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Lacustrine profundal meiobenthos as an environmental indicator

Jukka Särkkä
University of Jyväskylä, Department of Biology, P.O.B. 35, SF-40351 Jyväskylä, Finland

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Abstract

Organic loading and eutrophy is indicated at profundal depths by large numbers of resting copepodid stages of cyclopoid copepods, by the occurrence of the naidid oligochaete species, *Amphichaeta leydigii* and *Specaria josinae*, and the harpacticoid species *Canthocamptus staphylinus*, and by a low meiobenthos/macrobenthos biomass ratio. An oligotrophic environment is indicated by the occurrence of the aeolosomatid oligochaetes *Aeolosoma quaternarium*, *A. hemprichi* and *Rheomorpha neiswestnovae*, the naidid oligochaete *Chaetogaster langi* and the harpacticoid species *Attheyella crassa* and a high meiobenthos/macrobenthos biomass ratio.

Introduction

The meiobenthos of lakes has been little investigated in comparison with recent developments in marine studies (Pennak, 1988; Moore & Bett, 1989). In contrast to the macrobenthos, meiobenthos species usually have a shorter life cycle, a faster metabolism and quicker reactions to changes in their environment, but they also probably select their food more precisely (Lodge *et al.*, 1988). One notable difference between marine and lacustrine meiobenthos is that where planktonic larval stages of benthic species are found in a marine environment, benthic resting larvae of planktonic species can be an important component of the lacustrine fauna.

Regional differences in environmental conditions in Lake Päijänne caused by anthropogenic influences have been studied in the macrobenthos and meiobenthos, and also in meiobenthic oligochaetes and harpacticoids (Särkkä, 1975, 1979, 1987, 1989). This present paper reports some results derived mainly from the maximum depths, at which the environment for bottom organisms is often most critical.

Site descriptions

The southern and central parts of Lake Päijänne, the deepest (94 m) and second largest lake in Finland, are oligotrophic and clean, but the effects of eutrophication can be seen in certain places, partly accompanied by organic loading from pulp mills (Särkkä, 1979; Granberg, 1987; Meriläinen, 1987). Water quality improves and becomes more oligotrophic from the northernmost part, station 1, towards the south, stations 5 and 6 (Fig. 1), and from the central part of the lake, station 7, southwards to stations 9–11. The northernmost part has a loading of purified urban effluent and waste water from a pulp mill situated 40 km upstream, and the central part receives large amounts of pulp and paper mill effluent. The

