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Bottom fauna of Lake Keitele, Central Finland, in relation to hydrography and eutrophization

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Ecological and limnological studies of Lake Keitele (Central Finland) were carried out during the period June 24 – July 2, 1964, by a team from the Biological Departments of the University of Turku. Part of the material collected (aquatic plants) has already been dealt with by ELORANTA (1966).

In this paper an attempt is made to describe the bottom fauna and water quality, especially in the middle and southern parts of this large lake during the summer stagnation. Special reference will be made to the effects of pollution on the fauna and environmental factors, especially in the southern part of the lake, into which sewage from the market town of Suolahti is discharged, and also in Lake Kuhnamo (below the outlet of Lake Keitele), which receives effluents from the pulp and paper industries. The value of some benthic species and communities as indicators of the quality of water and bottoms will be discussed.

1. The study area

Lake Keitele, the central lake of the watercourse of Viitasaari (Fig. 1), receives an ample supply of water from its drainage area. The northern parts of the lake are fed from the two lakes Kivijärvi (mean flow = MQ = 25.4 m³/sec) and Pihtiputaanjärvi (MQ = 13.0 m³/sec) (AURA 1965). The watercourses of Viitasaari and Saarijärvi join near the outlet of Lake Keitele at Äänekoski and flow through Lake Kuhnamo into Lake Päijänne, the central lake of the Kymijoki water system. Lake Keitele lies in the north-south direction, its length being about 86 km. It consists of several large *selkä* areas connected by narrow sounds (Fig. 1). Some morphometric data of the lake are seen in the following tabulation compiled according to SIRKKA (1949), RENQVIST (1951) and AURA (1965):

Height above sea level	99.3	m
Drainage area	6305	km²
Area of lake	526	km²
Depth, max.	64	m
» mean	6.3	m
Volume	3480 × 10⁶	m³
Mean flow	51	m³/sec
Residence time	2.2	years
Shoreline	1250	km

The areas surrounding the lake are in general sparsely inhabited and the amount of agricultural land is small (Atlas of Finland 1960). The northern and central parts of the lake thus exemplify a typical Finnish oligotrophic large lake with a small mean depth. The southern parts of the lake receive sewage and industrial wastes from Suolahti (Fig. 1), a market town with about 5 000 inhabitants, a dairy plant and a pig-farm. Together, the load of wastes amounts to about 10 000 »human population units» (calculated according to NIEMELÄ 1961). The estimated 5-day B.O.D (biochemical oxygen demand) of the wastes discharged is about 600 – 700 kg of O_2 per day, according to the values of LIEBMANN (1962) and HYNES (1963). The annual surplus of nitrogen in the effluents is about 40 tons and of phosphorus 5 tons.

The watercourse below the outlet of Lake Keitele (Fig. 1), Lake Kuhnamo, receives effluents from both a sulphite and a kraft pulp mill, a paper mill and a chemical factory and sewage from Äänekoski, a market town with about 7500 inhabitants. The total amount of wastes discharged into Lake Kuhnamo can be estimated at about 200 000 m³ per day.

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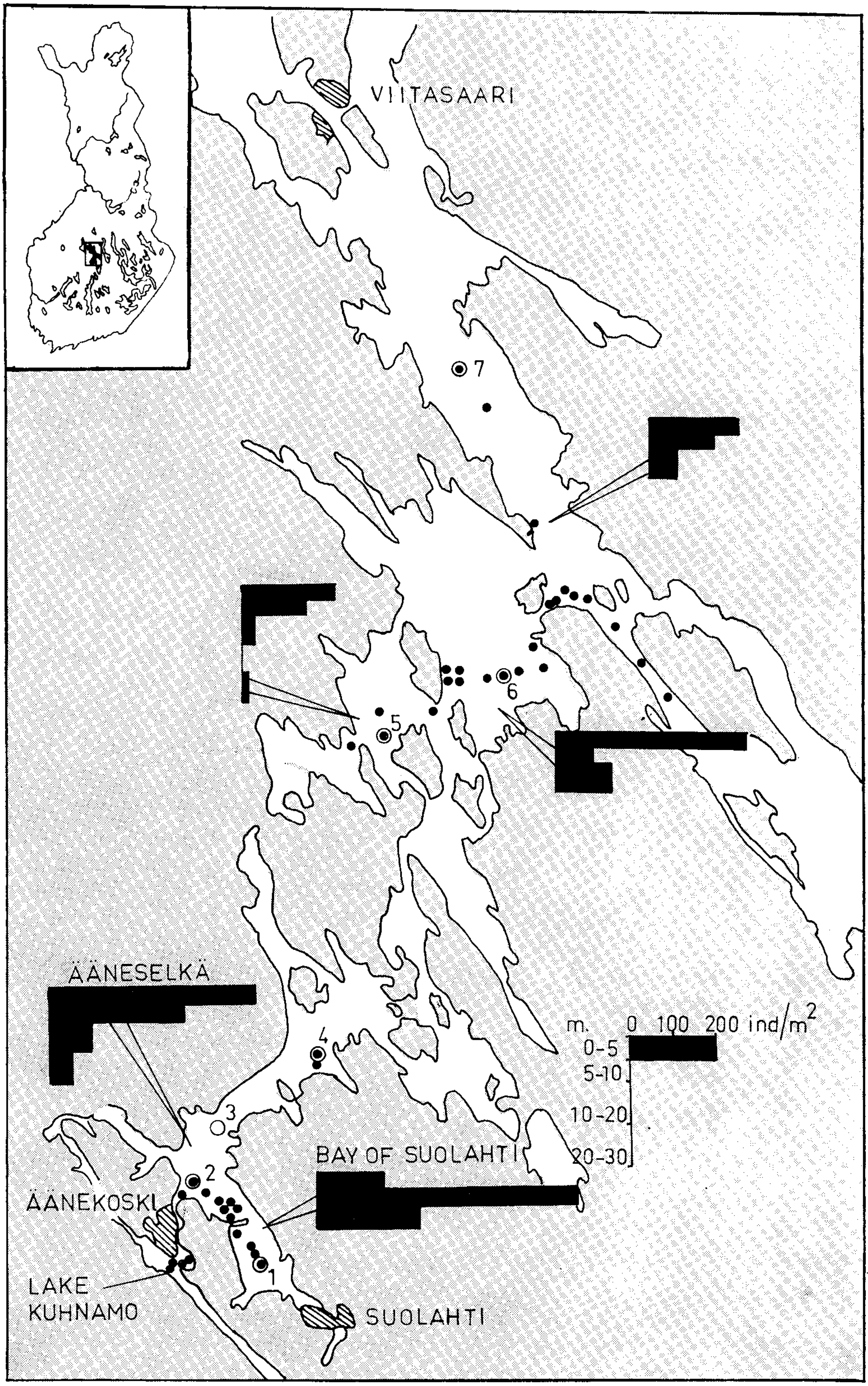

