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A SURVEY OF WATER TRANSPARENCY IN SMALL LAKES OF SOUTH-EAST ESTONIA

The anthropogenic eutrophication of waterbodies due to the increased load of plant nutrients from the catchment area leads to an increased algal growth which in its turn, causes a reduction of water clarity. A simple but rough method to determine water transparency by means of the Secchi disk is still in use, and it plays a significant role in limnology. Water transparency is readily evaluated and gives direct information about the trophic state of light-coloured lakes and is applied as an index for estimating the trophic state (Carlson, 1977; Бульон, 1977; Walker, 1979; Милиус, 1984).

Studies of water transparency in Estonian lakes were initiated by Prof. H. Riikoja of Tartu University in the 1920s (Riikoja, 1940a, b), and carried on by the hydrobiologists of the Institute of Zoology and Botany since 1951 (Eesti järved, 1968; Mäemets, 1977). The hydrochemistry team of the Institute of Zoology and Botany of the Estonian Academy of Sciences has been studying water transparency as a parameter as well as an index of the trophic state of light-coloured lakes (Милиус, 1984). The aim of this paper is to give a regional survey of water transparency as well as the changes in water transparency in small lakes of Estonia during 1978—1990. A comparison with earlier data on water transparency over the period 1925—1974 has been also carried out.

Material and methods

The 95 lakes studied are mostly located in South-East and South Estonia; only a few lakes are situated in the eastern part of the Republic, in the Jõgeva district. Lake areas varied considerably: 0.6—707.6 ha; most of them are smaller than 100 ha, while only the area of 11 lakes is bigger than 100 ha. Mean depths ranged from 2—14 m, and maximum depths varied from 3.5 to 33 m. 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, 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 water transparency was measured only twice — in July and in 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. The lakes studied are mostly light-coloured (water colour up to 50° by the scale of $CoSO_4$—$K_2Cr_2O_7$ standard solutions). Brown-coloured lakes, such as the lakes of Vidrike, Mäha, Kurna-

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kese, Otepää Kärnjärv, whose average colour was 60° and the lakes of Laanemetsa and Kadastiku, whose colour exceeded 100°, were examined during 1987—1989. Water transparency was measured using 30 cm white Secchi disk at the shady side of the boat. The transparency of water is determined by the depth of the disappearance of the Secchi disk. The data set was based on 1563 measurements from 1978—1990.

For comparison, we used the water transparency data of the same lakes which were studied during the years 1925—1939 (Riikoja, 1940a, b), 1950s (Eesti järved, 1968) and 1970—1974 (Mäemets, 1977) (Table 2). Since the lakes were studied in different years and at various frequencies, the quality of the data is different and difficult to compare. The water transparencies of the lakes studied were comparable only in the case when the incomplete initial data were processed using the analysis of variance in which the logarithmic values of the initial data applied. The effects of the sampling year, the month of observation and the particular lake, were taken into account as factors.

Results and discussion

Table 1 presents the mean data of water transparency in 95 small lakes of Estonia during the period 1978—1990. The trophic level of the lakes are classified according to three most essential parameters of the trophic state (total phosphorus, chlorophyll *a* and water transparency) as in our earlier papers (Milius et al., 1991; Milius 1991). The trophic state of the lakes studied ranged from mesotrophic to hypertrophic. Our results showed that 24 per cent of the investigated lakes are mesotrophic (23 lakes), 59 per cent eutrophic (56 lakes) and 17 per cent hypertrophic (16 lakes). The lakes were arranged in the order of their increasing trophic state. The values of water transparency in Table 1 represent the arithmetical means and the mean values of the analysis of variance (ANOVA). The difference between the arithmetical mean (0.9—6.7 m) and the mean values of ANOVA (0.8—6.6 m) is insignificant. The mean of ANOVA shows the water transparency of a lake during the observation period independent of the year or sampling times. Thus, the Table gives exact information about the lakes transparency in the year (or years) studied, which was obtained from the analysis (arithmetical mean), and prognosticated water transparency for the period 1978—1990 (mean of ANOVA).

