Ann. Zool. Fennici 15:1—7. 1978

Winter oxygen content in relation to water temperature and duration of ice cover in southern Finland

Jorma Aho

Aho, J. 1978: Winter oxygen content in relation to water temperature and duration of ice cover in southern Finland. — Ann. Zool. Fennici 15: 1—7.

The rate of oxygen depletion during the winter and its dependence on water temperature and length of ice cover were studied in two different lake ecosystems in the Lake District of southern Finland during the winters of 1962—1977. In the non-polluted lake the oxygen concentration in late winter depends primarily on water temperature, although also on how long the lake has been ice-bound, whereas in the system heavily loaded with waste waters the winter loss of dissolved oxygen is dependent primarily on the duration of the ice cover. The reason for the difference is discussed. The results have a practical application to the date of hydrographic measurements. In a non-polluted lake measurements can be made at a fixed date each year. In a polluted lake, however, the yearly hydrographic analyses should preferably be made at a fixed interval after the lake ices over, in attempts to estimate the changes due to the waste water load.

Jorma Aho, Department of Biology, University of Joensuu, PL 111, SF-80101 Joensuu 10, Finland.

1. Introduction

Winter is a critical period for a lake ecosystem in a climate as severe as Finland's. In the study area, the southern drainage basin of the river Kokemäenjoki, for instance, ice covers the lakes during an average winter from 8 December to 7 May (e.g. Vesihallitus 1972b). Thus, the lakes are cut off from the atmosphere for 5 months of the year.

In the winter ecology of lakes in general, one of the most important regulatory or limiting factors is oxygen concentration (e.g. Sawyer 1966, Odum 1971). The oxygen saturation of lake water is of enormous ecological importance, especially for the bottom fauna (Jónasson 1972).

In late winter the oxygen content is largely regulated by two factors, the water temperature and the length of the ice cover. In the study area, these factors vary appreciably from year to year. Because the study period of my macrozoobenthos collections (Särkkä & Aho, in preparation) included one winter (1965—1966) with distinctly the warmest water mass during the last 16 years, and one winter (1966—1967) with nearly the coldest water mass, and consequently there were also variations in the length of the ice cover (see Table 3), it was decided to analyse the effects of water temperature and duration of the ice cover on the oxygen content. Since the range of variation seemed to be wider for water temperature than for the duration of the ice cover, it appeared likely that, though both factors exert effects, the water temperature is the more important cause of the oxygen deficiency during the late winter before the ice on the lake has broken up.

This hypothesis is supported by the studies of Ryhänen (1962a—d) on the same watercourse. According to him, the physical conditions in winter are determined chiefly by the weather before the lake freezes. In autumn, when the water has cooled down to about the temperature at which density is greatest, the next spell of cold calm weather will cause the lake to freeze suddenly. In a windy autumn, in contrast, the water mass may become noticeably colder before the lake freezes, and therefore the aerobic processes will take place more slowly during the winter (Ryhänen 1962a).

Ryhänen (1962c) showed that the fall in oxygen content during the winter depends greatly on the water temperature, temperature differences of some tenths of a degree being enough to cause perceptible differences in oxygen consumption. The duration of the ice cover, however, was a factor that RYHÄNEN could not take into account.

2. Study area and material

The hypothesis mentioned above was tested in relation to two lakes. The first of these, Mallasvesi, is an oligotrophic lake (JÄRNEFELT 1956), and in almost natural condition. The other, Vanajaselkä, is heavily loaded with waste waters mainly originating from the towns of Hämeenlinna and Valkeakoski. Vanajanselkä is a eutrophic lake (JÄRNEFELT 1956).

The area of Mallasvesi is 56.3 km², and of Vanajanselkä 119.2 km². Mallasvesi has a maximum depth of 32 m and a mean depth of 7.3 m. In Vanajanselkä the corresponding values are 24 and 7.9 m (KAJOSAARI 1964). Some physical properties of the lakes are given in Tables 1 and 2.