Fig. 1. The sampling sites, density and bathygraphic distribution of bottom fauna in different *selkä* areas. • = bottom fauna stations, ○ = hydrographic stations.

Altogether 93 bottom samples covering an area of 3 m^2 and consisting of 3910 benthic animal specimens were dredged at 41 localities in the lake (Fig. 1). A Petersen type dredge 1/31 m^2 in area was used and the samples were washed through a 0.6 mm mesh sieve. Two or three samples were taken at each sampling site. The sieving residues were sorted separately on a white dish. The animals were preserved in 70 % alcohol and weighed about two months later.

Water samples were taken with a Ruttner sampler provided with a mercury thermometer. The pH was measured with a Radiometer T PHM 24 c and the electrolytic conductivity with a Normameter RW 1 conductivity-measuring bridge. Oxygen and $KMnO_4$ consumption of water were determined by standard methods (Deutsche Einheitsverfahren 1960).

2. Hydrography

Detailed hydrographic data of Lake Keitele, based on the studies made in winter 1963, have been published by Aura (1965). Our measurements, obtained during the summer stagnation, add some new information about the seasonal fluctuations.

Temperature. The temperatures at different depths in June are seen in Fig. 2. During that time the thermocline was at about 10 – 15 m depth. Temperatures of the hypolimnion ranged from 5.1 to 7.9°C. The temperatures of the bottom water in March and April 1963 ranged from 1.1 to 3.5°C at depths below 20 m (Aura 1965). No clear thermal stratification was found in June 1964 in the northern parts of the study area (Stats 6 and 7 in Fig. 2). At Stat. 2 only a slight temperature gradient was observed between the epi- and hypolimnion, probably owing to a great flowthrough of water and turbulence.

Transparency. The Secchi disc values were greatest in the central parts of the lake in June, ranging from 6.0 to 6.2 m. Transparency usually shows an inverse relation to colour (Järnefelt 1963). In the northern parts of the lake an increasing humus content and colour of water diminish the transparency (cf. Aura 1965). The low Secchi disc values obtained in the southern parts of the lake indicate a high primary production (cf. Rodhe 1958).

Oxygen. The vertical distribution of dissolved oxygen in the water was rather uniform except in the southern part of the lake. The northern and central parts of the lake were characterized by an orthograde curve of oxygen (cf. Åberg & Rodhe 1942), although a gradual decrease in the O_2 content of the hypolimnion may occur (Aura 1965).

A slight drop in the oxygen values in the hypolimnion has been observed even in the most oligotrophic, oligohumous lakes (Järnefelt 1963) during the stagnation period. It is partly due to the decomposition of allochthonous (often humus) substances or plankton in

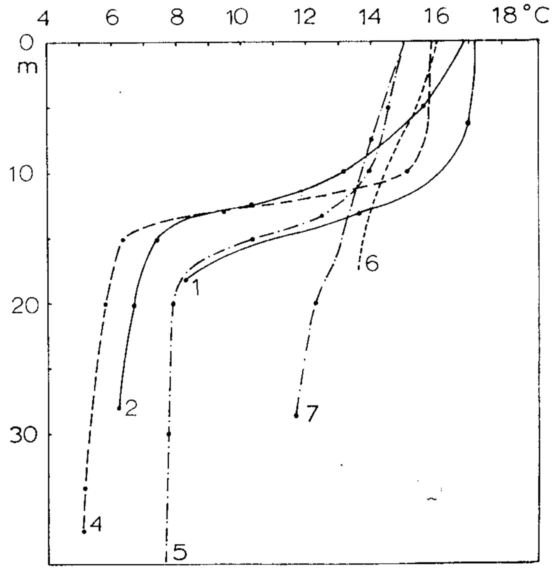

Fig. 2. Temperature curves for the localities indicated in Fig. 1.