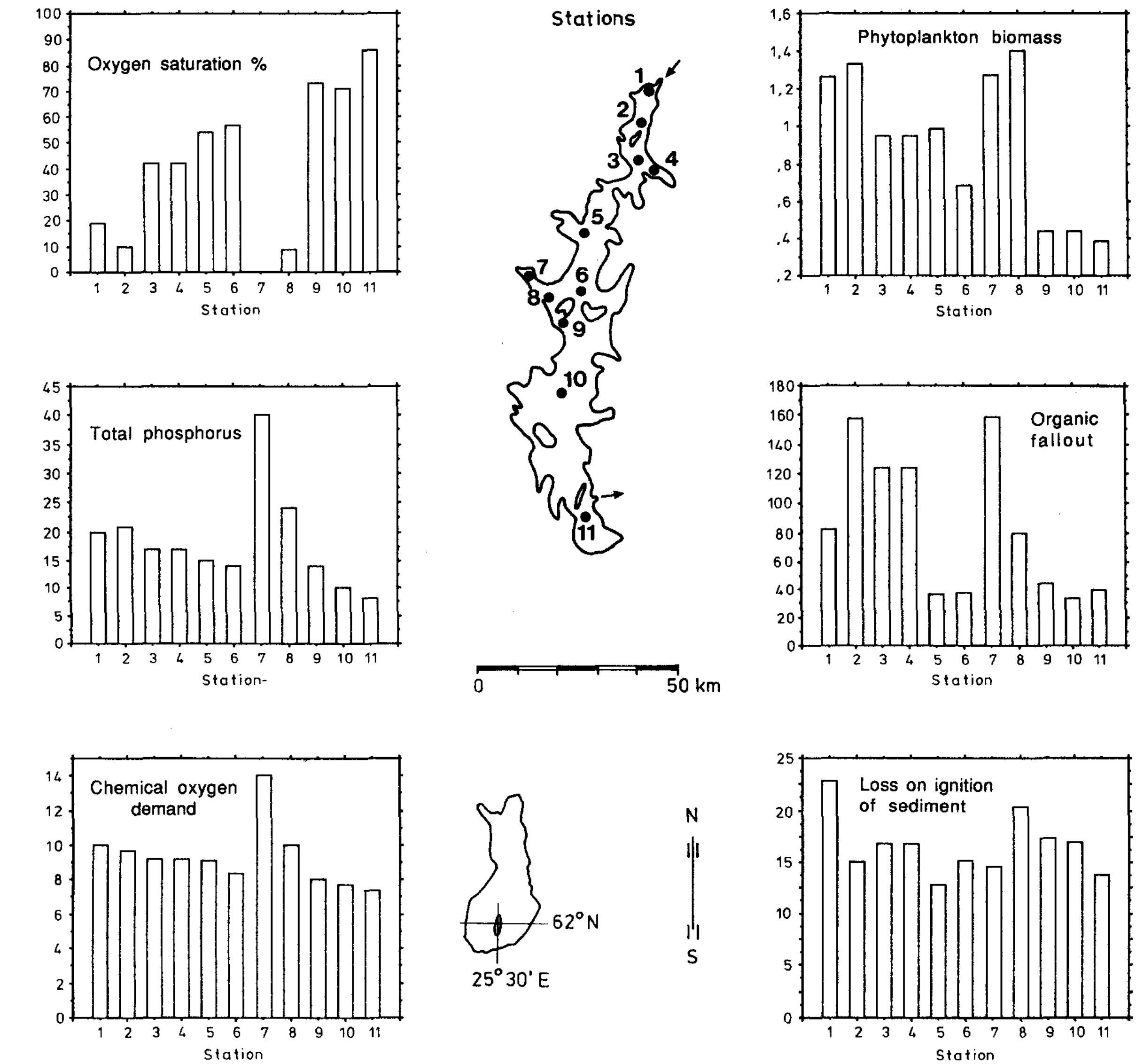

Fig. 1. Lake Päijänne, the sampling stations (1–11) and certain environmental variables. Oxygen saturation %, 1 m above the bottom in March (1984–86), total phosphorus mg m^{-3} in the epilimnion (average annual values 1984–86), chemical oxygen demand in the epilimnion in terms of $KMnO_4$ consumption (mg O_2 l^{-1}, average annual values 1984–86), average phytoplankton biomass (g m^{-3}) in growing seasons 1984–85, annual organic fallout (dry matter g m^{-2} in 1989) and loss on ignition (%) in the surface 1 cm of the bottom sediment.

southernmost part, stations 9–11, is more oligotrophic than the cleanest area of the central part of the lake. Station 4 belongs to the same subarea as station 3 but is deeper (94 m, while St. 3 represents an extensive area of depth 76 m) and thus involves slightly more critical conditions for zoobenthos than station 3.

Material and methods

The samples were collected in May–June, 1986, from a depth of 20 m and from the maximum depths (30–94 m) at 11 stations. The present paper considers the results from the maximum depths. 5 parallel samples, each a 5 cm column, were taken with a Kajak-type corer of inner diameter 45 mm and area 15.9 cm^2, preserved with formaldehyde (4%) and sieved through a 0.080 mm mesh in the laboratory and stained by the method of Thiel (1966). The environmental data were obtained from Granberg (1987), Meriläinen (1987), Maatela *et al.* (1990) and Dr. K. Granberg (pers. com.).

Results

The proportion of resting stages of cyclopoid copepods is highest in the organically polluted and somewhat eutrophicated northern part (88–96% of individuals at St. 1 and 2) and decreases southwards (Fig. 2). Another descending gradient exists from St. 7 towards the east and south. Harpacticoids are more conspicuous in the clean southern part, and the proportion of oligochaetes is high in the southern part, where that of cyclopoids is smaller.