In the mesotrophic lakes under study the mean visibility of the Secchi disk calculated with ANOVA varied between 2.8—6.6 m, the average being 3.6 m. The highest visibility was found in the lakes of the lowest trophic state — Nohipalu Valgjärv (6.6 m) and Väike-Palkna (5.2 m). High values of mean water transparency (4.0—4.5 m) were observed in the following lakes: Piigandi, Inni, Udsu, Uiakatsi, Koorküla Valgjärv, and Saadjärv. In the other mesotrophic lakes, the mean transparency varied between 2.8—3.9 m. In the eutrophic lakes the visibility of the Secchi disk ranged from 1.4 to 3.1 m, the mean value being 2.1 m. A higher visibility (3.0—3.1 m) in this type of lakes was found in such lakes as Tsolgo Pikkjärv, Tuuljärv and Rõuge Valgjärv. The mean transparency of water for many eutrophic lakes varied between 2—3 m, and the visibility decreased below 2 m with the increasing of the trophic state. The lowest transparency of water (1.1 m) in the eutrophic type was found in L. Kadastiku, which is due to the coloured water of the lake. In 16 hypertrophic lakes the mean transparency varied between 0.8—1.7 m, the average being 1.3 m. The mean least water transparency (0.8—1.0 m) was found in four lakes of the highest trophic status — Kriimani, Kooraste Linajärv, Otepää Pikajärv, and Pappjärv.

Table 1

Water transparency (m) in Estonian small lakes

Lake	Lake catalogue №	Year	Number of samples	Arithm. mean. ±S. E.	Mean of ANOVA ±S. E.
1	2	3	4	5	6
Nohipalu Valgjärv	1297	1977—83	39	6.7±0.3	6.6±0.2
Väike-Palkna	1517	1980—81	4	5.1±0.2	5.2±0.3
Piigandi	1084	1979; 81—86; 90	45	4.4±0.1	4.3±0.1
Inni	1200	1987—90	19	4.0±0.3	4.1±0.3
Hino	1555	1979	3	3.9±0.4	4.4±0.4
Peitlemäe	1054	1987—89	15	3.1±0.1	3.4±0.1
Roksi	1170	1987—89	18	3.7±0.1	4.0±0.1
Pulli	1552	1979—81	8	3.9±0.3	4.1±0.2
Saagjärv	1047	1987—89	14	2.9±0.1	3.1±0.1
Udsu	1177	1978; 81—86	34	4.8±0.2	4.5±0.1
Uiakatsi	1238	1979; 81—86; 90	45	4.2±0.2	4.0±0.1
Koorküla Valgjärv	1180	1978; 81—86	34	4.4±0.1	4.2±0.1
Virtsjärv	1178	1987—89	17	3.7±0.1	3.9±0.1
Tillijärv	835	1984	7	3.3±0.3	3.1±0.3
Saadjärv	653	1975—86	68	4.4±0.2	4.3±0.1
Viisjaagu	924	1979; 81—83	21	3.0±0.2	2.9±0.2
Tõrva Vanamõisa	1000	1984—86	20	3.5±0.3	3.0±0.2
Rõuge Suurjärv	1403	1980—81	5	3.8±0.7	3.6±0.4
Kisejärv	1532	1980—81	5	2.8±0.2	2.8±0.2
Kooraste Kõverjärv	1232	1981	4	2.8±0.5	2.9±0.5
Tõugjärv	1400	1980—81	5	2.9±0.5	2.9±0.3
Liinjärv	1404	1980—81	5	3.3±0.3	3.3±0.2
Rõikajärv	834	1984	7	2.6±0.2	2.4±0.2
Prossa	568	1980—81	5	2.5±0.1	2.7±0.1
Kooraste Suurjärv	1236	1979; 81; 90	15	2.3±0.1	2.5±0.1
Jõksi	1224	1979; 81—83; 85—86; 90	39	2.7±0.1	2.6±0.1
Agali	847	1978; 81—83; 85—86	35	3.0±0.1	2.9±0.1
Rõuge Ratasjärv	1401	1980—81	5	2.7±0.5	2.7±0.3
Nõo Suur-Karujärv	935	1979	3	2.6±0.4	2.9±0.3
Tsolgo Pikkjärv	1282	1982—83	9	3.2±0.3	3.1±0.3
Tuuljärv	1413	1979	3	2.7±0.2	3.1±0.2
Pühajärv	1053	1978; 81; 87—90	30	2.4±0.1	2.6±0.1
Kääriku	1059	1987—89	17	2.4±0.1	2.5±0.1
Jaanuse	1038	1987—89	18	2.6±0.1	2.7±0.1
Paidra	1284	1982—83	9	2.7±0.2	2.7±0.2
Nõuni	1013	1978; 81—82; 90	19	2.4±0.1	2.4±0.1
Pikrejärv	1171	1978; 87—89	19	2.4±0.2	2.5±0.2
Rõuge Valgjärv	1405	1980—81	7	3.0±0.3	3.0±0.3
Kavadi	1437	1979; 81	5	2.1±0.1	2.4±0.1
Kooraste Pikkjärv	1230	1984; 90	13	2.6±0.1	2.6±0.1
Kirikumäe	1447	1980—81	5	1.8±0.1	1.8±0.1
Karijärv	843	1979; 81—82	12	2.7±0.2	2.8±0.2
Vaskna	1443	1979	3	2.0±0.2	2.3±0.1
Vissi	727	1979	3	2.3±0.4	2.6±0.3
Kasaritsa Verijärv	1381	1979; 81—82; 90	17	2.3±0.1	2.4±0.1
Tornijärv	1057	1983	5	2.3±0.2	2.3±0.2
Kaussjärv	1402	1980—81	7	1.9±0.2	1.9±0.1