Mallasvesi is not a typical Finnish oligotrophic lake because, especially during late winter, the deeper water layers are rich in iron and other inorganic compounds (Tables 1 and 2). Ground water is believed to well up in the deeps of Mallasvesi. This belief is supported

Table 1. Hydrographic data for the lakes Vanajanselkä (Station 98 according to the Water Authority of Finland) and Mallasvesi (Station 105) derived from measurements made during March and April in 1962 – 1967. The sample from the greatest depth (GD) means 19.2 m in Vanajanselkä and 29.9 m in Mallasvesi.

Depth (m)	Temperature (°C)		Oxygen ($mg\ l^{-1}$)		Oxygen saturation (%)		Specific conductivity ($\varkappa_{18}$)		$KMnO_4$ consumption ($mg\ l^{-1}$)		pH		Colour of water ($mg\ Pt\ l^{-1}$)	
	98	105	98	105	98	105	98	105	98	105	98	105	98	105
1	0.4	0.7	11.8	12.0	84	86	101	55	65	21	6.8	7.0	55	15
5	1.1	1.4	12.1	11.8	89	87	100	54	63	20	6.9	7.0	55	15
10	2.2	2.1	10.4	10.7	78	80	103	53	66	19	6.8	6.9	60	15
15	3.2	2.7	6.4	7.7	49	59	110	57	94	19	6.6	6.7	60	15
20		3.2		5.0		39		98		19		6.6		20
25		3.4		2.7		20		155		23		6.6		50
GD	4.2	4.1	1.4	1.3	11	9	128	205	113	90	6.4	6.4	70	450

Depth (m)	Phosphorus ($mg\ l^{-1}$)		Nitrogen ($mg\ l^{-1}$)		Iron ($mg\ l^{-1}$)		Transparency (m)	
	98	105	98	105	98	105	98	105
1	0.13	0.02	1.2	0.5	0.30	0.06		
GD	0.10	0.68	1.4	2.7	0.61	12.30		
							2.24	6.20

Table 2. Hydrographic data from Vanajanselkä (Station 98) and Mallasvesi (Station 105) based on measurements made during July and August in 1962 – 1967.

Depth (m)	Temperature (°C)		Oxygen ($mg\ l^{-1}$)		Oxygen saturation (%)		Specific conductivity ($\varkappa_{18}$)		$KMnO_4$ consumption ($mg\ l^{-1}$)		pH		Colour of water ($mg\ Pt\ l^{-1}$)	
	98	105	98	105	98	105	98	105	98	105	98	105	98	105
1	17.3	15.8	8.4	9.1	90	94	103	52	60	18	7.0	7.0	55	20
5	16.8	15.7	7.9	9.0	84	93	106	53	60	20	7.0	7.0	55	20
10	16.8	15.6	8.1	9.0	86	93	106	53	60	18	7.0	7.1	55	20
15	14.6	14.6	5.5	7.8	58	79	107	54	60	18	6.8	7.0	60	20
20		13.3		6.7		67		55		18		7.0		20
25		13.1		6.4		64		55		20		6.9		20
GD	13.4	13.0	4.0	6.2	40	63	107	55	65	22	6.7	6.9	70	25

Depth (m)	Phosphorus ($mg\ l^{-1}$)		Nitrogen ($mg\ l^{-1}$)		Iron ($mg\ l^{-1}$)		Transparency (m)	
	98	105	98	105	98	105	98	105
1	0.04	0.03	1.1	0.3	0.32	0.10		
GD	0.07	0.08	1.2	0.9	0.33	0.32		
							1.71	3.63

by the high winter temperatures measured at the greatest depth (≤ 6.3 °C) (Hämeen vesiensuojeluyhdistys 1966).

Mallasvesi and Vanajanselkä nevertheless make a good contrast. The greatest differences are in transparency, specific conductivity, amount of organic matter, colour of water, and amount of the main nutrients in the surface water layer.