In terms of regional distribution (Fig. 3), in which the differences are clearer at maximum depths than at 20 m, *Attheyella crassa* (Sars) among the harpacticoids and the naidid species *Chaetogaster langi* Bretscher and three aeolosomatid species in particular among the meiobenthic oligochaetes reach their highest numbers in the clean, oligotrophic parts in central (St. 5 and 6)

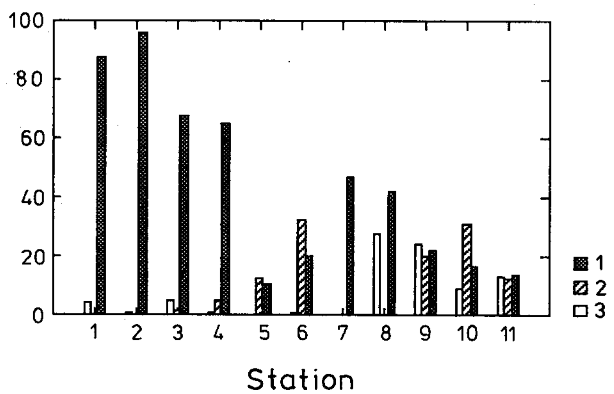

Fig. 2. Abundances of resting copepodid stages of cyclopoids (1), individual harpacticoids (2) and oligochaetes (3) as percentages of total meiobenthos at maximum depths at each station (May–June 1986).

and southern areas (St. 9–11). The northernmost station 1 is organically polluted and eutrophicated in terms of its water quality values, but differs from the two organically loaded, eutrophicated stations of a similar nature in the middle part of the lake (St. 7 and 8) owing to the almost lotic conditions at the narrow northern end. Aeolosomatid oligochaetes increase along a gradient from polluted to clean, although the abundance of *Aeolosoma hemprichi* Ehrenberg is exceptionally high at St. 1. The number of species clearly benefitting from eutrophy and organic loading is quite small, the most obvious being the oligochaetes *Specaria josinae* (Vejdovsky) and *Amphichaeta leydigii* Tauber.

The animals found by meiobenthos methods can be grouped into three categories: 1) true meiobenthos; 2) resting stages of cyclopoid copepods; and 3) mostly meiobenthic-sized individuals belonging to taxonomically macrobenthic groups (chironomids and tubificids). The biomasses of these groups (Fig. 4) are regionally distributed with the macrobenthic animals (mostly small individuals of *Tubifex tubifex* (Müller)) forming the bulk of the biomass in the northernmost St. 1. The resting stages of cyclopoids are well represented at the organically polluted stations 1 and 7 in particular.

The meiobenthos/macrobenthos biomass ratio (Fig. 5) in which the former includes only the true meiobenthos, shows that the true meiobenthos is almost as plentiful as the macrobenthos or even more so in the oligotrophic parts of the lake (St. 5, 6, 9, 10 and 11) (the values for the latter are taken from Särkkä, 1979, since when the situation as regards organic loading and eutrophication has not changed to any essential degree). This ratio seems to reflect the anthropogenic influence brought to bear on lacustrine profundal zone.

Discussion

Earlier research has shown that the resting stages of cyclopoid copepods are highly abundant in areas suffering from an oxygen deficit (Särkkä, 1975, 1979; Paasivirta & Särkkä, 1978), and these

