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Zooplankton in a watercourse polluted by a sulphite pulp mill

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The biomass and the species richness of the zooplankton communities were reduced in the most polluted parts of the watercourse below a sulphite pulp mill in central Finland. Only occasional cladocers and copepods were found in the vicinity of the mill, whereas the rotifers *Keratella cochlearis*, *K. ticinensis*, *Kellicottia longispina*, *Polyarthra remata* and *P. vulgaris* occurred more frequently. Ciliates were characteristic inhabitants of these areas. Dominant crustacean species were *Daphnia cristata*, *Diaphanosoma brachyurum*, *Eudiaptomus gracilis* and *Mesocyclops leuckarti*. Many zooplankton species probably avoided the polluted areas because of the scarcity of suitable food. The zooplankton biomass and species richness showed zonation similar to that of the phytoplankton biomass, and the zooplankton biomass maxima were found in the same areas as the phytoplankton maxima. The zooplankton biomass was rather small in the hypolimnic waters because of the oxygen depletion up to 35 km from the mills.

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1. Introduction

There are few studies concerning the zooplankton in polluted Finnish lake waters. Observations on the zooplankton in water polluted by chemical pulp mill effluents have only been published by Järnefelt (1961) and Hakkari (1967, 1972, 1978) and are mainly about the large lakes Saimaa and Päijänne.

The watercourse below the wood-processing mills at Mänttä has been polluted since the 1920s and several papers about the effects of pollution on the water quality and biology in this area have been published by, e.g., Silfversparre (1958), Eloranta (1970, 1972), Ilus (1970), Nyrönen et al. (1978), Eloranta & Kettunen (1979). This area is suitable for studies of the effects of effluents because of the clear gradient from high, toxic pollution to no pollution and because this watercourse has no other important loading factors.

The aim of this study is to supplement the knowledge of the biological effects of chemical pulp mill effluents on zooplankton in a normally dysoligotrophic watercourse. It was not possible to draw profound conclusions from the results available, because of the rather scanty material.

2. Study area

The study area is in the northeastern part of the Kokemäenjoki drainage basin. The waters coming from Lake Keurusselkä pass through the sulphite pulp and paper mills and carry the effluents into the northern part of Lake Kuorevesi (Fig. 1). These waters partly move against the normal direction of flow in Lake Kuorevesi and are diluted there quite rapidly. Downstream from the mills the watercourse resembles a river for the first 20 km, after which it builds several lake areas. The degree of pollution decreases rapidly at about 35 km below the mills due to unpolluted waters flowing in from the north and mixing with the polluted waters (Fig. 1).

The quality of the water is closely dependent on the discharge from Lake Keurusselkä and the degree of dilution of the effluents. Thus clear differences can be seen between water quality in different years (Eloranta & Kettunen 1979). Typical properties of polluted waters below sulphite pulp mills are low pH, increased concentrations of organic compounds, total S, lignosulphonate, total N and total P, increased conductivity and deeper colour of the water (Table 1).

3. Methods

The results concerning rhizopods, ciliates and rotifers are based on observations from phytoplankton counting of 50 ml samples. These samples were taken with a 2 metre long tube-sampler from the 0—2 m water layer