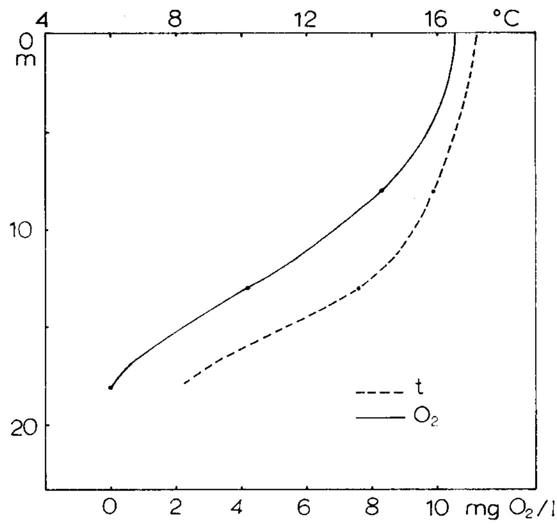

Fig. 3. Temperature and oxygen conditions in the Bay of Suolahti in June 1964.

the lakes. The oxygen content of the central parts of Lake Keitele ranged from 89 to 98 % in the hypolimnion and from 94 to 103 % in the epilimnion in June 1964. In the Bay of Suolahti, oxygen was absent below a depth of about 15 m. The clinograde curve of oxygen observed here is typical of eutrophic lakes (Fig. 3).

Other chemical properties. Some physical and chemical data of the water of the lake in June 1964 are seen in Tables 1 – 3. The values are calculated as mean values of the water column at different localities. The values of pH, electrolytic conductivity and $KMnO_4$ consumption of the water of the central parts of the lake are typical of most large oligohumous lakes in Finland (JÄRNEFELT 1956, 1963). The decreasing gradient found in the values of $KMnO_4$ consumption and colour of water from north to south indicate that the humus content is slightly decreased in the same direction and that the humus colloids precipitate in the basins. The eutrophization of the southern parts of the lake is indicated by increased values of conductivity, and $KMnO_4$ consumption, and by a considerable increase of nutrients (AURA 1965).

In Lake Kuhnamo below Äänekoski, high values of colour, electrolytic conductivity and $KMnO_4$ consumption as well as a slight decrease in pH values indicate pollution. The oxygen conditions, however, seem to be satisfactory, owing to the ample throughflow (MQ = about 80 m³/sec.) (Hydrologinen vuosikirja 1963 – 1964).

Table 1. Temperature and oxygen conditions in the bottom water in June 1964. For localities see Fig. 1.

Loc.	Depth, m	Temp., °C	O_2 mg/l	O_2 %
1	18	8.2	0	0
2	28	6.2	9.1	77.0
3	12	13.3	9.9	98.0
4	37	5.7	10.8	89.0
5	42	7.6	10.5	91.0
6	14	13.6	9.3	92.0
7	28	11.6	10.2	97.0

Table 2. Transparency, pH, electrolytic conductivity and $KMnO_4$ consumption of water as mean values of water column in June 1964.

Loc.	Transparency m	Conduct. µS at 18 °C	$KMnO_4$ cons. mg/l	pH
1	1.2	50	51	6.9
2	2.8	30	34	6.8
3	3.4	32	32	6.7
4	4.6	28	23	6.6
5	6.0	28	26	6.6
6	6.2	27	28	6.6
7	5.1	27	29	6.7

Table 3. Differences in some chemical properties of water between Ääneselkä and Lake Kuhnamo in spring 1963 (according to AURA 1965).

	Colour mg Pt/l	$KMnO_4$ cons. mg/l	pH	Conduct. µS at 18°	O_2 %
Stat. 2 (above the factories	25	25	6.5	29	73
Lake Kuhnamo (below the factories)	42	74	5.8	58	84

3. Bottom fauna

A. General review

The density, vertical distribution and wet weight of the preserved specimens of the bottom fauna in different parts of the area are seen in Figs. 1 and 4. According to the quantitative

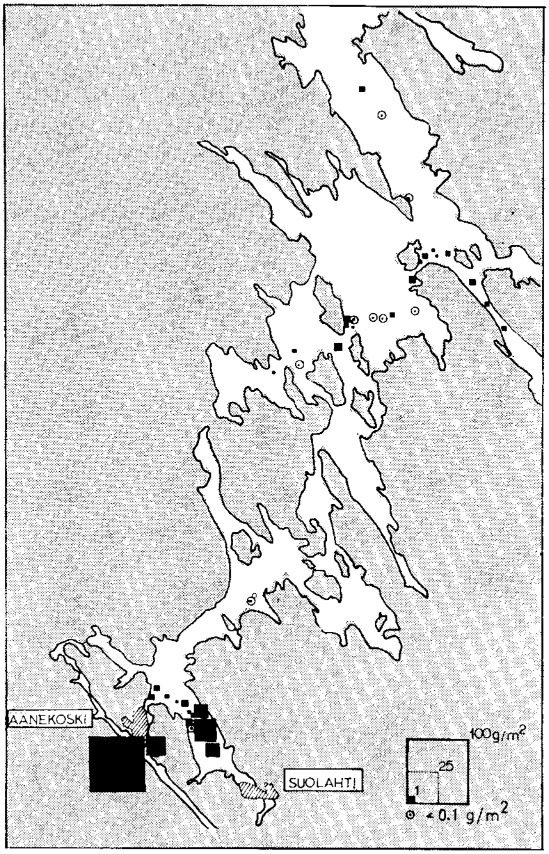

Fig. 4. Standing crop of the bottom fauna at the localitie studied.

differences in the mean density and biomass values, the study area can be divided into four subareas as follows:

Subarea	Number of localities	Depth range, m	Mean no. of specimens per m²	Mean biomass g/m²
Central part	26	1.5 – 34	140	0.4
Ääneselkä	8	1 – 30	248	1.0
Bay of Suolahti	3	3 – 15	491	6.4
Lake Kuhnamo	4	2 – 8	11 851	20.8

The small standing crop values obtained in the central parts of the lake (Fig. 4) are probably due to poor nutrient value of the sediments and slight siderotrophy of the profundal zone in that region. The biomass of the deposit- or detritus-feeding obligochaetes and chironomids is small in the central area (Table 4), while the biomasses of molluscs and crustaceans (except *Asellus aquaticus*) are higher here.