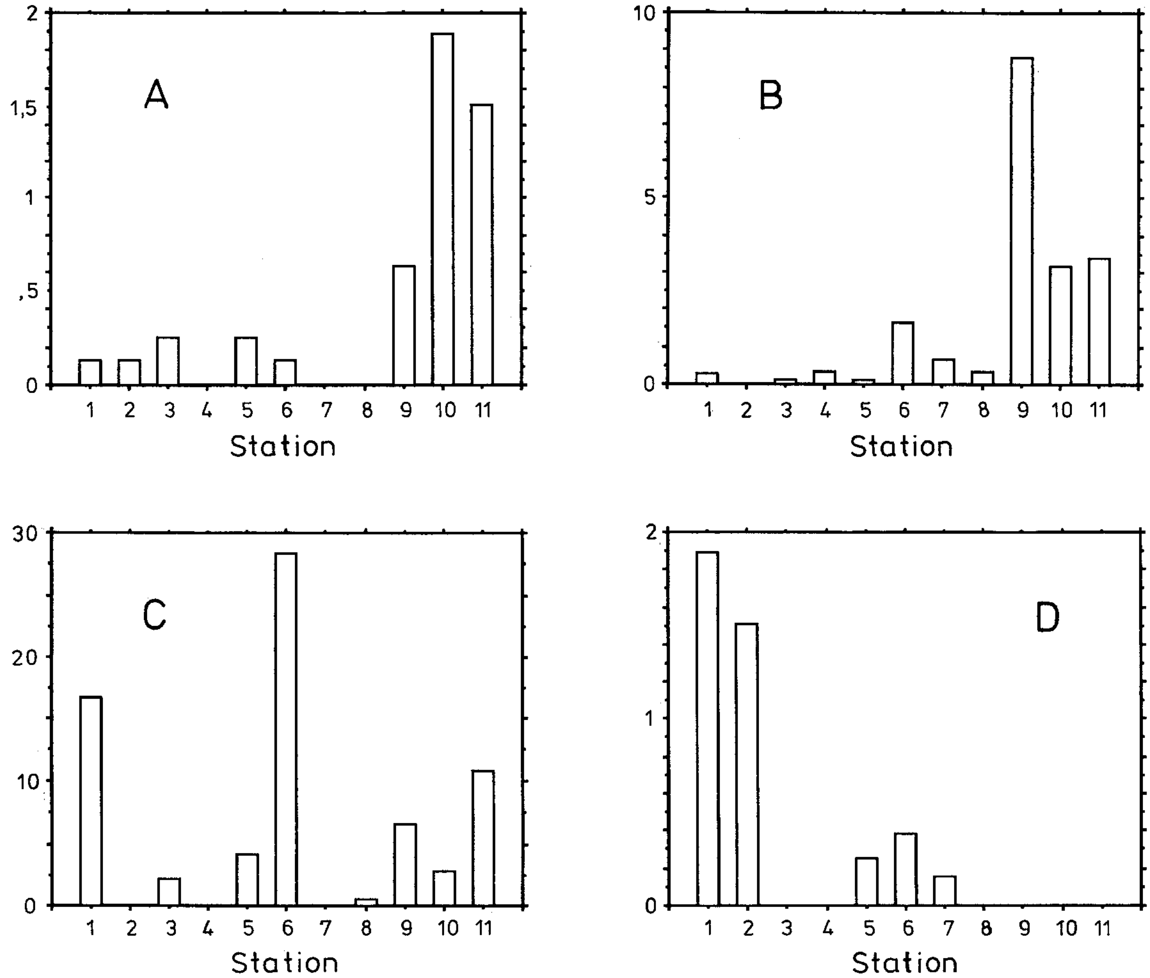

Fig. 3. Regional distributions (ind. 10 cm^{-2}) of *Attheyella crassa* (A), *Chaetogaster langi* (B), Aeolosomatidae (*Aeolosoma hemprichi* + *A. quaternarium* + *Rheomorpha neiswestnovae*) (C) and *Specaria josinae* (D). A and B from maximum depths, C and D from a depth of 20 m. Note the different scales. (May–June 1986).

cyclopoids can be dominant in the most seriously loaded areas (Fig. 2). Thus, it seems in general that a large number of resting cyclopoids could be used as the sole indicator of eutrophic, organically loaded or poorly oxygenated conditions. The low oxygen content near the bottom prevents predation by fish, although these may be replaced by another predator, larvae of *Chaoborus flavicans* (Meigen) (Särkkä, 1979). Marked seasonal variation can be seen in the numbers of resting cyclopoids, however, at the time when the 5th instar copepodids are changing their environment from benthic to planktonic, the numbers on the bottom being greatest in winter. The species found on the bottom are not often known, but in Lake Päijänne the most abundant species in spring are *Diacyclops languidoides* (Lilljeborg) and *D. nanus* (Sars), *Cyclops kolensis* Lilljeborg and *Mesocyclops leuckarti* Claus. The proportion of species belonging to the more benthic Eucyclopinae (*Paracyclops fimbriatus* (Fischer) and *Eucyclops serrulatus* (Fischer)) is in general very small as compared with the resting stages of the Cyclopinae.