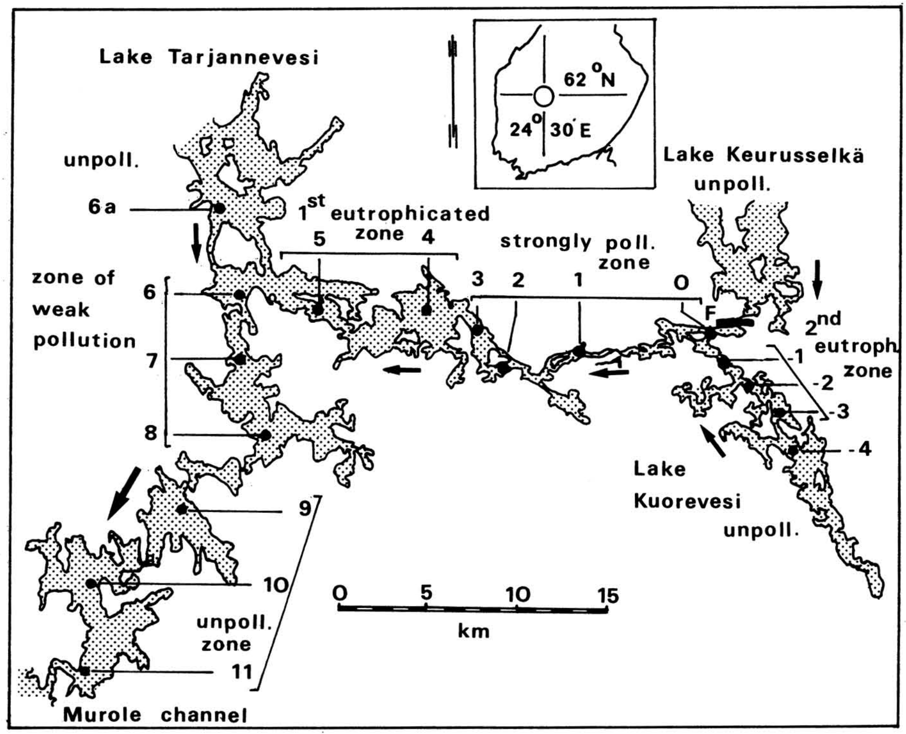

Fig. 1. Location of the study area and sampling stations. Arrows indicate the direction of water flow. F = mills at the southern end of Lake Keurusselkä.

and fixed with some drops of Lugol's solution with sodium acetate. These samples were usually taken at 14 stations (-3—9; Fig. 1) in June, July and August between 1973 and 1978. Zooplankton samples proper were taken from the 0—5 m water layer and also from the hypolimnion. The depths of the hypolimnion samples varied according to the conditions at each station. The zooplankton samples were preserved with about 5 ml of neutralized formalin in each 100 ml sample.

A 10 ml subsample was taken from each sample for counting under an inverted microscope. The samples counted corresponded on average to an unsieved sample of 4 litres. According to Hakkari (1978) more than 80 % of the taxa in a water volume of 18.5 l is found in a subsample with a volume of 2.3 l. The wet weight biomasses were calculated according to the mean volumes given by Hakkari (1978) and by assuming the specific gravity of zooplankton to be 1.0.

4. Results

4.1. Biomasses

Spatial distribution of the zooplankton biomasses reflected the same zonation as observed in the phytoplankton studies from the same area (Fig. 2). The biomasses in the 15 km stretch below the mills (stations 0—3) were low (less than 250 mg/m^3 wet weight) and increased rapidly with decreasing concentrations of the effluents further from the mills (at stations -1—-3 and 4—5). The increase in the phytophagous zooplankton biomass corresponded to the higher abundance of phytoplankton at these stations (Fig. 2, Eloranta & Kettunen 1979). Furthermore, the oxygen concentrations of deeper water layers were very low or zero at these stations (at depths greater than 10 m; G. A. Serlachius Ltd., unpubl. monitoring results) and therefore the zooplankton densities were low in the hypolimnion. Typical hypolimnion zooplankton was first found 35 km below the mills (Fig. 3).

Crustacean zooplankton was the main contributor to the biomass at all the stations (Fig. 2). The proportion of copepods increased in the eutrophicated zone in particular (stations 4—5) due to the high densities of *Mesocyclops leuckarti*

Table 1. The average values of some water quality parameters in different parts of the study area (see Fig. 1; G. A. Serlachius Ltd., unpubl. monitoring results) and the densities (indiv./l) of crustacean species in the zooplankton samples taken from the epilimnion in August 1979 (+ = density less than 1 indiv./l, L = littoral species).

