vana-Koiola	1249	1982—83	9	13.1±2.8	13.7±1.9
Kadastiku	1184	1987—89	18	14.6±2.0	10.2±1.2
Kaarepere Pikkjärv	569	1980—81	5	26.9±5.0	21.2±3.8
Raigastvere	650	1978	3	23.5±5.8	19.5±4.4
Tamula	1262	1978; 90	9	14.4±2.8	14.2±2.0
Jääva	1173	1987—89	18	33.2±7.2	17.4±2.0
Juusa	1055	1981—83; 85—89	46	24.5±2.9	16.4±1.2
Lasva	1290	1982—83	10	14.7±3.5	13.8±1.9
Linaleojärv	1289	1987—89	18	30.5±8.3	14.8±1.7
Holstre Linajärv	902	1984	7	10.8±1.7	14.1±2.3
Väike-Kodijärv	1010	1978	3	38.6±20.0	21.4±4.8
Kodijärv	1009	1982—83; 85—86	21	25.2±3.7	23.2±2.3
Ruusmäe	1537	1979	3	26.8±16.5	13.7±3.1
Kokora Mustjärv	587	1980—81	6	57.1±21.7	**33.0±5.5**
Laose Valgjärv	831	1984	7	20.9±9.7	15.2±2.4
Kriimani	948	1978; 80—86	53	42.1±5.3	31.4±2.3
Kooraste Linajärv	1233	1979; 81—86; 90	41	43.8±7.6	30.4±2.4
Otepää Pikajärv	1078	1978; 82—86	31	60.3±11.7	46.7±4.1
Pappjärv	1379	1979; 82—86; 90	39	69.3±11.1	54.5±4.4

Table 2

Geometrical mean and range of arithmetically averaged values of chlorophyll concentrations (mg/m^3) in the small lakes of Estonia

Year	Number of lakes	Number of samples	Mean ± S.E.	Min.	Max.
1978	25	83	8.2±0.6	2.5	46.5
1979	22	75	9.4±0.7	2.7	98.2
1980	21	59	7.6±0.6	2.2	46.8
1981	44	206	8.7±0.5	2.6	57.1
1982	30	152	6.6±0.4	2.0	86.5
1983	28	138	5.9±0.3	1.6	104.0
1984	19	118	5.3±0.4	1.8	115.8
1985	18	140	7.0±0.4	3.2	88.6
1986	19	93	6.6±0.4	2.2	59.6
1987	20	98	10.8±0.8	4.4	40.6
1988	20	120	9.7±0.7	3.1	44.8
1989	20	139	7.6±0.6	2.8	39.3
1990	20	120	5.3±0.3	2.4	52.7

Table 3

Geometrical mean values of chlorophyll *a* concentrations (mg/m³ ± S. E.) in the small lakes of Estonia

Lake	1978	1979	1981	1982	1983	1984	1985	1986	1990
Piigandi		2.2±0.4	3.5±0.5	1.9±0.3	1.4±0.2	1.8±0.3	3.6±0.5	1.8±0.3	2.2±0.4
Uiakatsi		4.4±0.7	4.1±0.6	2.9±0.4	3.4±0.5	1.6±0.2	2.7±0.3	3.0±0.4	2.2±0.3
Koorküla			2.6±0.6	3.1±0.5	2.4±0.5	2.7±0.5	4.5±0.7	2.6±0.5	
Valgjärv	3.4±0.7		3.3±0.4	2.8±0.3	2.1±0.3	1.7±0.2	3.6±0.4	3.8±0.4	
Udsu	2.4±0.3		4.7±0.7	1.7±0.3	1.8±0.3	2.7±0.5	2.9±0.4	3.2±0.5	
Saadjärv	4.9±0.7	6.6±1.0	6.0±0.5	4.3±0.4	3.2±0.3		6.7±0.6	6.5±0.6	5.2±0.5
Jõksi		5.9±0.6	4.5±0.4	5.2±0.5	3.7±0.4		5.4±0.5	4.0±0.4	
Agali	7.1±0.8		13.5±1.4	8.1±0.9	8.3±1.0	5.1±0.6	8.7±1.0	10.8±1.4	
Lavatsi	4.2±0.6		18.7±3.2	15.4±2.4	13.9±2.2		8.6±1.2	7.3±1.2	5.5±0.8
Pangodi	25.1±4.6			13.2±3.6	8.0±2.2		6.8±1.6	6.9±1.8	
Petajärv	7.1±2.1				11.0±2.7	7.9±1.7	8.3±1.7	9.5±2.2	
Verevi	6.9±2.9	9.8±2.7	7.5±1.9				27.1±7.1	16.1±4.8	
Juusa			17.2±6.0	13.7±3.9	8.4±2.5				
Kooraste									
Linajärv		49.3±20.4	31.4±13.0	9.5±3.4	26.4±9.3	13.2±4.4	35.9±11.1	50.8±18.0	35.4±11.9
Kriimani	38.3±13.8		41.9±10.2	26.8±7.1	28.9±8.8	25.3±7.3	28.9±7.6	17.6±5.8	
Otepää									
Pikajärv	21.4±7.1			63.1±18.1	32.3±9.3	67.7±19.5	32.6±8.4	41.4±11.0	
Pappjärv				69.5±22.4	95.2±27.3	52.1±14.3	28.7±7.6	54.3±16.4	27.1±7.8