1	2	3	4	5	6
Vagula	1261	1978; 90	9	2.5±0.1	2.6±0.1
Kuremaa	554	1980—81	8	2.3±0.2	2.4±0.2
Lavatsi	851	1978; 80—86	59	2.4±0.1	2.2±0.1
Vasula	753	1978; 79; 81	12	1.8±0.2	1.9±0.2
Kiidjärv	1107	1978; 81	7	1.9±0.2	2.1±0.2
Kasaritsa Valgjärv	1380	1979; 81—82; 90	13	2.0±0.1	2.1±0.1
Holstre	904	1984	6	2.1±0.2	2.0±0.1
Erastvere	1228	1979; 81—83; 90	23	2.4±0.2	2.4±0.1
Partsi Kõrtsijärv	1128	1978	3	1.7±0.1	1.9±0.1
Otepää Valgjärv	1077	1978	3	1.7±0.2	1.9±0.1
Vidrike	1203	1984; 90	13	2.0±0.1	2.0±0.1
Laanemetsa	1179	1987—89	17	1.4±0.1	1.4±0.1
Petajärv	1166	1978; 82—83; 85—86	23	2.0±0.1	1.7±0.2
Kurnakese	1037	1987—89	17	1.7±0.1	1.8±0.1
Kuningvere	588	1980—81	8	1.8±0.2	1.8±0.2
Elistvere	651	1978	3	1.4±0.2	1.5±0.2
Pangodi	1006	1978; 81—83; 85—86; 90	36	1.7±0.1	1.6±0.1
Karsna	1275	1982—83	9	1.7±0.4	1.5±0.3
Viljandi	828	1981	3	1.8±0.2	1.9±0.2
Vellavere Külajärv	925	1978—79; 81—83	23	1.8±0.1	1.8±0.1
Kubija	1378	1980—81; 90	11	1.4±0.1	1.5±0.1
Mäha	1048	1987—90	23	1.7±0.1	1.7±0.1
Väike-Juusa	1041	1987—89	17	1.6±0.1	1.6±0.1
Otepää Kärnjärv	1051	1987—90	23	1.5±0.1	1.6±0.1
Verevi	932	1978—79; 81; 83—89	51	1.9±0.1	1.8±0.1
Annejärv	1277	1982—83	9	1.9±0.1	1.9±0.1
Kaiavere	571	1978	3	1.5±0.2	1.6±0.2
Saare	573	1980—81	7	1.4±0.3	1.4±0.1
Pilkuse	1042	1987—89	17	1.5±0.1	1.5±0.1
Vana-Koiola	1249	1982—83	9	1.7±0.2	1.7±0.1
Kadastiku	1184	1987—89	18	1.0±0.04	1.1±0.04
Kaarepere Pikkjärv	569	1980—81	5	1.4±0.2	1.5±0.1
Raigastvere	650	1978	3	1.2±0.2	1.3±0.2
Tamula	1262	1978; 90	9	1.5±0.2	1.6±0.2
Jääva	1173	1987—89	18	1.7±0.1	1.7±0.2
Juusa	1055	1981—83; 85—89	46	1.5±0.1	1.4±0.1
Lasva	1290	1982—83	10	1.5±0.1	1.5±0.1
Linaleojärv	1289	1987—89	18	1.7±0.2	1.6±0.2
Holstre Linajärv	902	1984	7	1.4±0.1	1.4±0.1
Väike-Kodijärv	1010	1978	3	1.3±0.1	1.4±0.1
Kodijärv	1009	1982—83; 85—86	21	1.4±0.1	1.3±0.1
Ruusmäe	1537	1979	3	1.3±0.4	1.7±0.3
Kokora Mustjärv	587	1980—81	6	1.2±0.2	1.1±0.1
Laose Valgjärv	831	1984	7	1.4±0.3	1.1±0.3
Kriimani	948	1978; 80—86	57	1.1±0.1	1.0±0.1
Kooraste Linajärv	1233	1979; 81—86; 90	42	0.9±0.1	0.8±0.1
Otepää Pikajärv	1078	1978; 82—86	31	1.0±0.1	0.8±0.1
Pappjärv	1379	1979; 82—86; 90	39	0.9±0.1	0.8±0.1

