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Littoral oligochaete (Annelida: Oligochaeta) communities in neutral and acidic lakes in the Republic of Karelia, Russia

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The structure of littoral oligochaete communities in relation to pH was studied in five small lakes in South-western Karelia. Among the lakes, three were affected by acidification and characterized by low pH (mean pH = 4.2–5.9). Two lakes were neutral (mean pH = 6.9 and pH = 7.1, respectively). The oligochaete communities of the acidified lakes were poorer compared to the neutral ones. Taxa richness, total biomass of the oligochaetes, their relative density and relative biomass in macroinvertebrate communities were lower in the strongly acidified lakes. Changes of major taxon proportions in the total density and biomass of the oligochaetes were recorded with lowering of pH. For the analyses, the oligochaetes were separated into three functional feeding groups, as gatherers (S) that selectively ingest mainly on the sediment surface and other substrates, gatherers (T) that selectively ingest mainly in the sediments, and predators. Total density of gatherers (T) as well as their relative density in the oligochaete assemblage and macroinvertebrate communities were lower in the acidified lakes.

Introduction

Investigations on acidification and its effect on freshwater ecosystems have demonstrated that all trophic levels are affected, and the structure and function of an ecosystem are modified by acidification in many ways (Brodin 1995).

Oligochaete worms are widespread and abundant in freshwater ecosystems. Of these, several tubificids typically live and feed in sediments (Chekanovskaya 1962, Brinkhurst *et al*. 1972, McCall and Tevesz 1982). However, up to now information on the role of oligochaetes in the acidic ecosystems is scarce and contradictory (Lonergan and Rasmussen 1996). By comparing aquatic oligochaete community structure in terms of taxa richness, density of populations and functional feeding groups, insight may be gained into the effects of acidification on small lake ecosystems.

This paper presents the results from a survey

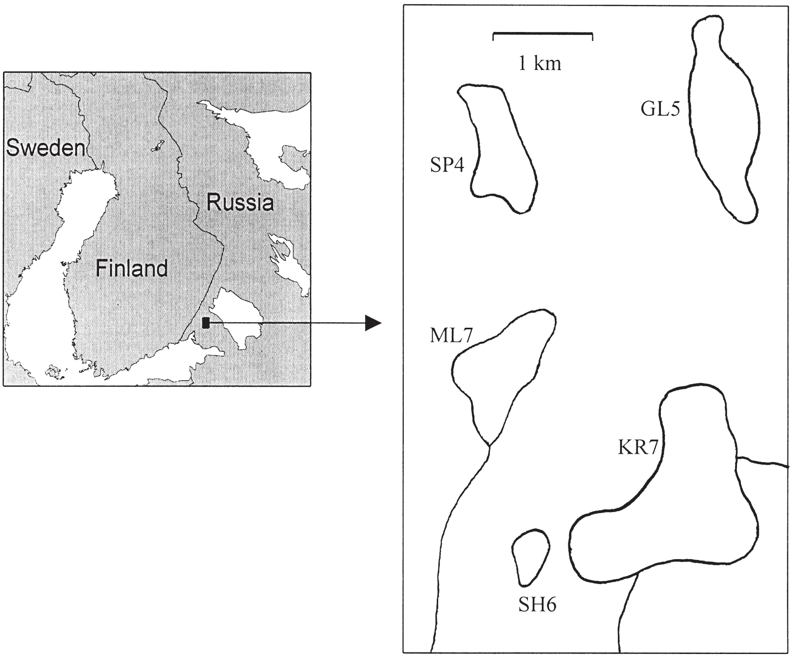

Fig. 1. Map of study area. — KR7: Kostomojärvi. — ML7: Lake Moll'usochnoye. — SH6: Lake Shkolnoe. — GL5: Lake Goluboe. — SP4: Lake Splavinnoye.

of littoral oligochaete communities in five small lakes that were characterized by differences in mean water pH. The lakes were specially selected to represent a broad range of pH. The objective was to investigate the effect of pH on the structure of littoral oligochaete communities.