In testing the hypothesis, I used values for water temperature, oxygen content (mg l^{-1}) and oxygen saturation at depths of 1, 5, 10, 15, 20, and 25 m, and at a depth of 1 m above the bottom (termed the sample from the greatest depth, GD, in Tables 1, 2 and 5—8). These data had been obtained by the Water Authority of Finland, and by a local association for water protection (Hämeen vesiensuojeluyhdistys 1964, 1965, 1966, 1968, Maataloushallitus 1967, 1968a, 1968b, 1969, 1970, Kokemäenjoen vesistön vesiensuojeluyhdistys 1969, 1970, 1971, 1972a, 1972b, 1974, Vesihallitus 1972a, and the files of the Water Authority of Finland).

Temperature was measured to the nearest 0.1 °C with a mercury thermometer connected with a Ruttner sampler. Dissolved oxygen was determined to the nearest 0.1 mg l^{-1} by Alsterberg's brom-salicylate method (Laaksonen 1972).

The physico-ecological measurements in Mallasvesi cover the 16 years 1962—1977, and in Vanajanselkä the 14 years 1964—1977. I consider these periods of observation long enough for valid testing of the hypothesis. Measurements were made between 16 March and 16 April.

There is no accurate or direct information about the freezing of the lakes in question. Therefore, the date of freezing for each year was estimated as a mean value of observations made at eight stations in different parts of the southern drainage basin of the river Kokemäenjoki (Tie- ja vesirakennushallitus 1963, 1965, 1968, 1970, Vesihallitus 1972b, 1975, 1976, and the files of the Water Authority of Finland).

Table 3. Mean temperature of the water mass (t^{o}) and the interval (days) between the dates of freezing and measurements (T_i) in the lakes studied.

Winter	Mallasvesi t^{o}	Mallasvesi T_i	Vanajanselkä t^{o}	Vanajanselkä T_i
1961–1962	1.98	117	–	–
1962–1963	1.94	127	–	–
1963–1964	3.03	144	1.98	116
1964–1965	2.44	115	1.84	113
1965–1966	3.96	138	3.64	142
1966–1967	1.70	113	1.42	101
1967–1968	2.31	103	2.48	115
1968–1969	2.47	139	1.94	144
1969–1970	2.04	117	1.68	122
1970–1971	2.14	117	2.08	127
1971–1972	2.39	130	1.74	129
1972–1973	2.10	85	2.22	85
1973–1974	2.56	117	2.16	122
1974–1975	1.51	79	1.42	79
1975–1976	2.03	123	1.24	110
1976–1977	1.70	112	1.44	107
$\bar{x}$	2.27	118.3	1.95	115.2
s	0.59	18.1	0.60	18.6

Table 4. Numbers of winters with different temperature regimes.

Temperature regimes (°C)	Mallasvesi	Vanajanselkä
1.01–1.50	0	4
1.51–2.00	5	5
2.01–2.50	8	4
2.51–3.00	1	0
3.01–3.50	1	0
3.51–4.00	1	1

3. Results

As a first step, the mean temperature of the whole water mass was calculated from measurements at different depths. The results are reported in Table 3, together with the interval (called ice period) between the dates of freezing and measurements.

During the winters of the study period the mean temperature of the water mass varied greatly. In Mallasvesi the means ranged from 1.51 °C to 3.96 °C, the average mean temperature being 2.27 °C. Correspondingly, in Vanajanselkä the means ranged from 1.24 °C to 3.64 °C, the average mean being 1.95 °C. In mean depth the two lakes are almost the same, but in area Vanajanselkä is more than twice the size of Mallasvesi. Therefore the water mass of Vanajanselkä cools more effectively before freezing. This is also seen from Table 4.

The freezing dates ranged from 1 November to 28 December, but the dates on which temperatures and oxygen contents were measured also varied. Thus, the ice period varied from year to year. In both lakes the ice period ranged from 79 to 144 days, and the difference in the average ice period between the two lakes was negligible.

Correlation between freezing dates and water temperature was studied. It would be expected that when the lake froze late in autumn, the water mass would have cooled more thoroughly than when the ice cover formed early. The negative correlation between water temperature and freezing dates is statistically significant for Mallasvesi ($r = -0.550$, $r_{.05,\ 14} = 0.497$), but not for Vanajanselkä. The reason for the difference is obscure.

