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Planktonic and zoobenthic communities in an oligotrophic, boreal lake inhabited by an endemic and endangered seal population

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In order to assess the present biological state and to give some guidelines for the planned monitoring of Pihlajavesi, one of the most important habitats for the threatened endemic relict Saimaa ringed seal (*Phoca hispida saimensis* Nordq.), the main communities of phytoplankton, zooplankton and benthic invertebrates were described using multivariate statistical analyses. The composition of phytoplankton assemblages was mainly determined by the nutrient concentration and the colour of the water so that the phytoplankton community of a clear-water basin differed in this lake from those of the other basins. In contrast there were no such differences in zooplankton assemblages between the basins, but the distinct difference between the pelagic and littoral communities was evident. The water depth and related parameters, such as bottom quality, were the most important factors affecting on zoobenthic assemblages. Species composition changed gradually with increasing depth, the rate of the change being greatest in the littoral area. The following soft bottom communities were distinguished from the lake: vegetated littoral (1–3 m), sublittoral (3–10 m), upper profundal (10–20 m) and deep profundal communities. The deep profundal assemblage in the effluent-loaded basin differed from that in other basins to such an extent that it could be considered to form a distinct community of its own. Special features of the communities resulting from the high transparency of water are discussed.

Introduction

Phytoplanktonic, zooplanktonic and zoobenthic communities in the oligotrophic Pihlajavesi, a large basin of the Saimaa lake complex, were studied in 1995–1996 in order to assess the present biological state of the lake and the impact of effluent loading. Pihlajavesi receives effluent loading from a chemical wood-processing industry in the town of Varkaus, some 50 km upstream from the lake, and municipal effluent from the town of Savonlinna.

According to Jumppanen (1976) the lake biota indicated eutrophy in areas around Savonlinna in the 1970s as a result of the discharge of untreated effluent from the town. The loading decreased considerably after 1978, when a water treatment plant was built in Savonlinna (Jumppanen 1992). The effluent loading from Varkaus began to decrease in the 1970s so that the water quality in the first recipient basin, Haukivesi, upstream from Pihlajavesi, was improved and the biological condition of the basin started to recover in the 1980s (Meriläinen and Marttila 1997). Comprehensive data on the ecosystem of the Saimaa lake complex is available from several main basins (Hakkari 1985), but not from Pihlajavesi, except for the publications of Jumppanen cited above. The present study forms the basis for the future biological monitoring of the lake.

Knowledge about the biological condition of the lake and its future development is urgently required, since Pihlajavesi is one of the most important habitats for the Saimaa ringed seal (*Phoca hispida saimensis* Nordq.). This endemic relict is the most threatened seal species in the world, and has a total population of only 200–220 individuals, of which about 25% inhabit Pihlajavesi (Helle *et al*. 1983, Hyvärinen and Sipilä 1984, Sipilä *et al*. 1990). The present seal population has been estimated to be only 5%–10% from the original population of Lake Saimaa (Hyvärinen and Sipilä 1992).

Although the effluent loading from the treatment plants has decreased, the rapidly increasing recreational activities around the lake pose a considerable threat to the lake ecosystem and especially to the seal population. The South Savo Regional Environmental Centre has estimated that the number of summer cottages in the lake area will soon increase up to 6 000 from the present number of 2 000.

Study area

Pihlajavesi, 490 km^2, is a part of the Saimaa lake complex, the main lake of the Vuoksi water system discharging into Lake Ladoga in Russia (Fig. 1). The drainage area of Pihlajavesi is 55 092 km^2 with a lake percentage of 18.5%. The mean inflow into the basin is relatively high, about 480 m^3 s^{-1}, and for this reason the theoretical retention time is short, only three weeks. The lake is divided into eight basins, all of which were studied here. The maximum depths of the basins are ca. 30 m (two), 40 m (one), 50 m (three) and 65–70 m (two).

The northern parts of the lake formerly received untreated effluent from the town of Savonlinna and effluent from a pulp and paper mill in the town of Varkaus, some 50 km upstream. For example in 1972 the daily load of sewage averaged 4 700 m^3 and the total amount of effluent discharging into the lake corresponded to a BOD load of 100 000 people (Jumppanen 1976). The effective wastewater treatment in the 1980s led to a rapid decrease in loading, which considerably improved the water quality even in the immediate vicinity of Savonlinna (Jumppanen 1992). The present nutrient status of the lake is low (Table 1). The water in the northernmost basins is slightly brown-coloured by humic substances, while the eastern basins are characterized by clear water with a high transparency. According to the chemical quality criteria presented by the National Board of Waters and Environment (Heinonen and Herve 1987), the pelagic water quality is excellent in all the eight basins of the lake.