Study area, material and methods

The studies were carried out in five, small (3–41 ha) Akkakharsky lakes: Kostomojärvi (KR7), Lake Moll'usochnoye (ML7), Lake Shkolnoe (SH6), Lake Goluboe (GL5) and Lake Splavinnoye (SP4), situated in South-western Karelia, Russia (61°40´N, 29°50´E) (Fig. 1). The lakes have a small forested (mainly *Pinus silvestris*) catchment, underlain with granitic bedrock and covered with soils ranging from acid brown to podzolic.

More specific information concerning limnological characteristics of these lakes is given by Ivanova *et al.* (1993) and Ilyashuk (1994, 1998).

Water samples for determination of the seasonal variationof colour and pH were collected monthly from June to October 1992. The samples were analysed immediately upon arrival in the laboratory. Colour (mg Pt l^{-1}) was determined with a platinum-cobalt standard. Water pH was determined with a portable pH meter.

Macrozoobenthic samples were taken every twenty days with an improved Ekman automatic box sampler DAK-100 (0.01 m^2) (Bakanov 1979) during June-October 1992. On each sampling date, six samples were taken from randomly selected locations along the macrophyte-free littoral (depth between 0.5 and 1.5 m) of each lake. The samples were sieved in the field through a sieve (mesh size 0.2 mm) and preserved in a 5% formalin solution.

In the laboratory, the samples were handsorted under at least 10× magnification. Macroinvertebrates were classfied to species when possible. Their wet weight was measured with a torsion balance to the nearest 0.1 mg. Total biomass in each sample was calculated as the sum of individual wet masses.

For the trophic organization analysis of the communities, species were assigned to the collector and predator functional feeding groups, according to the classification system for aquatic insect trophic relations described by Cummins and Merritt (1988). According to their known feeding strategies (Chekanovskaya 1962, Brinkhurst *et al.* 1972, McCall and Tevesz 1982, Popchenko 1988, 1993), the collectors were separated into two subdivisions, as gatherers (S) that selectively ingest mainly on the surface of sediments and other substrates, and gatherers (T) that selectively ingest mainly in sediments (Table 1).

The trophic conditions for macrozoobenthos in the littoral of the lakes were characterized with the Environmental Index (EI; values between 0 and 0.6 suggest oligotrophic conditions) (Milbrink 1983) that is based on the relative abundance of oligochaete species belonging to the families Tubificidae and Lumbriculidae.

$$\mathrm{EI} = c \times \frac{0.5\sum n_0 + \sum n_1 + 2\sum n_2 + 3\sum n_3}{\sum n_0 + \sum n_1 + \sum n_2 + \sum n_3},$$

were c is the coefficient adjusting the numerical result to the total abundance of oligochaetes; n_0, n_1, n_2 and n_3 = the total number of specimens belonging to each of the four ecological groups according to the classification of Milbrink (1983).

A Student *t*-test was used to test for differences in mean EI and mean macroinvertebrate densities and biomass between paired lakes; the level of significance used was 0.05.

Results

Colour and pH varied among the lakes (Table 2) but varied little within sites over time. Oligochaetes were found in benthic samples from the littoral of all the sampled lakes. Species of four families, Naididae, Tubificidae, Enchytraeidae and Lumbriculidae, were recorded among the oligochaete worms. All these species are common for the oligochaete fauna in the lakes of the Republic of Karelia (Popchenko 1988). The number of species were different among the lakes (Appendix).

The number of naidid species decreased from 14 in neutral lake KR7, 11 in neutral ML7 and in moderately acidified SH6, to 9 in acidic GL5 and

Table 1. Classification system for oligochaete trophic relations in the littoral communities of the Akkakharsky lakes.

Functional group	Subdivision of functional group		Taxon
	Feeding mechanism	Dominant food	
Collectors	Gatherers (S) selectively ingest mainly on the surface of sediment sand other substrates	Decomposed fine particulate organic matter (FPOM) and algae	Naididae (except *Ch. diaphanus*), *S. ferox*, *S. heringianus*, *L.variegatus,* Enchytraeidae
	Gatherers (T) selectively ingest mainly in sediments	FPOM	*L. hoffmeisteri, T. tubifex, A. limnobius, A. pluriseta*
Predators	Engulfers attack prey and ingest whole animals	Living animals	*Ch. diaphanus*

Table 2. Morphometrical characteristics and water chemistry of the studied lakes: Kostomojärvi (KR7), Lake Moll'usochnoye (ML7), Lake Shkolnoe (SH6), Lake Goluboe (GL5), and Lake Splavinnoye (SP4). For the water chemistry variables the mean during June–October 1992 is given (*N* = 5 for each lake); the range is in parentheses.