Results and discussion

Table 1 shows the chl content of the surface water of 95 small lakes of Estonia during the period 1978—1990. The lakes are classified according to the three most essential parameters of the trophic state (total phosphorus, chl and water transparency) developed by us (Милиус et al., 1987). The trophic state of the lakes studied ranged from mesotrophic to hypertrophic. The lakes were arranged in the order of their increasing trophic state. Chlorophyll *a* values in Table 1 represent the arithmetical and geometrical mean values, the latter being calculated from the analysis of variance.

In the case of 23 investigated mesotrophic lakes the mean chl content calculated with the analysis of variance varies between 1.9—5.7 mg/m^3, the average being 3.1 mg/m^3. The lowest level of chl was found in the lakes of Nohipalu Valgjärv, Väike-Palkna and Piigandi. The increase of the trophic state of the investigated lakes is accompanied by a steady increase of the mean and maximum chl contents. In 56 eutrophic lakes chl concentrations ranged from 3.8 to 17.5 mg/m^3, the mean value being 7.6 mg/m^3. A low level of chl was found in several eutrophic lakes such as Kirikumäe, Prossa and Agali. The highest level of chl was recorded for the hypertrophic lakes of Otepää Pikajärv and Pappjärv (46.7 and 54.5 mg/m^3, respectively). High mean chl concentrations (30—33 mg/m^3) were also found in the following hypertrophic lakes: Kooraste Linajärv, Kriimani, Kokora Mustjärv. In 16 hypertrophic lakes the geometrical mean content of chl varied between 14—54 mg/m^3, the average being 20 mg/m^3. The range of the arithmetical mean values of chl (2.2—69.3 mg/m^3) is a little wider (the values being usually a little higher) than the range of geometrical mean values (1.9—54.5 mg/m^3) calculated with the analysis of variance for all lake types. That is due to the fact that the analysis of variance eliminates the effects expressed in the arithmetical mean such as the effect of the observation year and the effect of the observation month.

Changes in the chl content 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 chl for 95 lakes varied from 5.3 to 10.8 mg/m^3. The changes in chl concentrations were fluctuating with the

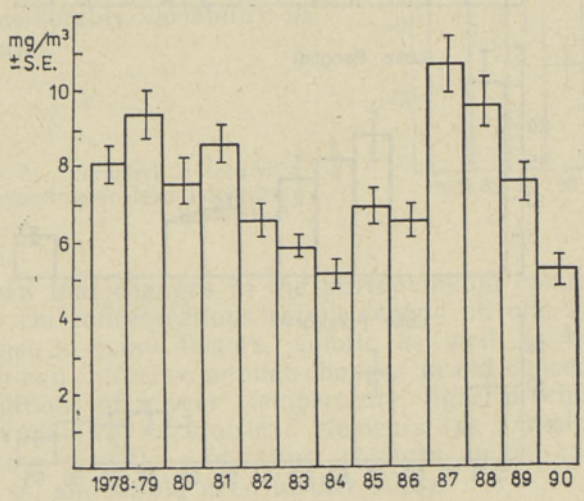

Fig. 1. Changes of chlorophyll *a* concentration in the small lakes of Estonia during 1978—1990.