Table 4. Maximum biomass of different groups of bottom animals (g/m²) in the subareas.

	L. Kuhnamo	Bay of Suolahti	Ääneselkä	Central part
1 – 5 m				
Oligochaeta	0.5	–	0.2	0.5
Crustacea	0.3	–	–	0.3
Chironomidae	9.8	2.6	0.6	0.4
Sphaeridae	–	–	0.1	0.1
Other groups	+	–	0.1	1.5
5 – 10 m				
Oligochaeta	68.8	–	–	0.1
Crustacea	–	–	–	0.1
Chironomidae	2.0	11.2	4.7	0.2
Sphaeridae	–	–	–	0.1
Other groups	+	+	+	0.2
10 – 20 m				
Oligochaeta	–	–	0.1	0.5
Crustacea	–	–	–	0.1
Chironomidae	–	5.3	0.6	0.2
Sphaeridae	–	–	0.1	0.1
Other groups	–	+	0.1	+
20 – 30 m				
Chironomidae	–	–	0.2	0.1
Other groups	–	–	+	–

B. Descriptions of the subareas

Central area

Depth range of the sampling sites 1.5 to 34 m. The following characteristics are typical of the central area:

Oxygen conditions good even in the hypolimnion (O_2 saturation in June over 90 %).

High Secchi disc values and low $KMnO_4$ consumption values indicate oligohumous conditions.

Silt and brown mineral bottoms dominate; iron-manganese concretions common at depths below 7.5 m.

Mean density and biomass values of the bottom fauna are small, but the animal diversity is greater than in other subareas, which indicates a good quality of water and bottoms, and oligotrophic conditions.

Twenty-six localities of this subarea were studied. The frequency (number of localities where the species was present), depth range and maximum density of the species collected in the subarea are seen from the following tabulation. In the last column, the figures in parentheses indicate the depth where the maximum density was observed.

	Frequency	Depth range, m	Number of specimens per m²	Maximum density, m
Stylaria lacustris (L.	1	3.5	16	
Tubifex tubifex (Müller)	4	4.5 – 19	109	(4.5)
Peloscolex ferox (Eisen)	11	3.5 – 19	62	(4.5)
Euilyodrilus hammoniensis (Mich.)	2	4.5 – 18	52	(18)
Limnodrilus udekemianus Clap.	1	9.5	21	
L. hoffmeisteri Clap.	5	3.5 – 19	62	(4)
Stylodrilus heringianus Clap.	1	4.5	10	
Lumbriculus variegatus (Müller)	2	5.5 – 17	15	
Eurycercus lamellatus O. F. Müller	1	1.5	15	
Pontoporeia affinis Lindström	2	4.5 – 10	31	
Ephemera vulgata L.	4	3.5 – 5.5	31	
Caenis horaria (L.)	1	3.5	31	
Sialis sp.	2	6 – 9.5	15	
Molanna angustata Curt.	2	1.5 – 5.5	31	
Athripsodes aterrimus Steph.	2	1.5 – 5.5	31	
Coleoptera (larvae)	2	13 – 15	15	
Bezzia sp.	4	3.5 – 6	62	(3.5)
Ablabesmyia spp.	6	1.5 – 9.5	120	(1.5)
Procladius spp.	11	4 – 19	51	(13)
Monodiamesa bathyphila Pag.	3	4 – 7	45	(4)
Orthocladiinae	12	2 – 17	201	(4.5)
Stictochironomus sp.	6	3.5 – 34	41	(9.5)
Limnochironomus sp.	1	4.5	10	
Microtendipes sp.	1	9.5	10	
Sergentia coracina Zett.	4	3.5 – 15	15	(15)
Cryptochironomus (*defectus* group)	3	4.5 – 20	31	(6)
Tanytarsus (*gregarius* group)	11	4 – 19	93	(6)
Tanytarsus sp.	3	13 – 18	15	
Valvata piscinalis (Müller)	1	4.5	15	
Bithynia tentaculata (L.), shells	1	4.5	+	
Pisidium casertanum (Poli)	3	4.5 – 19	15	
P. henslowanum (Sheppard)	6	4 – 19	31	(4)
P. subtruncatum Malm	3	13 – 18	10	
P. hibernicum Westerlund	2	4.5 – 6	21	
Sphaerium corneum (L.)	1	4.5	15	
Cristatella mucedo Cuv. (statoblasts)		4.5		

Table 5. The fauna at the different localities of Ääneselkä. C = clay, O = ooze, D = detritus.

Depth, m	1	4.5	6	7	12	12.5	15	30
Bottom	CD	C	OD	O	OD	C	O	O
Number of samples	2	2	3	2	2	1	3	3
Nematoda	3	–	–	–	–	–	3	-
Tubifex tubifex	–	–	–	–	–	–	2	–
Euilyodrilus hammoniensis	–	–	–	–	1	–	–	–
Peloscolex ferox	–	7	–	–	–	–	–	–
Limnodrilus udekemianus	–	1	–	–	–	–	–	–
Lumbriculus variegatus	–	1	–	–	–	–	–	–
Caenis horaria	2	–	–	–	–	–	–	–
Tabanus sp.	2	–	–	–	–	–	–	–
Bezzia sp.	–	–	1	–	–	–	–	–
Chaoborus (*flavicans* group)	–	–	–	–	–	–	2	–
Ablabesmyia spp.	3	3	–	–	–	–	–	1
Procladius spp.	6	7	12	4	–	1	2	1
Orthocladiinae	5	2	1	–	–	–	–	–
Chironomus anthracinus Zett.	2	–	–	–	1	–	–	–
Ch. plumosus L.	–	–	9	–	1	–	1	–
Ch. (*salinarius* group)	–	–	9	–	–	–	–	–
Polypedilum sp.	–	3	1	–	1	–	4	3
Glyptotendipes sp.	4	2	–	–	–	–	1	–
Stictochironomus sp.	1	–	–	–	–	–	1	–
Limnochironomus sp.	1	–	–	1	–	–	–	–
Tanytarsus (*gregarius* group)	2	–	9	5	–	–	–	–
T. (*inermipes* group)	–	2	–	2	–	–	–	–
Pisidium hibernicum	–	2	–	–	–	–	–	–
Sphaerium corneum	–	–	–	–	–	–	2	–
Specimens per m²	496	465	433	186	62	31	185	51