	Lake				
	KR7	ML7	SH6	GL5	SP4
Surface area (ha)	41	9	3	11	8
Mean depth (m)	2.4	3.0	3.5	5.3	6.8
Maximum depth (m)	8.0	6.0	11.0	13.0	13.3
pH	7.1 (6.9–7.3)	6.9 (6.5–7.3)	5.9 (5.8–6.0)	5.3 (5.2–5.3)	4.2 (4.1–4.2)
Colour (mg Pt l^{-1})	125 (110–140)	40 (20–60)	5 (3–7)	5 (3–7)	290 (270–310)

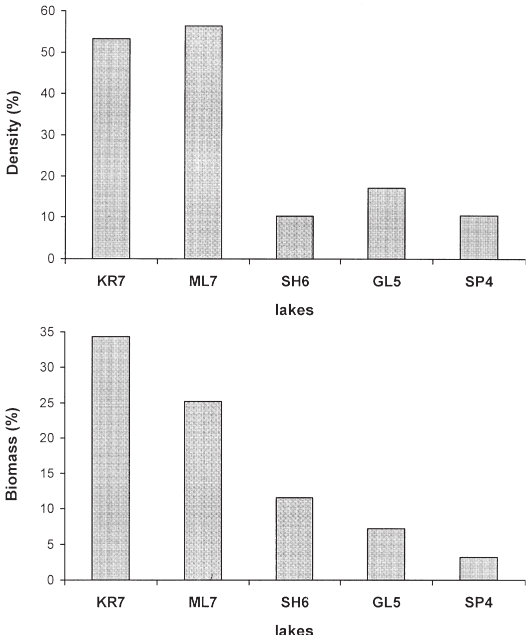

Fig. 2. Mean relative density (%) and biomass (%) of oligochaetes in the littoral macroinvertebrate communities of the studied lakes (N = 42 for each lake).

2 in the strongly acidified SP4. Only naidids, *Vejdovskyella comata* (Vejdovsky), and *Pristina foreli* Piguet, occurred in SP4. Among tubificids, oligochaete worms, *Tubifex tubifex* (Müller), were found in all the lakes. Few individuals of *Aulodrilus limnobius* Bretscher and *A. pluriseta* (Piguet) were found only in ML7. The number of tubificid species decreased from 5 in neutral ML7 and 3 in neutral KR7, to 2 in moderately acidic SH6, and 1 in strongly acidified GL5 and SP4. Enchytraeidae were common in all the lakes; Lumbriculidae were found in all the lakes, except SP4.

Mean total densities and biomass of all the benthic macroinvertebrate during the sampling period were lowest in neutral KR7, and highest in strongly acidified SP4 (Table 3). However, the differences were not significant.

On the other hand, mean oligochaete densities were lower in SH6, GL5, and SP4, as compared with KR7 and ML7, but the differences were not significant (Table 4). The total oligochaete biomass was about 1.0 g m^{-2} in neutral lakes KR7 and ML7, 0.7 g m^{-2} in SH6, and about 0.4 g m^{-2} in strongly acidified lakes GL5 and SP4. The differences between the neutral and strongly acidified lakes were significant ($p < 0.05$).

The relative contribution of oligochaetes to the total macroinvertebrate density and biomass varied among the lakes (Fig. 2). Mean relative densities of oligochaetes were over 50% in neutral lakes KR7 and ML7, and under 18% in SH6, GL5, and SP4. In KR7 and ML7, oligochaetes formed 34% and 25% of the macroinvertebrate biomass, respectively. Whereas in GL5 and SP4 their shares were less than 8%.

Changes of major taxonomic proportions in the total density and total biomass of oligochaetes

Table 3. Total mean density (ind. m^{-2}) and biomass (g m^{-2}) of benthic macroinvertebrates in the studied lakes for the period of June–October 1992 (N = 42 for each lake); SE is in parentheses.