Harpacticoids are absent when the oxygen content is zero or near zero, as at St. 7 and 8, but in cleaner areas their abundance amounts to about

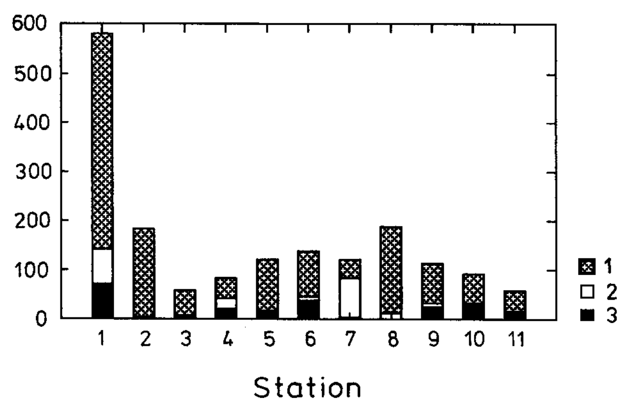

Fig. 4. Regional distribution of biomass (dry weight mg m^{-2}) of meiobenthos-sized individuals of macrobenthic species (1), resting stages of cyclopoids (2) and true meiobenthos (3) at maximum depths.

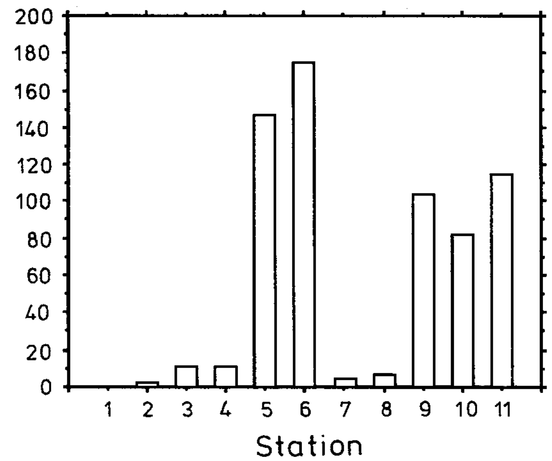

Fig. 5. Regional distributions of the meiobenthos/macrobenthos biomass ratio (%) at maximum depths. Meiobenthos without resting cyclopoids and macrobenthic groups, macrobenthos as winter values from Särkkä (1979).

13–33% of the total. Of oligochaetes, the species favouring pollution are generally of macrobenthic size, but many species of meiobenthic size prefer oligotrophic conditions, where the families Naididae and Aeolosomatidae in particular are represented, but not Tubificidae.

Little information has been acquired on the relation of meiobenthic species to the environment. Aeolosomatid and naidid oligochaetes have been assumed to represent environments other than the profundal depths of lakes (littoral zone, lotic waters and small water basins). However, 20 species of oligochaetes were found in the present study, of which 9 species belong to the family Naididae and 3 species to Aeolosomatidae, and species-level differences exist within these groups. While within naidids there are species preferring either oligotrophic or eutrophicated environments (Fig. 3), all 3 aeolosomatid species (*Aeolosoma hemprichi*, *A. quaternarium* Ehrenberg and *Rheomorpha neiswestnovae* (Lastochkin)) prefer oligotrophic environments (cf. Särkkä, 1989). Of the harpacticoids, the profundal species are also known for a very small number of lakes, but *Canthocamptus staphylinus* (Jurine), when found in as high numbers at profundal depths, seems to be an indicator of organic loading. The harpacticoid species *Attheyella crassa* and *Paracamptus schmeili* (Mrazek) are the clearest indicators of oligotrophy on profundal bottoms, while *Bryocamptus minutus* (Claus) and *Moraria brevipes* (Sars) seem to have a somewhat larger amplitude on the oligotrophy-eutrophy scale (Särkkä, 1987), and *Bryocamptus echinatus* (Mrazek) prefers oligotrophic and mesotrophic conditions.