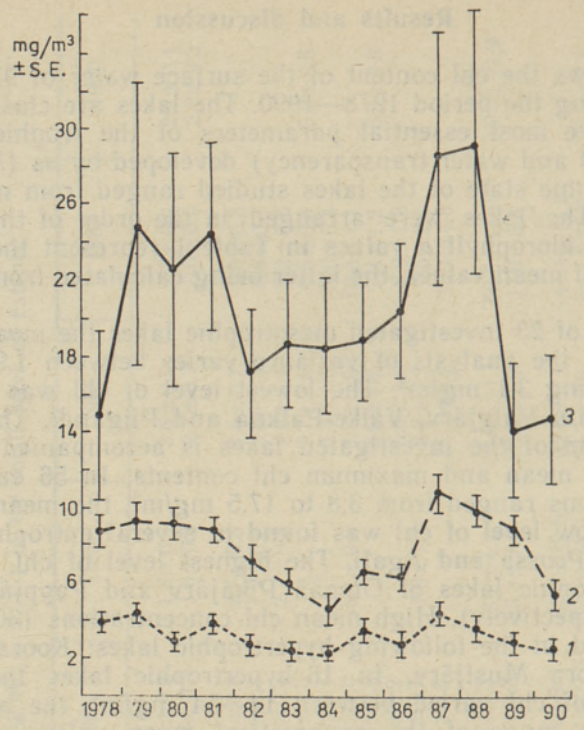

Fig. 2. Changes of chlorophyll *a* concentration in mesotrophic (*1*), eutrophic (*2*) and hypertrophic (*3*) lakes during 1978—1990.

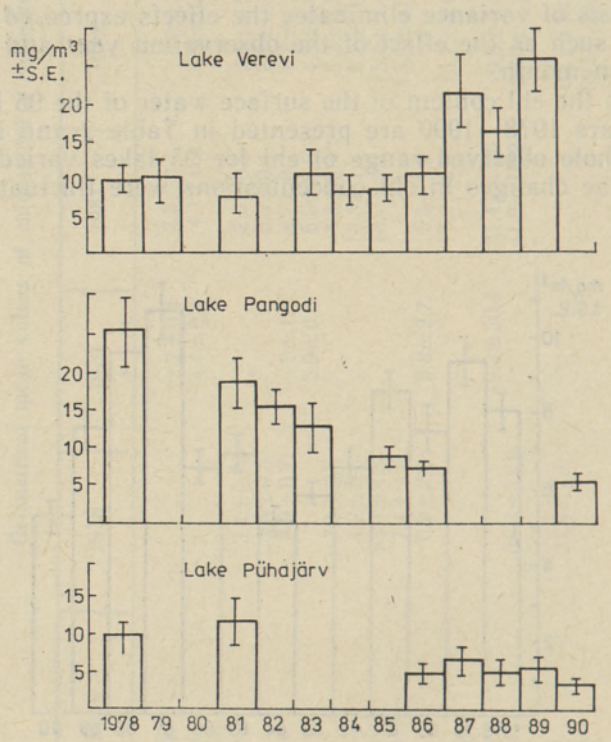

Fig. 3. Changes of chlorophyll *a* concentration in eutrophic lakes (Pühajärv, Pangodi, Verevi).

maxima in 1979 and 1987—1988. Starting from 1979, there was a decreasing trend in the chl concentration, by 1984 the values were as low as 5.3 mg/m³. Later, the stabilization of the chl content at about 6—7 mg/m³ could be seen. In 1987—1988 a considerable increase in chl values was observed, with a maximum (10.8 mg/m³) in 1987, but already by 1990 it had decreased about twofold, to the level of 1984 (5.3 mg/m³).

Typical wavy changes in chl concentrations were well revealed in each trophic lake type (Fig. 2). In all types the chl content showed a maximum in 1979 and 1981 and, after a temporary and gradual decline, a minimum in 1984; a second, higher maximum, was reached in 1987—1988, after which the chl content decreased again. However, chl data for the second maximum (1987—1988) are lacking in the case of the so far most intensively studied lakes; consequently, typical undulating changes in the chl content are not revealed in each lake during the observation period.