	Lake				
	KR7	ML7	SH6	GL5	SP4
Density	4 836 (2 150)	5 892 (1 809)	8 470 (3168)	6 093 (2 382)	11 724 (3 908)
Biomass	3.38 (1.17)	4.01 (1.12)	6.12 (1.86)	6.15 (1.80)	11.67 (4.51)

Table 4. Mean density (ind. m^{-2}) and biomass (g m^{-2}) of oligochaetes in the studied lakes for the period of June–October 1992 (N = 42 for each lake); SE is in parentheses.

	Lake				
	KR7	ML7	SH6	GL5	SP4
Density	2 578 (1 398)	3 324 (1 091)	872 (541)	1 042 (402)	1 208 (555)
Biomass	1.16 (0.32)	1.01 (0.22)	0.71 (0.45)	0.44 (0.17)	0.37 (0.18)

were recorded with a lowering of the pH. The greatest shares of Enchytraeidae in the total oligochaete density (84%) and total oligochaete biomass (94%) were recorded in the most acidic lake, SP4 (Fig. 3). The mean relative densities of Tubificidae were about 40%–60% in neutral KR7 and ML7, but less than 20% in acidified lakes, SH6, GL5 and SP4. Tubificids made up about 34%–54% of the total oligochaete biomass in the neutral lakes, and less than 5% in the other three lakes.

Gatherers (S) were generally well represented in the oligochaete communities of the lakes. The oligochaete feeding group gatherers (T) were significantly ($p < 0.05$) less frequent in the acidic lakes, than in the neutral lakes (Fig. 4a). Earlier investigations of these lakes (Ilyashuk 1994,1995) showed that species belonging to other macroinvertebrate groups such as Trichoptera, Ephemeroptera, Odonata, Chironomidae, Hirudinea and Mollusca may be assigned to one of the following functional feeding groups: shredders, filterers, scrapers, gatherers (S) and predators, but not gatherers (T). The gatherer (T) shares in the total macroinvertebrate density were 32% in ML7 and 18% in KR7. Whereas in the acidic lakes their shares were 3% or even less. The contribution of gatherers (T) in terms of abundance to the oligochaete assemblages and macroinvertebrate communities is given in Fig. 4b.

The littoral of all lakes was characterized as oligotrophic (EI = 0.04–0.29). However, the mean EI values were significantly ($p < 0.05$)higher in the neutral lakes than in the acidic lakes (Table 5).

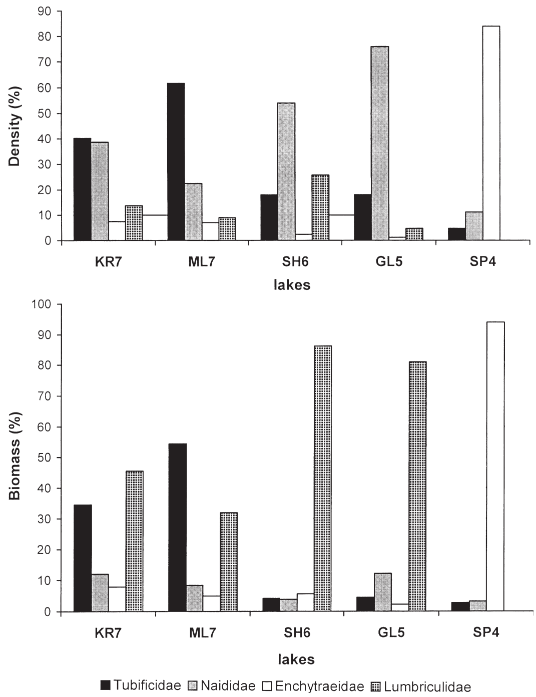

Fig. 3. Mean oligochaete community structure in the studied lakes. The contribution of each major taxonomic group is expressed as a percent of mean density and mean biomass (N = 42 for each lake).