The mean data of water transparency of the 95 lakes studied during the years 1978—1990 are presented in Table 2. The mean water transparency of different years vary only slightly, from 2.0 to 2.5 m; thus, yearly changes are very small. There is only a little increase in water transparency in 1985 and 1986. After that the stabilization of visibility at 2.1 m can be observed. The comparison of yearly changes with the earlier data indicates no tendency of change in water transparency in the lakes under study over as long a period as 1925—1990 (Table 2). Likewise, during 1925—1939, in the 1950s as well as the early 1970s the mean water transparency data vary only from 2.0 to 2.1 m (Table 2). Consequently, water transparency in the lakes under study had not statistically changed during the period 1925—1990. It can be mentioned that water transparency carries relatively less information in lakes than the total phosphorus and chlorophyll *a* concentrations (Milius et al., 1991; Milius, 1991).

Table 2

Mean values of water transparency (m) during 1925—1990

Year	Number of lakes	Number of samples	Mean ± S. E.
1925—1939	16	17	2.0±0.1
1951—1963	46	66	2.1±0.1
1970—1974	47	52	2.0±0.1
1978	25	83	2.1±0.1
1979	22	75	2.0±0.1
1980	21	61	2.2±0.1
1981	44	205	2.1±0.05
1982	30	155	2.3±0.1
1983	28	138	2.2±0.1
1984	18	129	2.3±0.1
1985	18	141	2.5±0.1
1986	18	90	2.5±0.1
1987	20	89	2.1±0.1
1988	20	118	2.1±0.1
1989	20	133	2.1±0.1
1990	20	119	2.1±0.05

In most intensively studied lakes the values of water transparency showed no essential year-to-year changes during 1978—1990 (Table 3). However, some lakes show a tendency of an increase in transparency over the observation period. The water of the mesotrophic lakes of Piigandi and Saadjärv was less transparent in the late 1970s and early 1980s (3.1—3.4 m and 3.3—4.3 m, respectively) than in the following years of 1982—1986 (4.1—5.2 and 4.7—5.8 m) at the probability level $p=0.12$ and 0.05, respectively (Table 3, Fig. 1). The same tendency was observed in the eutrophic lakes of Pangodi and Pühajärv ($p=0.19$ and 0.12, respectively) during the years under study. Yearly changes in the hypertrophic L. Poppjärv were relatively smaller (Fig. 1) than in the other trophic types, while the increase in transparency values was proved statistically ($p=0.11$). Two lakes, L. Verevi and L. Juusa, did not follow this pattern but, instead, revealed decreasing transparency ($p=0.06$ and 0.22) during the period (Table 3, Fig. 2). It should be mentioned that these lakes have undergone a strong anthropogenic impact.