Resting cyclopoids and small individuals of macrobenthic groups form the bulk of the biomass obtained by the meiobenthos method (Fig. 4), while the true meiobenthos makes up only a small proportion. This shows that the total biomass as such is not sufficient if one needs meiobenthos values for depicting the anthropogenic influence, and a species-level identification, or at least the separation of resting cyclopoid copepodids and macrobenthic groups from the true meiobenthos, is recommendable. Total biomass was seen here to be highest at St. 1, but the semilotic conditions must be one reason for the large number of small tubificids. In other parts of the lake the total biomass does not show any distinct dependence on environmental variables.

The biomass ratio (Fig. 5), which is much higher in unchanged than in changed environments, has been shown to depict anthropogenic influence (Paasivirta & Särkkä, 1978; Kurashov & Belyakov, 1987). This ratio is correlated with a number of environmental variables (Table 1),

Table 1. Correlations between the meiobenthos biomass/macrobenthos biomass ratio at maximum depths and certain water and sediment quality values. Meiobenthos biomass values are exclusive of resting stages of cyclopoids and macrobenthic taxa, macrobenthos biomass values are winter values according to Särkkä (1979).

Pearson correlation with	*r*	*p*
Oxygen saturation %	+ 0.76	0.019
COD	− 0.59	0.095
Total phosphorus	− 0.64	0.065
Phytoplankton biomass	− 0.68	0.045
Sedimentation rate	− 0.77	0.016
Loss on ignition	− 0.44	0.242
Organic fallout	− 0.84	0.004

the most significant of which is oxygen content near the bottom (Fig. 6). This ratio also needs a distinction between true, temporary and taxonomically macrobenthic elements in the meiobenthos.

The diversity and number of species are in general higher in oligotrophic and clean waters than in eutrophic or loaded environments, as can be seen both in the group diversity values quoted earlier by Särkkä (1979) and in the present material, in which these variables are presented for certain taxonomic groups only (Fig. 7, Table 2).

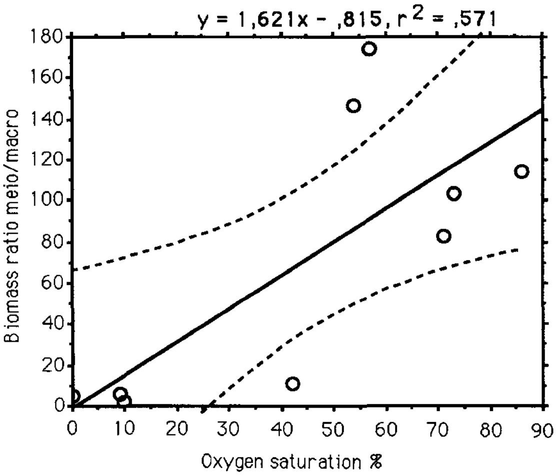

Fig. 6. Relationship of meiobenthos/macrobenthos biomass ratio (%) at maximum depths to oxygen saturation near the bottom (%) at the sampling stations. $r = 0.756$, $p = 0.019$.