		Stations																
		0	1	2	3	4	5	-1	-2	-3	6	7	8	-4	6a	9	10	11
Parameters																		
pH			4.2— 4.6			5.1— 5.3		5.6— 6.5			6.0— 6.1			6.2— 6.8				
Electrol. conduct.	µS/cm (20°C)		90 —180			68 —74		47 —66			50 —52			35 —52				
Lignosulphonates	mg/l		18 —31			5.8— 9.3		2.3— 6.5			2.7— 4.1			<3.3				
Colour	mg Pt/l		89 —107			107		53 —66			66 —77			<60				
C.O.D.	mg O_2/l		34 —55			18 —25		11 —17			14 —15			<15				
Total S	mg S/l		8.8—12.9			6.4— 7.1		3.4— 4.3			4.1— 4.5			2 — 4				
Cladocera																		
Acroperus harpae Baird	(L)	(+)																
Alonella nana (Baird)	(L)			(+)														
Bosmina coregoni Baird						+		+	2	+	2	+	+	+	1	+		+
B. c. var. *longicornis* (Schödler)						1		1	2		2		+		+			1
B. c. var. *longispina* (Leydig)					2	+	+	1	2	+	+	3	+	1	1	+	1	1
B. c. var. *obtusirostris* (Sars)				3	4			1	1			+	+			+	+	
B. longirostris Müller					+	1							+					
Ceriodaphnia quardrangula (Müller)		+		+	+	2					+							
C. reticulata Sars												+						
Chydorus sphaericus (Müller)			+		+	1		1	2	2	+	+	+	2	6			
Daphnia cristata Sars		3	+	+	3	7	13	7	30	23	11	12	7	11	18	5	6	15
D. galeata Sars										+			+					
D. longispina Müller							+					+						
Diaphanosoma brachyurum (Liévin)			+		5	10	3	+	2	2	1	2	2	7	11	1	+	7
Holopedium gibberum Zaddach									+		+		+			+		
Leptodora kindti (Focke)					+			+					+					
Limnosida frontosa Sars					3	5	3	+	+	1	+	+	+	+	2		+	1
Polyphemus pediculus (L.)	(L)													(+)	(+)			
Copepoda																		
Eudiaptomus gracilis Sars					1	5	2	3	4	4	1	1	3	4	2	1	6	9
Heterocope appendiculata Sars								+	+	+			+			+		+
Mesocyclops leuckarti (Claus)		3	+	1	12	54	62	25	48	27	23	39	18	20	49	11	15	23

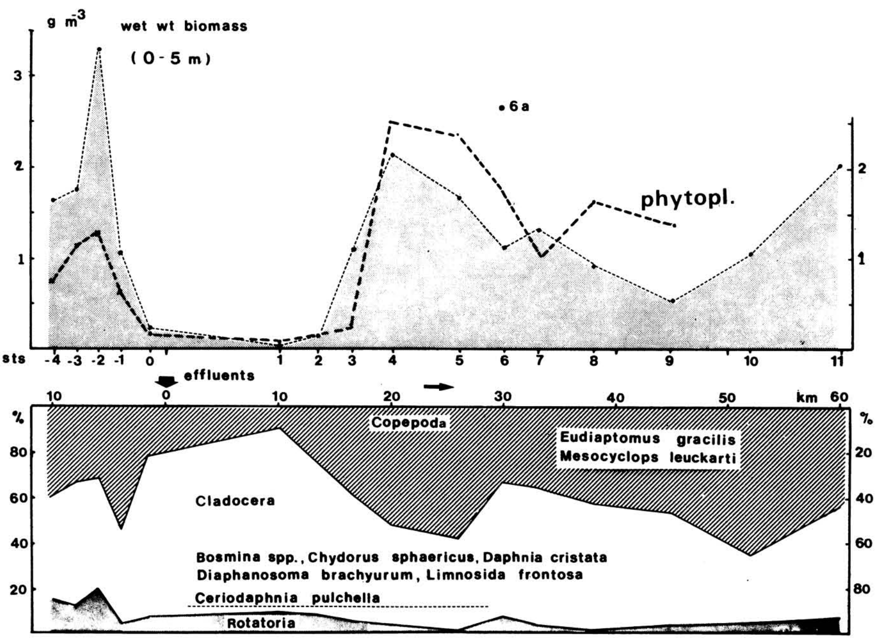

Fig. 2. The wet weight biomasses of zooplankton in the epilimnion (0—5 m) in August 1979 and average phytoplankton biomasses in August 1973—1978 (Eloranta & Kettunen 1979). The lower part shows the contributions of main zooplankton groups in different areas and the dominant species.