To sum up, the results of the present study generally showed, on the basis of all the material, that merely water transparency in lakes is not a very informative parameter. However, studies of water transparency in separate lakes gave evidence that the determination of visibility with the Secchi disk can be a quick and easy way to get meaningful information about changes in lakes.

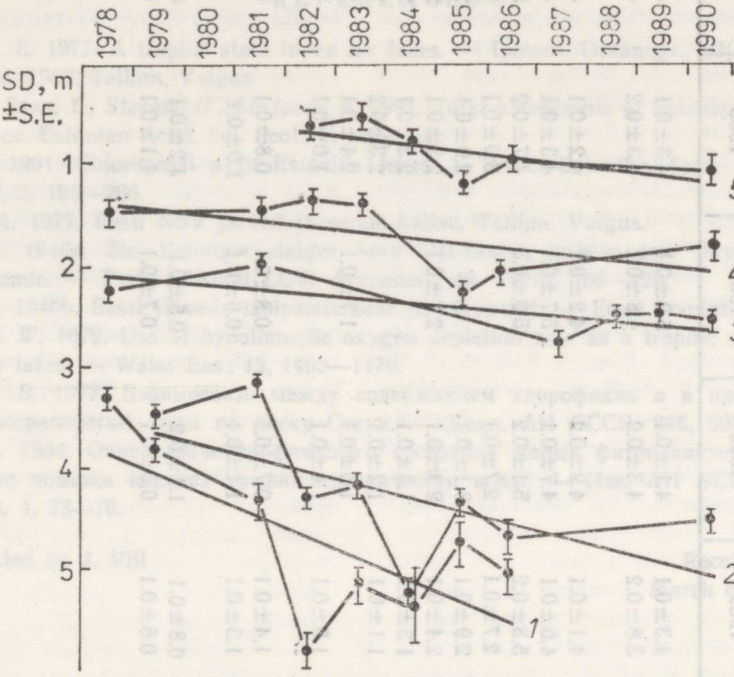

Fig. 1. Changes of water transparency in mesotrophic lakes Saadjärv (*1*), Piigandi (*2*), eutrophic lakes Pühajärv (*3*), Pangodi (*4*) and hypertrophic Lake Pappjärv (*5*) during 1978—1990.

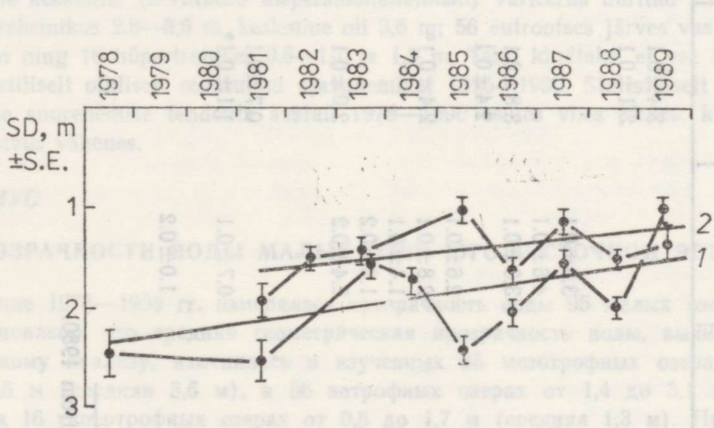

Fig. 2. Changes of water transparency in Lake Verevi (*1*) and Lake Juusa (*2*) during 1978—1989.