Discussion

The results of this study show that oligochaete worms are acid-tolerant macroinvertebrates. This conclusion is confirmed by the findings of Wiederholm and Eriksson (1977) in Sweden, Meriläinen and Hynynen (1990) in Finland, and McNicol *et al.* (1996) in Canada, who have described oligochaetes in benthos of lakes with water pH = 4.2–4.3. Meanwhile, the density of oligochaetes as well as their biomass were significantly higher in the neutral lakes than in the studied acidic lakes. This corroborates the results of Kullberg (1992), who sampled benthic macroinvertebrates in 20 streams of varying pH (from 4.2 to 8.0) in Norway, and found that oligochaete densities were positively correlated with pH. The increase in oligochaete abundance with increasing pH is in accordance with results of a study of acidic lakes

Table 5. Mean Environmental Index (MEI ± SE) for the littoral zone of lakes for the period of June–October 1992 (N = 42 for each lake).

	Lake				
	KR7	ML7	SH6	GL5	SP4
MEI	0.26 (± 0.06)	0.29 (± 0.08)	0.09 (± 0.05)	0.07 (± 0.05)	0.04 (± 0.06)

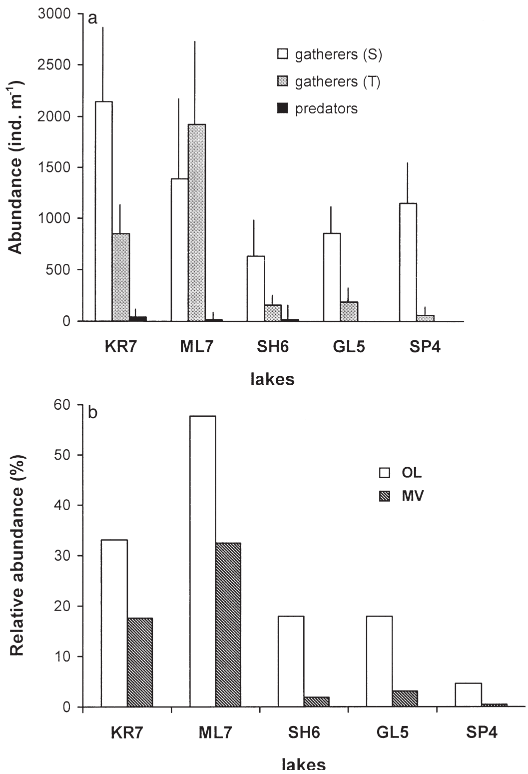

Fig. 4. — a: Mean abundance (±SE) of the functional feeding groups of oligochaetes (*N* = 42 for each lake). — b: Relative abundance of the gatherer (T) functional feeding group for the oligochaete assemblages (OL) and macroinvertebrate communities (MV) in the studied lakes.

in Florida (Crisman *et al.* 1980). After liming of acidified lakes, population density of oligochaetes usually increase in the littoral zone (Keller *et al.* 1990). However, both Raddum (1980), and Harvey and McArdle (1986) reported that oligochaete abundances were similar in acidic and neutral lakes. Such discrepancies may be attributed to the considerable variation in pH tolerance found among oligochaete species (Økland and Økland 1986), or to the differences in other physical-chemical variables of lakes (Lonergan and Rasmussen 1996).

Oligochaetes were the common macroinvertebrates in the littoral zone of all three acidic lakes in this study, but they were not a dominant group in any of them. However, oligochaetes may dominate in benthic communities of acidic streams with pH in the range 4.8–5.9 (Guerold *et al.* 1995).

Distributions of enchytraeids in all our lakes suggest that they tolerate a wide range of pH. Smith *et al.* (1990) also sampled enchytraeids in streams of pH between 4.9 and 6.2. He found the greatest enchytraeid density at pH = 4.9. Moreover, Simpson *et al.* (1985), and Meriläinen and Hynynen (1990) found enchytraeids in streams and forest lakes with pH ≈ 4.4–4.7, and pH = 4.4, respectively. In Russia, oligochaete communities of strongly acidic water bodies with high concentrations of humic substances were characterised by a high dominance of enchytraeids (Popchenko 1988).

Lumbriculids are another acid-tolerant group of oligochaetes. In Ontario, they were found in experimental lakes with pH below 5.8 (Stephenson *et al.* 1994), and in Finnish lakes at pH = 4.3 (Meriläinen and Hynynen 1990). In an oligochaete survey in Russia, lumbriculids were still recorded at pH = 4.2, which was the lowest recorded pH for their occurrence (Popchenko 1988). However, in the present study lumbriculids were not recorded at pH ≈ 4.1–4.2.