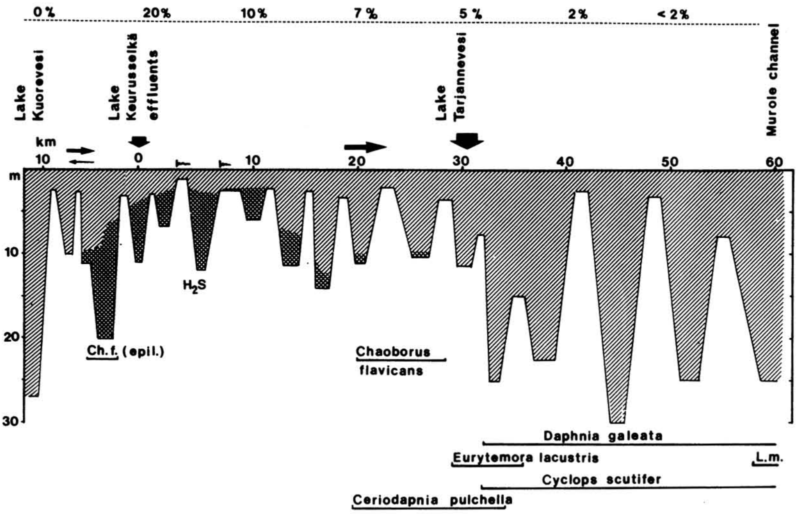

Fig. 3. Schematic representation of the depth at different places within the study area and the main zooplankton species in the hypolimnion (L.m. = *Limnocalanus macrurus*). Percentages indicate the average relative concentrations of the effluents in different parts of the watercourse.

(53—62 indiv./l, Fig. 2). Ciliata was the dominant group on the basis of densities in the most polluted zones, but its proportion of the total biomass was small.

4.2. Spatial occurrence of different taxa

There was a clear decrease in the species richness of the zooplankton communities, excluding ciliates, in the polluted zones (stations 0—5). An average of 8—10 rotifer species were found in each phytoplankton sample from the unpolluted zones and the corresponding number in samples from the polluted zones was 2—5 (Fig. 4). A similar decrease was also seen in the number of crustacean species in zoopalnkton samples in August 1979.

The most frequent ciliate taxa in the strongly polluted part of the watercourse were *Vorticella* spp. and *Paramecium* sp. (Table 2). Taxa with higher frequencies and densities in the other zones were *Laboea* sp., *Tintinnidium fluviatile, Tintinnopsis lacustris* and *Strombidium* sp., which are also typical taxa of unpolluted lakes within the district (Eloranta 1972, 1975).

Excluding *Keratella ticinensis,* the frequencies of all rotifer species were lower in polluted zones than in unpolluted or slightly polluted zones (Table 2). The most common rotifers were *Polyarthra remata, P. vulgaris, Keratella cochlearis, Kellicottia longispina, Trichocerca rousseleti* and *Ascomorpha ecaudis* (Table 2). Several littoral species occasionally appeared in the samples from the strongly polluted zone, because this part of the watercourse is very narrow and has dense macrophytic vegetation (mainly *Nymphaea candida*) on the shores. These species were *Brachionus angularis* Gosse, *Trichotria pocillum* (Müller), *Diplax* sp., *Euchlanis* sp., *Lecane* sp. and *Ploesoma triacanthum* (Bergendahl). Species found occasionally in the other areas were *Chromogaster ovalis* (Bergendahl), *Collotheca* sp., *Conochilus hippocrepis* (Schrank), *Gastropus hyptopus* (Ehr.), *Lecane lunaris* (Ehr.), *Ploesoma hudsoni* (Imhof), *Trichocerca cylindrica* (Imhof), *T. similis* (Wierz.) and *T. birostris* (Mink).