As a second step, the winters were divided into two groups of equal size by mean temperature, and correspondingly by ice period (i.e. duration of ice cover). Mean values for oxygen content and saturation at different depths were then calculated for each group of winters.

In Mallasvesi there were clear differences in the amount of dissolved oxygen between the colder and the warmer winters (Tables 5 and 7). In Vanajanselkä the difference was statistically significant only at 1 m (see also Fig. 1A and B).

In Mallasvesi there was only a slightly significant statistical difference at 10—15 m between the winters with a shorter and a longer ice period (Tables 6 and 8). In Vanajanselkä, in contrast, the differences in this respect were more distinct and statistically significant through almost the whole water mass (see also Fig. 2A and B).

As a third step the oxygen concentration and its dependence on water temperature and duration of the ice cover was studied by partial correlation analysis. The analysis was made between the mean temperature of the whole water mass, the mean oxygen values for the whole water mass (calculated in the same way as the mean temperature; see p. 3), and the ice period. The mean oxygen saturation of the whole water mass was the same in the two lakes (Mallasvesi: $\bar{x}$ = 55.6 %, s = 7.5, n = 16; Vanajanselkä: $\bar{x}$ = 55.6 %, s = 8.8, n = 14). This increases the reliability of the analysis.

For the correlation between the ice period and the oxygen content in Vanajanselkä the values (in ppm) gave -0.637, and the saturation values -0.668 ($r_{.05,\ 12}$ = 0.627), after any effect of water temperature interaction was eliminated. In Mallasvesi there was no significant correlation between these variables.

No statistically significant correlation existed between water temperature and oxygen content in either lake when the effect of ice period was eliminated.

Table 5. Mean values of dissolved oxygen (mg l^{-1}) in the lakes studied. A = winters with a colder water mass, B = winters with a warmer water mass, *t* = results of the *t* test.

Depth	Mallasvesi A	B	*t*	Vanajanselkä A	B	*t*
1	12.8	12.1	1.59	12.4	10.9	2.78*
5	12.4	11.9	1.67	11.7	10.8	1.63
10	11.8	10.4	3.48**	10.0	9.0	1.14
15	9.1	7.3	3.20**	4.8	4.4	0.28
20	6.3	3.6	4.75***			
25	4.6	0.9	5.16***			
GD	1.4	0.5	2.17*	0.9	1.2	0.85
n	8	8		7	7	

$t_{.05,\ 14} = 2.14$
$t_{.01,\ 14} = 2.98$
$t_{.001,\ 14} = 4.14$

$t_{.05,\ 12} = 2.18$
$t_{.01,\ 12} = 3.06$

Table 6. Mean values of dissolved oxygen (mg l^{-1}) in the lakes studied. A = winters with a shorter ice period, B = winters with a longer ice period, *t* = results of the *t* test.

Depth	Mallasvesi A	B	*t*	Vanajanselkä A	B	*t*
1	12.7	12.1	1.52	12.1	11.3	1.15
5	12.3	12.1	0.54	11.8	10.7	2.05
10	11.6	10.5	2.29*	10.7	8.3	3.98**
15	8.9	7.4	2.42*	6.7	2.5	3.97**
20	5.5	4.5	1.12			
25	3.4	2.1	1.11			
GD	1.1	0.9	0.27	1.2	0.9	1.14
n	8	8		7	7	

Table 7. Mean values of oxygen saturation (%) in the lakes studied. A = winters with a colder water mass, B = winters with a warmer water mass, *t* = results of the *t* test.

Depth	Mallasvesi A	B	*t*	Vanajanselkä A	B	*t*
1	91.8	87.3	1.59	88.7	79.0	2.63*
5	90.1	87.6	1.21	83.9	77.3	2.08
10	87.0	78.0	3.47**	73.6	67.9	0.86
15	67.9	55.6	2.98**	35.9	33.4	0.20
20	48.0	28.0	4.71***			
25	35.1	7.4	5.10***			
GD	10.6	3.9	1.92	7.0	9.4	0.94
n	8	8		7	7	

Table 8. Mean values of oxygen saturation (%) in the lakes studied. A = winters with a shorter ice period, B = winters with a longer ice period, *t* = results of the *t* test.