Among the naidids observed in this study, the high acid-tolerance of *Vejdovskyella comata* was confirmed by Popchenko (1988), who recorded this species at pH = 4.2.

In the present study, *T. tubifex* proved to be the most acid-tolerant species among tubificids, although Popchenko (1988) recorded a similar pH minimum for *T. tubifex*, *Spirosperma ferox* (for both species pH minimum of 4.8), and *Limnodrilus hoffmeisteri* (pH minimum of 4.6), for their occurrence in water ecosystems in Northern Russia.

Low relative densities and biomass of gatherers (T) in the littoral oligochaete assemblages and macroinvertebrate communities may be an indirect effect of lowered pH in lakes (Ilyashuk 1994, 1996) causing an alteration of quality and quantity of organic material in the sediments. Gatherers (T) of the studied lakes were characterized by a high dominance of *T. tubifex* and *L. hoffmeisteri*. These species feed mainly in thickness of sediments and selectively ingest fine organic particles with attached microflora, but coarse organic particles are less accessible for them (Chekanovskaya 1962, Brinkhurst *et al.* 1972). However, the coarse organic material accumulates in the littoral zone of acidified lakes, which leads to more oligotrophic conditions in this zone (Grahn *et al.* 1974). According to EI values, the trophic conditions for macroinvertebrates in the littoral of acidified lakes, SH6, GL5, SP4, were poorer, than in non-acidic KR7 and ML7. Hence, low relative abundance of gatherers (T) in the oligochaete assemblages and macroinvertebrate communities of the acidified lakes may be a result of oligotrophication in the littoral zone of these lakes.

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Appendix. Presence of oligochaete taxa in samples from littoral of Akkakharsky lakes (+ : < 100 ind. m^{-2}; ++ : 100–300 ind. m^{-2}; +++ : > 300 ind. m^{-2}) and the lowest observed pH limits for species from Popchenko (1988).

Taxon	Lake (pH)					Min. pH
	KR7 (7.1)	ML7 (6.9)	SH6 (5.9)	GL5 (5.3)	SP4 (4.2)	
Naididae						
Stylaria lacustris (Linnaeus)	+	+				4.8; 4.7[1)]
Ripistes parasita (Schmidt)	+++	+				4.6
Vejdovskyella comata (Vejdovsky)	++	+	+++	++	+	4.2
V. macrochaeta (Lastockin)			+	++		
Slavina appendiculata (d'Udekem)	+	+	+	+		5.8
Nais pseudobtusa Piguet	+					6.0
N. communis Piguet	++	+	+	+		4.2
N. pardalis Piguet	+	+++	+	+		6.5; 6.0[3)]
N. elinguis Müller			+	+		6.2; 4.4[2)]
N. simplex Piguet		+				
Specaria josinae (Vejdovsky)	+		+	+++		6.6; 6.0[3)]
Piguetiella blanci (Piguet)	++					6.6
Haemonais waldvogeli Bretscher	+					6.2
Uncinais uncinata (Oersted)	+					5.8
Chaetogaster diaphanus (Gruithuisen)	+	+	+			4.2
Pristina foreli Piguet	+	+	+	+	+	6.2
P. aequiseta Bourne		+	+	+		6.4
P. longiseta Ehrenberg	+	+	+			5.0
Tubificidae						
Aulodrilus limnobius Bretscher		+				5.8
A. pluriseta (Piguet)		+				6.2
Limnodrilus hoffmeisteri Claparede	+	+++	+			4.6; 4.7[1)]
Spirosperma ferox Eisen	++	+				4.8; 4.7[1)]
Tubifex tubifex	+++	+++	++	++	+	4.8
Enchytraeidae						
Enchytraeidae Genus *sp.*	++	++	+	+	++	4.2; 4.4[1)]
Lumbriculidae						
Stylodrilus heringianus Claparede	+++	++	++	+		5.0, 4.5[1)]
Lumbriculus variegatus (Müller)	+		+			4.2

[1)] Meriläinen and Hynynen (1990), [2)] Simpson *et al.* (1985) and [3)] Timm *et al.* (1994).

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