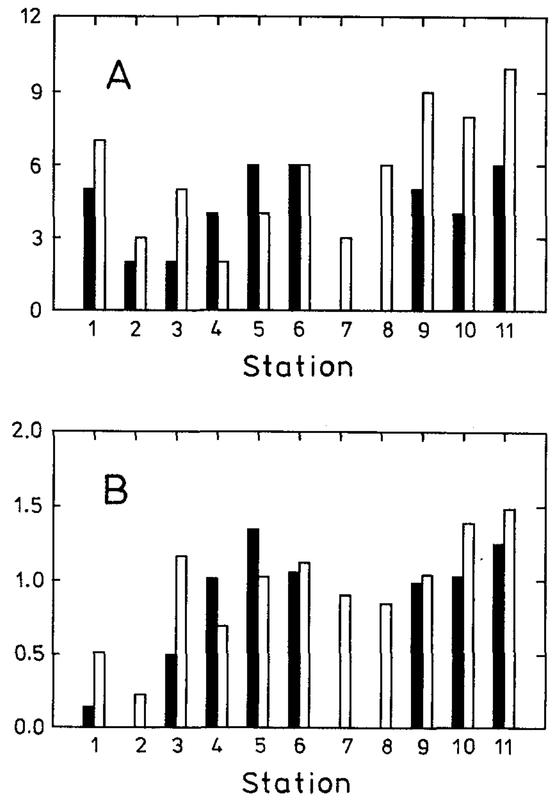

Fig. 7. Regional distributions of numbers of species (A) and diversity (B, Shannon index, ln based) of Oligochaeta (open bars) and Harpacticoida (filled bars) at maximum depths at different stations.

Table 2. Ranges of values for diversity (Shannon, ln based) and number of species of Harpacticoida and Oligochaeta at eutrophicated or organically polluted stations (Stat. 2, 3, 4, 7 and 8) and at oligotrophic stations (Stat. 5, 6, 9, 10 and 11). The semi-lotic station 1 is omitted.

	Eutrophicated stations	Oligotrophic stations
Diversity of Harpacticoida	0–1.01	0.98–1.34
Number of species of Harpacticoida	0–2	4–6
Diversity of Oligochaeta	0.23–1.17	1.03–1.48
Number of species of Oligochaeta	2–6	4–10

Thus, although from a practical point of view it may be sufficient to identify the animals to genus or family level in pollution studies, as proposed by Herman & Heip (1988), the stations can also be separated using values based on certain classes or orders only. The diversity within oligochaetes is on average higher (mean 0.95) than that within harpacticoids (mean 0.66) and this may suggest that oligochaetes as a group are better adapted to living on the profundal bottoms of lakes than harpacticoids.

Warwick (1986) has shown that the Species Abundance Biomass or ABC curves depicting cumulative abundance/biomass ratios are good indicators of the anthropogenic influence in marine environments. This is based on the assumption that large K-selected species dominate in terms of biomass but not numerically in undisturbed areas whereas small r-selected species dominate numerically but not in terms of biomass in disturbed or polluted areas. When calculated for different sampling stations in Lake Päijänne, however, this ratio does not seem to behave as predicted (e.g. Fig. 8 from stations 1 and 5), as the biomass curve for unpolluted parts of the lake often lies below the abundance curve, contrary to the situation in marine benthos. It is possible, however, that there may be differences between meiobenthos and macrobenthos as also between marine and lacustrine environments, and the data of Warwick (1986) mainly apply to marine macrobenthos. Also, the present ABC values were based on group-level figures which may behave differently from the species-level values used by Warwick.

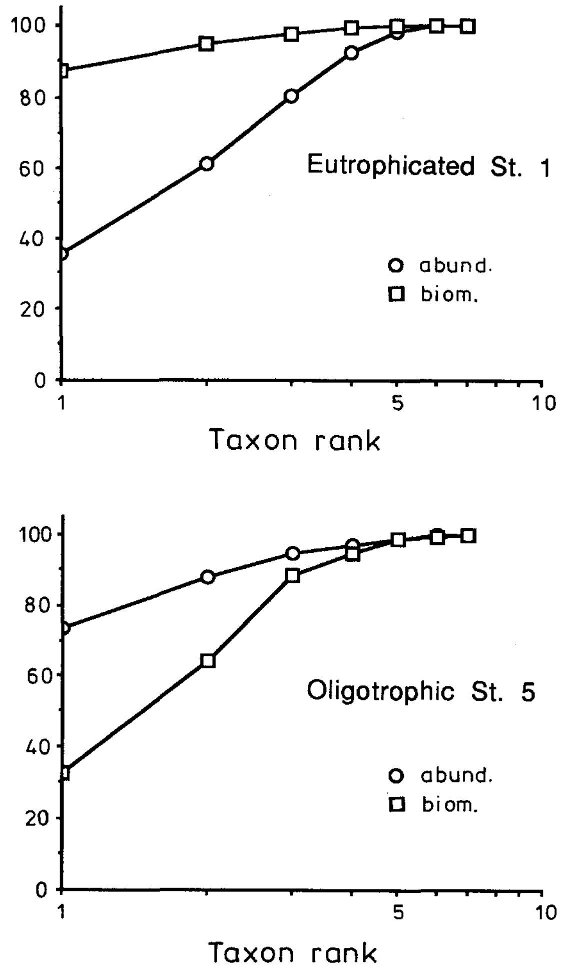

Fig. 8. Cumulative abundance and biomass curves (%) at maximum depths at the eutrophicated St. 1 and the oligotrophic St. 5. Meiobenthos without resting cyclopoids.