Owing to the predominance of the larvae of *Tanytarsus*, *Sergentia coracina* and *Stictochironomus rosenschöldi* (Zett.), the deeper profundal areas of the central parts of Lake Keitele represent the Tanytarsus lagens community (cf. BRUNDIN 1958). The dominant species as percentages of the total number of specimens in some depth zones is seen in the following tabulation:

1.5 – 10 m	%
Peloscolex ferox	10
Procladius spp.	19
Orthocladiinae	28
Tanytarsus (*gregarius* gr.)	10
10 – 20 m	%
Peloscolex ferox	9
Procladius spp.	32
Orthocladiinae	8
Tanytarsus (*gregarius* gr.)	17
20 – 34 m	%
Stictohironomus rosenschöldi	50
Cryptochironomus sp.	50

Ääneselkä

Depth range of the sampling sites from 1 to 30 m.

The following characteristics are typical of this area:

Oxygen conditions good, especially in the northern part of the area, owing to the ample throughflow. O_2 saturation of the water in the hypolimnion (89 – 98 % in June). In the southern parts of the area an oxygen deficit in the mud-water interface seems probable.

Secchi disc values vary from 3.4 to 3.6 m and $KMnO_4$ consumption values from 32 to 34 mg/l in June).

Electrolytic conductivity values were rather low, ranging from 29 to 30 μS at 18°C.

Silt and mineral bottoms dominate in the central and western parts of the area, mud and gyttja bottoms in the southern parts. Near the outlet of Äänekoski residues of timber, wood chips and sawdust are common.

The dominant species at different depth zones, as percentages of the whole number of specimens are as follows:

1 – 10 m	%
Procladius spp.	25
Chironomus plumosus	10
Tanytarsus (*gregarius* gr.)	14
10 – 20 m	%
Procladius spp.	13
Chironomus plumosus	9
Polypedilum sp.	22
Chaoborus (*flavicans* gr.)	9
20 – 30 m	%
Ablabesmyia sp.	20
Polypedilum sp.	60
Chaoborus (*flavicans* gr.)	20

The area represents a transitional zone between the eutrophic Bay of Suolahti and the

Table 6. The distribution of the fauna at the localities studied in Lake Kuhnamo and the Bay of Suolahti in June 1964. O = ooze, D = detritus, F = fibre.

	Lake Kuhnamo				Bay of Suolahti		
Depth, m	2	3	6	8	3	8	15
Bottom	OD	OF	OD	O	OD	O	O
Number of samples	2	2	1	2	2	2	2
Nematoda	–	–	3	–	–	1	–
Tubifex tubifex	6	–	12	750	–	–	–
Limnodrilus hoffmeisteri	3	–	9	1783	–	–	–
Lumbriculus variegatus	–	–	–	5	–	–	–
Asellus aquaticus	1	–	–	–	–	–	–
Chaoborus (*flavicans* gr.)	–	–	–	–	–	–	1
Bezzia sp.	2	–	–	–	–	–	–
Ablabesmyia sp.	5	–	–	–	–	–	–
Procladius spp.	–	–	–	–	–	7	–
Chironomus plumosus	91	1	1	4	10	25	15
Ch. (*salinarius* gr.)	–	–	–	–	–	34	–
Tanytarsus (*gregarius* gr.)	–	–	–	–	–	2	–
Specimens per m²	1674	16	680	39 448	155	1 070	248
g/m²	10.5	+	1.8	70.8	2.6	11.2	5.3

oligotrophic central parts of Lake Keitele. The western and central parts of Ääneselkä belong to the Tanytarsus lugens community, while the southern parts represent the Chironomus plumosus community. An increased eutrophization of the area compared with the central parts of the lake is also reflected in the higher biomass values (Fig. 4).

The Bay of Suolahti

Greatest depth about 22 m.

The area is isolated from the other parts of Lake Keitele by a ground sill (of 2 – 3 m). Owing, presumably, to the retarded exchange of water and sewage discharged into the area, the process of eutrophization is strong.

Oxygen was totally absent from water at depths below 15 m in June.

Low Secchi disc values (1.2 m), high $KMnO_4$ consumption (51 mg/l) of the surface water and increased conductivity (50 μS) indicate eutrophic conditions.

The bottom is characterized by loose black gyttja, with a high content of detritus.

High biomass values of the bottom fauna (mean 6.4 g/m²) indicate a clear eutrophization of the area compared with the central parts of the lake. The diversity of the fauna is small and molluscs and crustaceans, especially, were totally absent from the profundal area.

The dominant species in the different depth zones of the area, as percentages of the whole number of specimens collected, were as follows:

3 – 10 m	%
Procladius spp.	9
Chironomus plumosus	42
Ch. (*salinarius* group)	43

10–20 m	%
Chironomus plumosus	94
Chaoborus (*flavicans* gr.)	6

According to the predominance of the species living at depths below 10 m, the area may be characterized as a Chironomus plumosus – Chaoborus community. The composition of the fauna at different localities is seen in Table 6.

Lake Kuhnamo

The area is situated south of Lake Keitele proper and has a more lotic character.