Depth	Mallasvesi A	B	*t*	Vanajanselkä A	B	*t*
1	91.6	87.4	1.48	86.7	81.0	1.32
5	88.9	88.9	0.00	85.0	76.1	3.34**
10	85.8	79.3	2.11	79.1	62.3	3.53**
15	66.9	56.6	2.26*	50.3	19.0	3.81**
20	41.4	34.6	1.03			
25	26.1	16.4	1.11			
GD	8.1	6.4	0.45	9.6	6.9	1.09
n	8	8		7	7	

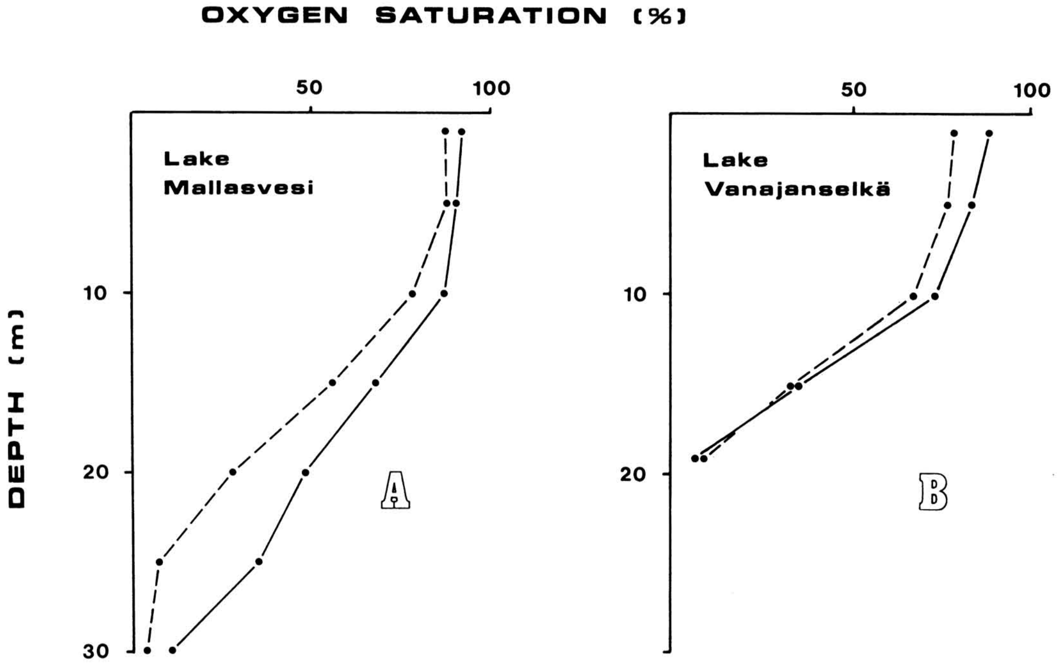

Fig. 1. Oxygen saturation in the lakes studied during the warmer (dashed line) and colder (solid line) winters of 1962–1977.