Table 3

Mean values of water transparency (m± S. E.) in Estonian small lakes during 1978—1990

Lake	1978	1979	1981	1982	1983	1984	1985	1986	1990
Piigandi		3.4±0.1	3.1±0.1	4.3±0.1	4.1±0.1	5.2±0.1	4.3±0.1	4.6±0.2	4.4±0.1
Uiakatsi		3.1±0.1	3.7±0.2	3.8±0.2	4.3±0.2	4.8±0.2	4.3±0.2	4.0±0.2	3.8±0.2
Koorküla									
Valgjärv	3.9±0.1		4.3±0.2	4.1±0.1	4.9±0.2	4.2±0.1	4.2±0.1	4.7±0.2	
Udsu	4.6±0.1		4.0±0.1	4.6±0.1	4.7±0.1	5.7±0.1	4.3±0.1	4.4±0.1	
Saadjärv	3.3±0.1	3.8±0.1	4.3±0.2	5.8±0.2	5.1±0.2	5.3±0.3	4.7±0.2	5.0±0.2	
Jõksi		2.4±0.1	2.4±0.1	2.7±0.1	2.7±0.1		3.0±0.1	2.9±0.1	2.5±0.1
Agali	2.6±0.1		3.2±0.1	2.9±0.1	3.1±0.1		2.9±0.1	2.9±0.1	
Lavatsi	2.8±0.1	2.4±0.1*	1.8±0.1	2.4±0.1	2.3±0.1	2.7±0.1	2.3±0.1	2.5±0.1	
Pangodi	1.4±0.1		1.4±0.1	1.3±0.1	1.3±0.1		2.2±0.1	2.0±0.1	1.7±0.1
Petajärv	1.8±0.2			1.1±0.1	1.2±0.1		2.3±0.2	2.5±0.2	
Verevi	2.4±0.2	2.0±0.1	2.5±0.2		1.5±0.1	1.7±0.1	2.4±0.1	2.0±0.1	
Juusa			1.9±0.2	1.5±0.1	1.4±0.1		1.0±0.1	1.6±0.1	
Kooraste									
Linajärv		0.7±0.1	0.6±0.1	1.4±0.1	0.7±0.1	0.8±0.1	0.8±0.1	0.9±0.1	0.8±0.1
Kriimani	0.7±0.1	1.1±0.1*	0.8±0.1	1.3±0.1	1.1±0.1	0.9±0.1	1.0±0.1	1.2±0.1	
Otepää									
Pikajärv	1.0±0.2			0.8±0.1	1.1±0.2	0.5±0.1	1.2±0.1	0.9±0.1	
Pappjärv				0.6±0.1	0.5±0.1	0.7±0.1	1.1±0.1	0.9±0.1	1.0±0.1

* Data from 1980.

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ÜLEVAADE KAGU-EESTI VÄIKEJÄRVEDE VEE LÄBIPAISTVUSEST

Aastail 1978—1990 uuriti 95 Eesti väikejärve vee läbipaistvust. Vee läbipaistvuse geomeetriline keskmine (arvutatud dispersioonanalüüsil) varieerus uuritud 23 mesotroofses järves vahemikus 2,8—6,6 m, keskmine oli 3,6 m; 56 eutroofses järves vastavalt 1,4—3,1 ja 2,1 m ning 16 hüpertroofses 0,8—1,7 ja 1,3 m. Tehti kindlaks, et vee läbipaistvus ei ole statistiliselt oluliselt muutunud ajavahemikul 1925—1990. Statistiliselt oluline vee läbipaistvuse suurenemise tendents aastail 1978—1990 esines viies järves, kahes järves vee läbipaistvus vähenes.

Ану МИЛИУС

О ПРОЗРАЧНОСТИ ВОДЫ МАЛЫХ ОЗЕР ЮГО-ВОСТОЧНОЙ ЭСТОНИИ

В течение 1978—1990 гг. измерялась прозрачность воды 95 малых озер Эстонии. Было установлено, что средняя геометрическая прозрачность воды, вычисленная по дисперсионному анализу, изменялась в изученных 23 мезотрофных озерах в пределах 2,8—6,6 м (средняя 3,6 м), в 56 эвтрофных озерах от 1,4 до 3,1 м (средняя 2,1 м), а в 16 гипертрофных озерах от 0,8 до 1,7 м (средняя 1,3 м). Прозрачность воды статистически существенно не изменилась за период 1925—1990. Выявлен тренд увеличения прозрачности воды в пяти озерах и уменьшения — в двух озерах за период с 1978 по 1990 г.