Meiobenthos seems to deserve greater attention for the investigation of regional effects of anthropogenic loading in lakes, particularly in the profundal. One of the clearest environmental indicators seems to be the meiobenthos/macrobenthos biomass ratio. However the differences in the regional abundance of certain species of meiobenthic oligochaetes and the numbers of species of harpacticoids also serve to depict the state of the environment. Use of the latter figures has nevertheless been limited by lack of information on the profundal meiobenthic species and their characteristic environments and environmental requirements.

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References

Granberg, K., 1987. Phytoplankton of Lake Päijänne. Biol. Res. Rep. Univ. Jyväskylä 10: 77–85.

Herman, P. M. J. & C. Heip, 1988. On the use of meiofauna in ecological monitoring: who needs taxonomy? Mar. Pollution Bull. 12: 665–668.

Kurashov, Y. V. & V. P. Belyakov, 1987. Role of meiofauna in benthic communities of lakes of various types in the Lattgalian Hills. Hydrobiol. J. 23: 46–50.

Lodge, D. M., J. W. Barko, D. Strayer, J. M. Melack, G. G. Mittelbach, R. W. Howarth, B. Menge & J. E. Titus, 1988. Spatial heterogeneity and habitat interactions in lake communities. In S. R. Carpenter (ed.), Complex Interactions in Lake Communities. Springer-Verlag, New York, Berlin, Heidelberg: 181–208.

Maatela, P., J. Paasivirta, J. Särkkä & R. Paukku, 1990. Organic chlorine compounds in lake sediments. II. Organically bound chlorine. Chemosphere 21: 1343–1354.

Meriläinen, J. J., 1987. The profundal zoobenthos used as an indicator of the biological condition of Lake Päijänne. Biol. Res. Rep. Univ. Jyväskylä 10: 87–94.

Moore, C. G. & B. J. Bett, 1989. The use of meiofauna in marine pollution impact assessment. Zool. J. Linnean Soc. 96: 263–280.

Paasivirta, L. & J. Särkkä, 1978. Effects of pulp mill and municipial effluents and humus load on the macro- and meiozoobenthos of some Finnish lakes. Verh. int. Ver. Limnol. 20: 1779–1788.

Pennak, R. W., 1988. Ecology of the freshwater meiofauna. In R. P. Higgins & H. Thiel (eds), Introduction to the Study of meiofauna. Smithsonian Institute Press, Washington, D.C., London: 39–60.

Särkkä, J., 1975. Effects of the pollution on the profundal meiofauna of Lake Päijänne, Finland. Aqua Fenn. 5: 3–11.

Särkkä, J., 1979. The zoobenthos of Lake Päijänne and its relations to some environmental factors. Acta Zool. Fenn. 160: 1–46.

Särkkä, J., 1987. Meiobenthos of the profundal depths of Lake Päijänne. Biol. Res. Rep. Univ. Jyväskylä 10: 95–104.

Särkkä, J., 1989. Meiobenthic naidid and aeolosomatid oligochaetes from the profundal zone, and relations of species to eutrophication. In J. L. Kaster (ed.), Aquatic Oligochaete Biology IV. Developments in Hydrobiology 51. Kluwer Academic Publishers, Dordrecht: 185–190. Reprinted from Hydrobiologia 180.

Thiel, H., 1966. Quantitative Untersuchungen über die Meiofauna des Tiefseebodens. Veroff. Inst. Meeresforsch. Bremerhaven, Sonderb. 2: 131–147.

Warwick, R. M., 1986. A new method for detecting pollution effects on marine macrobenthic communities. Mar. Biol. 92: 557–562.