In mesotrophic lakes the maximum chl content amounted to 3.4—6.6 mg/m³ in 1978—1981, but already by 1983 and 1984 the chl level had fallen down to 1.4—2.4 mg/m³; the next maximum content in 1985—1986 reached about the same level as the first one (Table 3). A comparison of chl values in eutrophic lakes during the investigated years showed maximum concentrations in the same years, 1978 and 1981 (6—13.5 mg/m³), and 1985—1986 (6.7—10.8 mg/m³), and a minimum content (3.2—5.1 mg/m³) in 1983—1984 (Table 3). In the case of L. Verevi, however, there appeared a tendency of increase in the chl content in 1987 and 1989 (20.8—25.3 mg/m³) in comparison with the previous period 1978—1986 (7.5—11.0 mg/m³, Fig. 3). The minimum chl content (7.5 mg/m³) in L. Verevi was observed in 1981 while the chl level was highest in the other eutrophic lakes. A decreasing trend in the chl content can be seen in the eutrophic lakes of Pühajärv and Pangodi (Fig. 3), which is characteristic of these lakes. A noticeable decrease appeared very clearly in the hypertrophic L. Pappjärv, too (Fig. 4). Chl values decreased from about 70—95 mg/m³ in 1982—1983 to 28 mg/m³ in 1985 and 1990 (Table 3). In general, hypertrophic lakes showed a considerably variability in the chl content.

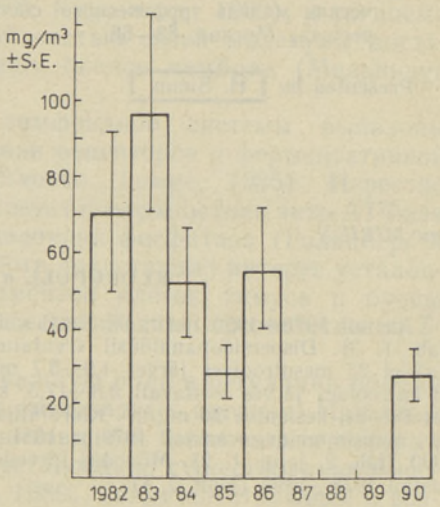

Fig. 4. Changes of chlorophyll *a* concentration in the hypertrophic lake Pappjärv.

It is known that changes in the phytoplankton community and, consequently, in chl concentrations rarely depend on one single factor and reflect response to many factors, abiotic as well as biotic. The main factors which can influence annual changes in chl concentrations are the weather conditions of a year (temperature, light, precipitation) and the biological availability of nutrient elements (as a limiting factor). The factors causing specific undulating changes in chl concentrations are unknown to us, and would need further study.

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Anu MILIUS

KLOROFÜLL *a* EESTI JÄRVEDES

Aastail 1978—1990 uuriti 95 Eesti väikejärve pindmise veekihi klorofüll *a* sisaldust (tab. 1, 3). Dispersioonanalüüsil arvutatud klorofülli geomeetriline keskmine varieerus uuritud 23 mesotroofses järves 1,9—5,7 mg/m^3, troofsustaseme keskmine oli 3,1 mg/m^3; 56 eutroofses järves vastavalt 3,8—17,5, keskmine 7,6 mg/m^3 ning 16 hüpertroofses järves 14—54, keskmine 20 mg/m^3. Klorofüllisisaldus oli Eesti väikejärvedes laineliselt muutuv, maksimumidega aastail 1979 ja 1981 ning 1987—1988 ning miinimumidega 1984 ja 1990 (tab. 2, joon. 1, 2). Mõnedes järvedes esines klorofüllisisalduse vähenemistendents aastail 1978—1990 (joon. 3, 4).

Ану МИЛИУС

ХЛОРОФИЛЛ *a* В ОЗЕРАХ ЭСТОНИИ

В 1978—1990 гг. было изучено содержание хлорофилла *а* в поверхностном слое воды 95 малых озер Эстонии (табл. 1). Средняя геометрическая концентрация хлорофилла, вычисленная по дисперсионному анализу, изменялась в изученных 23 мезотрофных озерах в пределах 1,9—5,7 мг/м^3, средняя для трофического статуса составляла 3,1 мг/м^3, в 56 эвтрофных озерах она изменялась от 3,8 до 17,5 при среднем значении 7,6 мг/м^3, а в 16 гипертрофных озерах от 14 до 54, а их среднее значение составляет 20 мг/м^3. Количество хлорофилла в озерах Эстонии изменялось волнисто, максимумы отмечены в 1979 и 1981 и в 1987—1988 гг., а минимумы в 1984 и 1990 гг. (табл. 2, рис. 1, 2). В некоторых озерах отмечалась тенденция понижения содержания хлорофилла в интервале 1978—1990 гг. (рис. 3, 4).