Owing to a considerable throughflow of water (MQ = 80 m³/sec), the effluents from the pulp mills and other factories at Äänekoski become so diluted that no severe depletion of oxygen was observed below the factories in March – April 1963 (Aura 1965). A slight fall of pH values and a clear increase in the electrolytic conductivity and $KMnO_4$ consumption of the water below the factories indicate pollution (Table 3).

The bottoms are characterized by silt and loose gyttja below a depth of 3 m. In one locality wood chips and fibre in black mud were observed.

In the upper littoral zone of Lake Kuhnamo *Asellus aquaticus* (L.) and *Erpobdella octoculata* (L.) were common.

Owing to partly lotic conditions in the area and to the special composition of the fauna, no definition of the lake type can be made. The fauna has a polysaprobic character typical of waters polluted by sewage and industrial wastes in Central Europe (cf. ZELINKA & MARVAN 1961, LIEBMANN 1962, etc.).

5. The relation of some benthic species to pollution

Although the material is rather limited and although the seasonal variation of the fauna has not been studied, some conclusions can be reached from the occurrence of the species in different subareas. In order to assess the value of the species or groups as indicators of the quality of the water and bottoms, the fauna is divided into three groups:

1. *Oligotrophic species*

Peloscolex ferox	Orthocladiinae
Stylodrilus heringianus	*Pisidium casertanum*
Pontoporeia affinis	*P. subtruncatum*
Ephemera vulgata	*P. hibernicum*
Monodiamesa bathyphila	

These forms were observed only in the central parts of the lake or in the northern part of Ääneselkä. Many of them are steno-oxybiontic and cold-stenothermal, preferring deep oligotrophic lakes in Fennoscandia (cf. VALLE 1927, BRUNDIN 1949).

2. *Eurybiontic species occurring in all subareas in almost equal numbers*

Lumbriculus variegatus	*Ablabesmyia* sp.
Asellus aquaticus	*Procladius* spp.
Caenis horaria	*Bezzia* sp.

The *Procladius* larvae are widespread in the lake and may include several species with differing ecological requirements.

3. *Eurybiontic species favouring polluted parts of the study area*

Tubifex tubifex	*Chironomus plumosus*
Limnodrilus hoffmeisteri	*Ch.* (*salinarius* group)
Erpobdella octoculata)	(*Sphaerium corneum*)
Chaoborus (*flavicans* group)	

Sphaerium corneum was found only once and *Erpobdella* occurred only in littoral samples.

6. Bottom fauna communities as indicators of the quality of the water and bottoms

In the lake type systems based on the bottom fauna (ALM 1922, THIENEMANN 1923, VALLE 1927, BRUNDIN 1958, etc.) the classification is usually based on the communities living in the profundal, and the types are named according to predominant species. In the most oligotrophic (ultraoligotrophic) lakes the animal community living in the deep profundal zone in Fennoscandia is the Heterotrissocladius subbpilosus community (BRUNDIN 1958, BAGGE 1968), which thus indicates conditions optimal for the occurrence of cold-stenothermal steno-oxybiontic species.

In most eutrophic lakes (and some meromictic lakes, cf. BAGGE & TULKKI 1967) Chironomus plumosus or Chironomus plumosus – Chaoborus communities are common, especially in areas rich in nutrients and with an oxygen deficit. Between these extreme types there are several other communities with different indicator values. Lakes with a high humus content (i.e. many Fennoscandian lakes) in many respects occupy a special position in the classification, often having a poor profundal fauna (VALLE 1927, JÄRNEFELT 1934, ZHADIN & GERD 1963, BAGGE 1968).

In lakes polluted by sewage or other wastes that increase the amount of nutrients, the bottom fauna usually resembles that found in eutrophic lakes. As pointed out by HYNES (1963), there are no macroscopic animals occurring only in polluted habitats, and the influence of pollution is reflected in the quantitative and qualitative changes of the communities.

In the Finnish lakes the main cause of pollution is usually sewage or industrial wastes from the pulp mills or other wood-processing factories. Both may affect the bottom fauna directly by increasing the nutritive value of the sediments or by changing the substrate, or indirectly by changing the productivity rate of other trophic levels (plankton or aquatic plants) or by increasing the microbial activity of the bottoms and the oxygen deficit in water and sediments when decomposed. The toxicity of the wastes from pulp mills may also play some rôle within a short distance from the pulp mills.

The bottom fauna of the large lakes in Central Finland is rather poor under natural conditions (VALOVIRTA 1959). The standing crop values of the profundal zone of Lake Päijänne range from 0.1 g/m² in the southern end to appr. 0.5 g/m² in the northern end of the lake (VALOVIRTA *op. cit.*). The higher biomass values of the northern part of Lake Päijänne indicate a slight eutrophization. The dominant forms in that lake are almost exactly the same as in the central parts of Lake Keitele, but the number of relict crustaceans such as *Pontoporeia affinis* and *Pallasea quadrispinosa* G. O. Sars is higher in Päijänne.

Most parts of the lakes Päijänne and Keitele can be included in the Tanytarsus lugens community (cf. Brundin 1958), but part of Päijänne was found by Valovirta (1959) to belong to the Oligochaeta type.

Owing to the ample amounts of allochthonous material coming into these lakes via the watercourses draining into the northern parts of them, the lakes undergo a slow process of morphometric eutrophization. During this process large amounts of nutrients may be deposited in the deep basins of the lakes. In the course of time this natural succession may lead to more eutrophic communities.