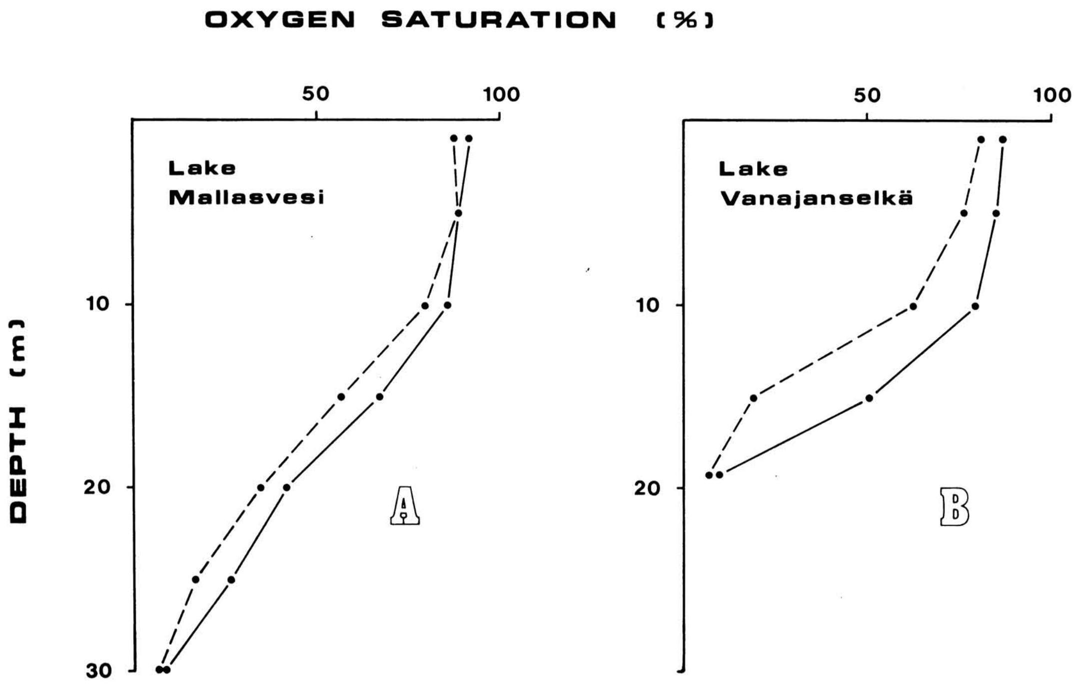

Fig. 2. Oxygen saturation of winters with the longest (dashed line) and shortest (solid line) ice period in the lakes studied.

4. Discussion

Jónasson (1972) considers it best to interpret the biology of a lake in relation to oxygen saturation. I would emphasize the biological significance of data about dissolved oxygen as well as about oxygen saturation, especially in Finland, where winter imposes a heavy strain on the entire ecosystem of a lake. For aquatic organisms, dissolved oxygen can be regarded as one of the basic components in their *n*-dimensional fundamental niche. As it is impossible to determine fully all the dimensions of the (Hutchinsonian) niche of any one organism, it is best to concentrate on the apparent minimum factors (bottlenecks). Thus, analysis of dissolved oxygen and the factors influencing it form an indispensable part of research on the functioning of lake ecosystems.

This study indicates that in the non-polluted oligotrophic lake the oxygen content in late winter depends on both the water temperature and the duration of the ice cover, the more important factor being water temperature (Tables 5 and 6). In the lake loaded with waste waters, in contrast, the oxygen content is dependent primarily on the duration of the ice cover. Thus, the hypothesis is valid only in a non-polluted lake ecosystem.

The reason for the difference is evident. In a natural ecosystem, whether oligotrophic or not, the flow of allochthonous materials is reduced to a minimum when freezing isolates the lake ecosystem from the soil, the running waters and the other lakes of the drainage basin. Furthermore, when the ice cover forms on the lake, the trophogenic processes cease, and the suspended material, both organic and inorganic, sinks towards the bottom (cf. Tables 1 and 2; transparency). During the winter there is no increase in the amount of decomposable material. The rate of decomposition and the loss of oxygen depend primarily on the water temperature, but also on the duration of the ice cover.

A lake loaded with waste waters is an entirely different system. Despite the freezing of the drainage basin, and thus despite the decreased flow of natural, allochthonous materials, the waste waters continue to run into the system at an even speed all the year round. In such a lake, it is more important how long the ecosystem is separated from the atmosphere. The load, which may change in amount from year to year, masks the effect of temperature differences on values for oxygen content and saturation.

For a long time Vanajanselkä has been heavily polluted by waste waters that originate on the one hand from the sewage and diverse industry of the town of Hämeenlinna, and on the other from the wastes of the wood-processing industry of the town of Valkeakoski (Ryhänen 1962b, 1962c). Under the circumstances, Vanajanselkä has so far tolerated the waste waters quite well, perhaps because the lake cools so effectively in autumn (cf. Table 4). Thus, even in the polluted lake the water temperature plays an important role in the winter ecology.