Crustacean species occurred only occasionally in the strongly polluted zone, but in the other areas their population densities were higher and the communities in the epilimnion were spread

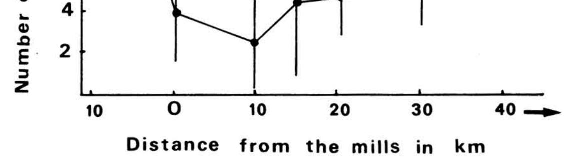

Fig. 4. Mean numbers of rotifer species in the phytoplankton samples in 1973—1978. Vertical lines = S.D. of the means.

rather uniformly between different zones (Table 1). Dominant cladocera species were *Daphnia cristata, Diaphanosoma brachyurum, Limnosida frontosa* and *Bosmina coregoni* var. *longispina* (Fig. 2, Table 1). *Ceriodaphnia quadrangula* and *Chydorus sphaericus* preferred moderately polluted and eutrophicated zones, whereas e.g. *Holopedium gibberum* and *Daphnia galeata* were found only in unpolluted waters (Table 1). Very large females of *Daphnia galeata* were found in the hypolimnion at stations 9—11. The individuals were 2.5—3.2 mm long.

The dominant copepods of the epilimnetic waters were *Eudiaptomus gracilis* and *Mesocyclops leuckarti* (Fig. 2, Table 1). *Heterocope appendiculata* occasionally occurred at the unpolluted stations and, according to Almer *et al.* (1974), it avoids particularly acid waters. *Cyclops scutifer, Eurytemora lacustris* and at two stations (6 and 11) also *Limnocalanus macrurus* were found in unpolluted hypolimnetic waters without oxygen depletion. *Chaoborus* sp. was found in polluted waters, both in deeper waters and in the epilimnion (Fig. 3).

Table 2. The percentage frequencies of some common species of Protozoa and Rotatoria according to observations from phytoplankton samples taken in 1973—1978.

	Stations				
	0—3	4—5	-1—-3	6—8	-4, 6a, 9—11
Protozoa					
Cyphoderia sp.	0	0	0	2	0
Difflugia limnetica Levander	9	16	35	36	30
Carchesium sp.	4	13	5	13	0
Colpidium sp.	2	0	0	0	0
Epistylis rotans Švec.	0	0	13	4	5
Laboea sp.	16	44	53	85	90
Lionotus sp.	4	0	3	9	5
Nassula sp.	0	25	18	17	25
Paramecium sp.	30	19	2	4	0
Staurophrya elegans	0	0	2	2	0
Strombidium sp.	5	25	53	50	65
Tintinnidium fluviatile S.Kent	4	9	18	40	40
Tintinnopsis lacustris Entz.	5	6	40	42	45
Vorticella sp.	34	6	45	16	5
Rotatoria					
Anuraeopsis fissa (Gosse)	2	0	18	21	5
Ascomorpha ecaudis Perty	7	3	48	27	40
Asplanchna priodonta Gosse	0	9	10	4	40
Cephalodella sp.	9	0	13	0	0
Conochilus unicornis Rouss.	2	3	13	8	25
Gastropus stylifer Imhof	2	3	25	13	10
Kellicottia longispina (Kell.)	18	19	52	65	76
Karatella cochlearis (Gosse)	18	31	67	65	52
K. ticinensis (Callerio)	5	9	2	0	0
Polyarthra dolichoptera Idelson	2	0	15	4	8
P. major Burckh.	4	6	18	25	30
P. remata Skor.	18	47	58	71	95
P. vulgaris Carlin	23	56	58	77	85
Synchaeta sp. (small)	4	28	10	19	28
Trichocerca rousseleti (Voigt.)	2	9	18	38	35

5. Discussion

The strong decrease in the zooplankton biomass in the highly polluted parts of the studied watercourse has been reported previously (Eloranta 1972). Hakkari (1978) found eutrophicating effects of sulphite pulp mill effluents in the middle of Lake Päijänne. The concentrations of the effluents in those polluted parts of Lake Päijänne (stations 655—657, 675) correspond to the average effluent concentration at stations 4 and 5 of this study (1st eutrophicated zone, Table 1, Figs. 2 and 3).