When effluents with a high nutritive value are discharged into the lakes, the process of eutrophization is rapidly accelerated. The coldstenothermal steno-oxybiontic component of the bottom fauna soon disappears and species more tolerant to low oxygen levels inhabit the bottoms. Usually these species consist of deepburrowing unselective deposit feeders (Tubificidae) or algal and detritus feeders (most Chironomidae). Owing to lack of competition from other species, these species may have mass outbreaks on polluted bottoms.

The effect of low oxygen tensions upon the bottom fauna in the Bay of Suolahti is clearly visible. The Chironomus plumosus – Chaoborus community found in this area may represent the climax stage in the development of the macrofauna communities in polluted habitats and in very eutrophic lakes (cf. Alm 1922, Valle 1927, etc.). If the oxygen from the bottom water totally disappears for a long period, the macroscopic fauna is eliminated, and the only animals found in the profundal area are the semipelagic larvae of *Chaoborus* (Valle 1930). The rapid changes in the bottom fauna community inhabiting the profundal zone of Lake Lievestuoreenjärvi were shown by Järnefelt (1940). The lake is polluted by effluents from a sulphite pulp mill. In 1932, the fauna consisted mainly of the larvae of Chironomidae (of *Chironomus salinarius* group, *Stictochironomus* and *Tanytarsus gregarius* group) but in 1937 – 1938 the *Chironomus plumosus* larvae predominated. During the same period a drastic decrease in the population of *Coregonus albula* occurred (Järnefelt *op. cit.*).

A typical succession of the communities in low-level oxygen habitats was studied by Zelinka (1962) in some reservoirs of the Morava River, Czechoslovakia. Because the succession in many respects resembles that found in the southern parts of Lake Keitele, some of these data are presented in Table 7.

In both the reservoirs of the Morava River and the southern parts of Lake Keitele the

Table 7. The succession of the bottom fauna in some reservoirs of the Morava River, according to Zelinka 1962, Table 1).

Reservoir	Depth, m	O_2 minimum, mg/l	H_2S	NH_4 mg/l	Species	Maximum no. of specimens per m^2	% of fauna
1	7	0	+++	1.8 – 6.8	*Chaoborus flavicans*	300	100
2	7.5	0	+	0.3 – 2.0	*Chaoborus flavicans*	300	75
					Chironomus plumosus	100	25
3	6.5	0	(+)	0.3	*Chironomus plumosus*	200	67
					Chironomus semireductus	100	33
4	30	0.2	–	0 – 0.5	*Tubifex tubifex*	1600	88
					Limnodrilus sp.	200	12
5	15	0.3	–	0.1 – 2	*Chaoborus flavicans*	300	43
					Chironomus plumosus	200	29
					Tubifex tubifex	100	14
					Stictochironomus sp.	100	14
4	16	0.5	–	0 – 0.4	*Tubifex tubifex*	1800	75
					Limnodrilus sp.	500	21
					Chironomus plumosus	100	4
6	10	2.9	–	1.1	*Limnodrilus* sp.	600	41
					Tubifex tubifex	200	14
					Procladius sp.	200	14
					Ch. plumosus	200	14
					Polypedilum sp.	100	
					Microtendipes sp.	50	
					Ceratopogonidae	100	

animal diversity was found to increase with increasing content of oxygen. *Chironomus plumosus* and oligochaetes were seldom dominants at the same time in the same habitat, while the different species of oligochaetes, such as *Tubifex tubifex* and *Limnodrilus* species, usually occurred together in large numbers.

Although the bottom fauna usually presents only one or a few trophic levels in the whole biocoenosis, it has some advantages as an indicator of habitats, compared with some other biological and hydrographic units. 1) Many bottom animals have a long life span and thus they may serve to indicate long-term fluctuations in environmental conditions. 2) Bottom animals are relatively stationary, although some of them may perform seasonal migrations. In very unfavourable conditions, however, many bottom animals leave their habitats (cf. LINDROTH 1947). 3) They are comparatively easy to sample quantitatively, since their vertical distribution in the substrate seldom exceeds 20 cm (LENZ 1931, BRINKHURST & KENNEDY 1965). 4) Many of them have a wide area of distribution. It is true that some planktonic organisms, being cosmopolitan, would be still more suitable as indicators. 5) A number of studies on the bottom fauna of lakes (especially in Fennoscandia) can be used as reference material in evaluating the degree of pollution.

The difficulties in describing and classifying the habitats according to their bottom fauna communities are well-known, but in spite of this the study of the bottom fauna is a useful and fairly rapid method for evaluating the environmental conditions and degree of pollution. It should thus be included in routine studies of water pollution in lakes.

Summary

The hydrography of the large Lake Keitele, central Finland, is described, and its bottom fauna outlined. The northern and central parts of the lake represent a typical natural oligotrophic, oligohumous lake with a small mean depth and a bottom fauna relatively rich in species, but low standing crop values, especially in the profundal zone. The low biomass values are supposed to be due to low nutritive value and slight siderotrophy and humus content of the bottoms, especially at depths below 7.5 m. The eutrophization of the southern parts of the lake is seen from increased potassium permanganate consumption, electrolytic conductivity and pH of the surface water and from lower transparency as well as deoxygenated conditions below a depth of 15 m. The standing crop values of the bottoms were here about 10 times as high as in the central part, but the animal diversity was decreased. In the southern part of the lake a succession of bottom fauna communities according to pollution is clearly seen. The northern parts of the Ääneselkä area are inhabited by an impoverished Tanytarsus lugens community (dominant in the central parts of the lake), the southern part of Ääneselkä by the Chironomus plumosus community and the deoxygenated bottoms of the Bay of Suolahti by the Chironomus plumosus – Chaoborus community. Lake Kuhnamo, south of Lake Keitele, receives effluents from pulp and paper mills; here tubificids reach high densities on the bottoms below the factories.