5. Conclusions

The rate of oxygen depletion in natural waters has not been treated independently in the Finnish biological literature. In this paper attention has been focused on the relation between oxygen, temperature, and duration of the ice cover. For practical reasons the study was limited to two contrasted lake ecosystems. Nevertheless, the result was conclusive. In a polluted lake, loss of oxygen during the winter is primarily determined by the duration of the ice cover, but in a non-polluted lake system it is determined primarily by water temperature, the duration of the ice cover being a secondary factor. The main difference lies in the rate of oxygen consumption. In the polluted lake this is high the whole year round, but in the non-polluted lake it is substantially lower when the lake is ice-bound. The study afforded new information about the lake ecosystems of the Lake District of southern Finland. It also raised several theoretical questions for future investigation.

This work also has a practical application. This concerns the choise of dates for making hydrographic measurements on a lake ecosystem in winter. Such data are nowadays collected by the Water Authority of Finland at a fixed date each year. This procedure is suitable in a non-polluted lake, such as Mallasvesi. But in a polluted lake, such as Vanajanselkä, it would be preferable to make these yearly observations at the same period after the lake freezes, especially when estimating changes in the waste water load. Such a procedure would lead to an increase in comparability between the hydrographic values for different years.

Acknowledgements. My sincere thanks are due to Associate Professor OSSI V. LINDQVIST and Professor REINO RYHÄNEN for reading the manucript and for making valuable suggestions, and to Mrs. JEAN MARGARET PERTTUNEN, B.Sc.(Hons.), for kindly revising the English text. This study was supported by grants from the National Research Council for Science, Academy of Finland.

References

Hämeen vesiensuojeluyhdistys 1964: Vanajavesitutkimus. — Hämeen Vesiensuojeluyhdistyksen Julkaisuja 6:1—502.

—»— 1965: Vanajaveden tarkkailu I. — Hämeen Vesiensuojeluyhdistyksen Julkaisuja 6A:1—67.

—»— 1966: Vanajavesitutkimus. Tarkkailu II. — Hämeen Vesiensuojeluyhdistyksen Julkaisuja 9: 1—68.

—»— 1968: Vanajaveden ja Kokemäenjoen vesistöjen tarkkailu vuonna 1967. — Hämeen Vesiensuojeluyhdistyksen Julkaisuja 13:1—94.

JÄRNEFELT, H. 1956: Zur Limnologie einiger Gewässer Finlands XVI. — Ann. Zool. Soc. Zool.-Bot. Fennicae Vanamo 17 (1): 1—201.

JÓNASSON, P. M. 1972: Ecology and production of the profundal benthos in relation to phytoplankton in Lake Esrom. — Oikos, Suppl. 14:1—148.

KAJOSAARI, E. 1964: Toimialueen hydrologian pääpiirteet. — Hämeen Vesiensuojeluyhdistyksen Julkaisuja 3:1—53.

Kokemäenjoen vesistön vesiensuojeluyhdistys 1969: Vanajaveden vesistön tarkkailu v. 1968. — Kokemäenjoen Vesistön Vesiensuojeluyhdistyksen Julkaisuja 15:1—72.

—»— 1970: Vanajaveden vesistön tarkkailu v. 1969. — Kokemäenjoen Vesistön Vesiensuojeluyhdistyksen Julkaisuja 22:1—60.

—»— 1971: Vanajaveden vesistön tarkkailu v. 1970. — Kokemäenjoen Vesistön Vesiensuojeluyhdistyksen Julkaisuja 31:1—57.

—»— 1972 a: Vanajaveden ja Pyhäjärven vesistön tarkkailu 1971. — Kokemäenjoen Vesistön Vesiensuojeluyhdistyksen Julkaisuja 40:1—49.

—»— 1972 b: Vanajaveden ja Pyhäjärven vesistön tarkkailu 1972. — Kokemäenjoen Vesistön Vesiensuojeluyhdistyksen Julkaisuja 41:1—69.