The abundance of ciliates in zooplankton communities in the strongly polluted parts of the watercourse reflects its polysaprobic character (Sládeček 1973). Hakkari (1972, 1978) found positive correlations between the effects of pollution by the wood-processing industry and the frequencies of *Keratella hiemalis* Carlin, *K. ticinensis* (Callario), *Anuraeopsis fissa* (Gosse), *Filinia longiseta* (Ehr.), *Bosmina longirostris* Müller and *Chaoborus flavicans* (Melgen) in Lake Päijänne. According to these positive correlations the species were mentioned as indicators of wood-processing industry effluents. However, these species do not indicate these effluents; they indicate changes and conditions in the environment, which can be independent of the industrial effluents. Of the species mentioned as indicators, *Keratella hiemalis* and *Filinia longiseta* are typical cold-water species (Carlin 1943, Nauwerck 1978). In Lake Päijänne these species were found in early summer in deep water layers which had both cool water and also higher concentrations of effluents. These species are also very typical and abundant winter species in the oligohumic, eutrophic pond, Vasikkalampi, in the town of Jyväskylä at the northern end of Lake Päijänne (Eloranta 1980). *Chaoborus* occurs abundantly in hypolimnetic waters with low oxygen concentration (e.g. Eloranta 1975, Särkkä 1979), but it is not especially connected with effluents from the wood-processing industry. *Bosmina longirostis* and *Anuraeopsis fissa* prefer all kinds of eutrophication and the resultant increase in the concentrations of detritus and bacteria in the water.

According to Almer *et al.* (1974) the number of rotifer species is reduced in Swedish lakes with low pH (especially below pH 5.4), but some species can still live in water with pH below 4.5. Roff & Kwiatkowski (1977) obtained similar results from lakes in northern Ontario where the zooplankton diversity index declined sharply below pH 5.3 and rotifers showed the greatest changes in conjunction with the changing pH of the water. Common species in acid Swedish lakes were *Keratella cochlearis*, *Kellicottia longispina* and *Polyarthra remata*. These are also dominant rotifers in a Swedish watercourse polluted by a sulphite pulp mill (Nylander 1969), but the pH of the water in this case was usually higher than 6.0. *Keratella cochlearis* feeds mainly on bacteria and detritus (Pourriot 1977), but also on brown flagellates, such as chrysomonads and cryptomonads (Nauwerck 1963, Pourriot 1977). These flagellates are absent from the most polluted areas (Eloranta & Kettunen 1979) and the sulphur bacteria are obviously not suitable food for the species. The scarcity of *Kellicottia longispina* and *Polyarthra* remata in the vicinity of the mills was probably caused by lack of suitable food, too, because these species mainly feed on planktonic algae (Pourriot 1977).

Soft species such as *Asplanchna priodonta* and *Synchaeta* spp. probably avoid the polluted zones because of the low pH of the water, but on the other hand *Synchaeta* is generally not a very frequent or abundant genus in the study area, especially in the summer months.

Anuraeopsis fissa prefers detritus and becteria in its diet. Thus the species is common among the late summer plankton of eutrophic waters, especially during the fall overturn with its subsequent good food supply, but its occurrence in the study area did not reflect any special preference for the effluents (cf. Hakkari 1972, 1978, Järnefelt 1961).

Among the rotifers, *Keratella ticinensis* seemed to be the only species to prefer the new environmental conditions caused by acid, dark brown effluents. This species was not found in unpolluted areas and it is known to prefer acid, polyhumic bog water (Carlin 1943, Pejler 1957, Koste 1978).

The genus *Bosmina* is known to be a common cladocera even in acid water up to pH 3.3 (Almer et al. 1974). Some species of this genus were also found in the studied area, but nowhere at higher densities (Table 1). Dominant cladocera species in August 1979 were *Daphnia cristata, Diaphanosoma brachyurum* and at some stations also *Limnosida frontosa* (Table 1). These taxa are generally dominant in late summer and the scarcity of the genus *Bosmina* was obvioisly due to the sampling time, because this genus is usually at its maximum in the early summer. The densities of the dominant cladoceras mentioned were also reduced near the mills, mainly due to low pH (Almer et al. 1974) and probably also to scarcity of suitable food, as in the case of the dominant copepods. *Daphnia pulex*, mentioned by Schräder (1958), Järnefelt (1961) and Hakkari (1978) as a reliable indicator of pollution, was not found in the study area.

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