The succession of the bottom fauna communities in polluted habitats and the importance of oxygen as a selective factor acting on the communities is discussed. It is emphasized that the bottom fauna is a good indicator of the quality of bottoms and grade of pollution in lakes.

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References

ÅBERG, B. & W. RODHE, 1942: Über die Milieufaktoren in einigen südschwedischen Seen. – Symb. Bot. Ups. 5: 3, 1 – 256.

ALM, G., 1922: Fiskens biologi i Yxtasjön samt jämförande undersökningar över bottenfauna och fiskproduktion i svenska insjöar. – Medd. K. Lantbruksstyrelsen 253, 1 – 188.

Atlas of Finland 1960. Geographical Society of Finland. Helsinki.

AURA, U. O., 1965: Viitasaaren reitin ja Äänekosken alapuolisen väylän vesistötutkimus. – Vesiensuojelutoimiston Tiedonantoja 18, 1 – 21.

BAGGE, P., 1968: Ecological studies on the fauna of subarctic waters in Finnish Lapland. – Ann. Univ. Turku A II: 40, 28 – 79.

BAGGE, P. & P. TULKKI, 1967: Studies on the hydrography and biota of recently isolated lakes. – Merentutkimuslaitoksen Julk./Havsforskn. Inst. Skr. 223, 13 – 34.

BRINKHURST, R. O. & C. R. KENNEDY, 1965: Studies on the biology of the Tubificidae (Annelida, Oligochaeta) in a polluted stream. – Journ. Anim. Ecol. 34, 429 – 443.

BRUNDIN, L., 1949: Chironomiden und andere Bodentiere der südschwedischen Urgebirsseen. – Inst. Freshw. Res. Drottningholm, Rep. 30, 1 – 914.

– » – 1958: The bottom faunistical lake type system and its application to the southern hemisphere. Moreover a theory of gracial erosion as a factor of productivity in lakes and oceans. – Verh. internat. Ver. Limnol. 13, 288 – 297.

Deutsche Einheitsverfahren zur Wasser-, Abwasser- und Schlammuntersuchung. Veinheim, 1960.

ELORANTA, P., 1966: Vesikasvihavaintoja Keiteleeltä (PH) kesällä 1964. – Luonnon Tutkija 70, 62 – 63.

Hydrologinen vuosikirja 18 (1963 – 1964). – 89 pp. Helsinki 1966.

HYNES, H. N. B., 1963: Biology of polluted waters. – 202 pp. Liverpool.

JÄRNEFELT, H., 1934: Zur Limnologie einiger Gewässer Finnlands. XI. Petsamo. – Ann. Soc. Vanamo 14: 10, 172 – 347.

– » – 1940: Die Wirkung einer Sulfitfabrik auf den Lievestuoreenjärvi. – Verh. internat. Ver. Limnol. 9, 180 – 187

– » – 1956: Zur Limnologie einiger Gewässer Finnlands. XVII. – Ann. Zool. Soc. Vanamo 18: 2, 1 – 61.

– » – 1963: Id. XX. Zusammenfassende Besprechung der Thermik und Chemie finnischer Seen. – Ibid. 25: 1, 1 – 52.

LENZ, F., 1931: Untersuchungen über die Vertikalverteilung der Bodenfauna im Tiefensediment von Seen. Ein neuer Bodengreifer mit Zerteilungsvorrichtung. – Verh. internat. Ver. Limnol. 5, 232 – 260.

LIEBMANN, H., 1962: Handbuch der Frischwasser- und Abwasserbiologie. – 588 pp. München.

LINDROTH, A., 1947: Vattenförorening och vattenfaunans andningsproblem. – Vattenhygien 3: 2, 32 – 44.

NIEMELÄ, J., 1961: Yleinen viemärilaitos. – Kaupunkiliiton toimiston teknillisen osaston julkaisuja. 658 pp. Helsinki.

RENQVIST, H., 1951: Sisävedet. – Suomen maantieteen käsikirja, 145 – 180. Helsinki.

RODHE, W., 1958: Primärproduktion und Seetypen. – Verh. internat. Ver. Limnol. 13, 121 – 141.

SIRKKA, P. V., 1949: Keiteleen vesikasvilajien ekologiasta. – Ann. Bot. Soc. Vanamo 23: 2, 1 – 42.

THIENEMANN, A., 1923: Die beiden Chironomusarten der Tiefenfauna der norddeutschen Seen. Ein hydrobiologisches Problem. – Verh. internat. Ver. Limnol. 1, 108 – 143.

VALLE, K. J., 1927: Ökologisch-limnologische Untersuchungen über die Boden- und Tiefenfauna in einigen Seen nördlich vom Ladoga-See. 1. – Acta Zool. Fenn. 2, 1 – 179

– » – 1930: Über das Auftreten von Mysis relicta und Corethra plumicornis während des Sommers in einigen Seen Südost-Finnlands. – Arch. Hydrobiol. 21, 483 – 492.

VALOVIRTA, E. J., 1959: Quantitative Untersuchungen über die Bodenfauna des Sees Päijänne, Mittelfinnland. – Ann. Zool. Soc. Vanamo 20: 2, 1 – 50.

ZELINKA, M., 1962: Wztah zoobenthosu Moravskych ych udolnich nadrzi k chemismu vody. – Scient. Papers from Inst. of Chem. Technol. Prague 6: 1, 293 – 312.

ZELINKA, M. & P. MARVAN, 1961: Zur Präzisierung der Reinheit fliessender Gewässer. – Arch. Hydrobiol. 57, 389 – 407.

ZHADIN, V. I. & S. V. GERD, 1963: Fauna and flora of the rivers, lakes and reservoirs of the U.S.S.R. – 626 pp. Jerusalem.

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