—»— 1974: Vanajaveden ja Pyhäjärven vesistön tarkkailu 1973. I. Vesistön veden laatu. — Kokemäenjoen Vesistön Vesiensuojeluyhdistyksen Julkaisuja 44:1—45.

LAAKSONEN, R. 1972: Järvisyvänteet vesiviranomaisen 1965—1970 maaliskuussa tekemien havaintojen valossa (Observations on Lake Deeps by the Water Authority in March 1965—1970). — Publ. Water Research Inst. 4:1—80.

Maataloushallitus 1967: Syvännetutkimus I. — Vesiensuojelutoimiston Tiedonantoja 26.

—»— 1968 a: Syvännetutkimus II. 15.—31.3.1966. — Vesiensuojelutoimiston Tiedonantoja 33.

—»— 1968 b: Syvännetutkimus III. 15.—31.3.1967. — Vesiensuojelutoimiston Tiedonantoja 35.

—»— 1969: Analyysituloksia valtakunnallisilta syvännehavaintopaikoilta (IV) v. 1968. — Vesiensuojelutoimiston Tiedonantoja 45.

—»— 1970: Analyysituloksia valtakunnallisilta syvännehavaintopaikoilta (V) v. 1969. — Vesiensuojelutoimiston Tiedonantoja 59.

ODUM, E. P. 1971: Fundamentals of Ecology. — 574 pp. Philadelphia.

RYHÄNEN, R. 1962a: Über den Zustand der Gewässer im südlichen Einzugsbebiet des Kokemäenjoki (Finnland). I. Zweck und Methodik der Arbeit. — Ann. Acad. Sci. Fennicae (A III) 62:1—40.

—»— 1962b: Über den Zustand der Gewässer im südlichen Einzugsgebiet des Kokemäenjoki (Finnland). II. Das Untersuchungsgebiet und seine Belastung. — Ann. Acad. Sci. Fennicae (A III) 63:1—27.

—»— 1962 c: Über den Zustand der Gewässer im südlichen Einzugsgebiet des Kokemäenjoki (Finnland). III A. Ergebnisse der chemischen und physikalischen Winteruntersuchungen. — Ann. Acad. Sci. Fennicae (A III) 64:1—82.

—»— 1962 d: Über den Zustand der Gewässer im südlichen Einzugsgebiet des Kokemäenjoki (Finnland). III B. Ergebnisse der chemischen und physikalischen Sommeruntersuchungen. — Ann. Acad. Sci. Fennicae (A III) 65:1—41.

SÄRKKÄ, J. & AHO, J.: Distribution of freshwater Oligochaeta in relation to eutrophication and pollution in the Lake District of southern Finland. — In preparation.

SAWYER, C. N. 1966: Basic concepts of eutrophication. — J. Water Pollution Control Fed. 38:737—744.

Tie- ja vesirakennushallitus 1963: Hydrologinen vuosikirja 17 (1961—1962). — 61 pp. Helsinki.

—»— 1965: Hydrologinen vuosikirja 18 (1963—1964). — 89 pp. Helsinki.

—»— 1968: Hydrologinen vuosikirja 19 (1965—1966). — 97 pp. Helsinki.

—»— 1970: Hydrologinen vuosikirja 20 (1967—1968). — 103 pp. Helsinki.

Vesihallitus 1972a: Analyysituloksia syvännehavaintopaikoilta v. 1970. — National Board of Waters, Finland, Report 23:1—150.

—»— 1972 b: Hydrologinen vuosikirja 1969—1970 (Hydrological review 1969—1970). — Publ. Water Res. Inst. 3:1—145.

—»— 1975: Hydrologinen vuosikirja 1971 (Hydrological review 1971). — Publ. Water Res. Inst. 10:1—115.

—»— 1976: Hydrologinen vuosikirja 1972—1973 (Hydrological review 1972—1973). — Publ. Water Res. Inst. 18:1—182.

Received 16. VII. 1977
Printed 20. III. 1978