Material and methods

Phytoplankton and zooplankton were sampled on seven occasions from one pelagic and two littoral sites, including stony and vegetated shores in Hirkivenselkä and Kokonselkä basins in 1995, and nine times from Kokonselkä and eight from Väistönselkä basin in 1996 (Fig. 1). Since the species composition in the Hirkivenselkä basin appeared to be very similar to that of Kokonselkä, the clear-

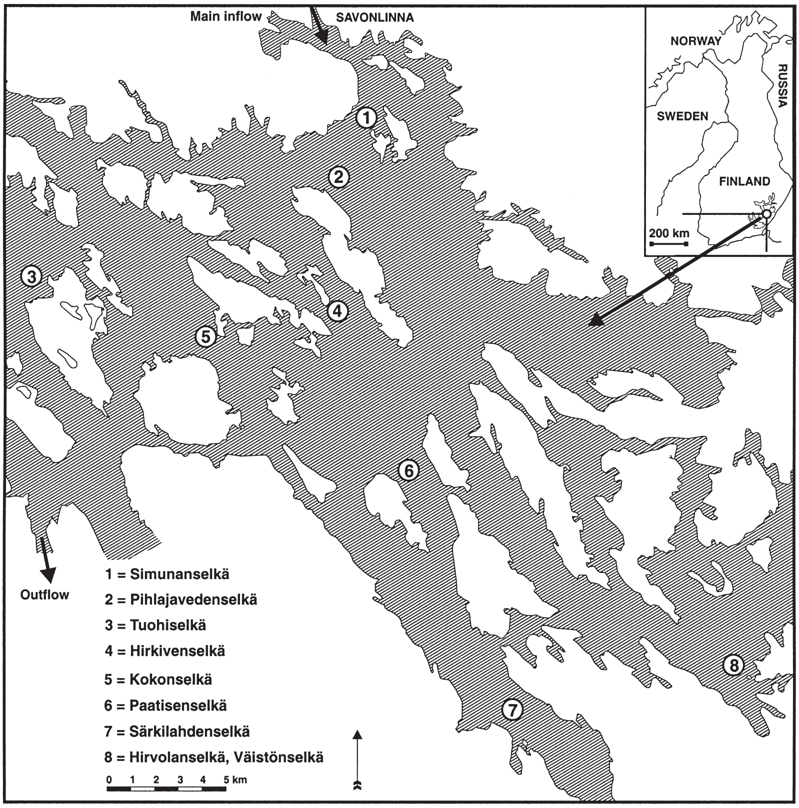

Fig. 1. Location of Pihlajavesi and sampling sites.

water Väistönselkä area was selected for study instead of Hirkivenselkä in 1996.

Pelagic phytoplankton samples were taken from 0–4 m as composite samples without replicates and pelagic zooplankton from 0–5, 5–10 and 10–20 m depth zones with a Limnos plankton sampler (volume seven litres), three replicates on each occasion. Littoral plankton was sampled from 0–1 m with a Ruttner sampler. Zooplankton samples were divided into appropriate subsamples in the laboratory by a Folsom device. In one half of the sampling occasions the replicates were analysed separately, and in another half of occasions the replicates were combined. The phytoplank-

Table 1. Annual average water quality in the water column, hypolimnetic oxygen minimum and the chlorophyll-*a* concentration (0–2 m) in the research area in years 1995–1996. Numbers in parentheses relate to location of sampling area in Fig. 1.

Station	O_2-min. (mg l^{-1})	Alkal. (mmol l^{-1})	pH	Colour (mgPt l^{-1})	COD_{Mn} (mg O_2 l^{-1})	Cond (mS m^{-1})	Tot. N (µg l^{-1})	Tot. P (µg l^{-1})	Chl. *a* (µg l^{-1})
Simunanselkä (1)	8.9	0.14	6.7	34	7.7	4.9	–	7.7	3.3
Pihlajavedenselkä (2)	6.8	0.14	6.7	33	7.6	4.9	444	9.2	3.6
Tuohiselkä (3)	8.6	0.14	6.7	33	7.4	4.9	451	7.7	3.4
Hirkivenselkä (4)	7.0	0.14	6.6	37	7.8	4.9	470	8.2	4.0
Kokonselkä (5)	8.9	0.14	6.8	32	7.2	4.9	463	7.6	3.9
Paatisenselkä (6)	8.0	0.14	6.8	31	7.2	4.9	466	7.4	3.5
Särkilahdenselkä (7)	7.8	0.14	6.8	29	6.7	5.0	469	6.8	2.9
Väistönselkä (8)	3.0	0.15	6.8	12	4.3	5.2	356	5.6	3.5

ton biomass was measured as wet weight. The zooplankton biomass (WW) was calculated using the mean volumes of species presented in the literature (Naulapää 1966, Bottrell *et al.* 1976, Hakkari 1978).

The relative precision of the density and biomass of a single zooplankton sample was estimated by examining the relative standard error of mean density and biomass of the replicates. The relative standard error of the mean density was often < 10% and in almost every case < 20% in pelagic areas, but higher in littoral areas. The precision of biomass was not as good as that of density. The relative standard error of the biomass estimate was in some cases < 20%, and in most cases < 30% in the pelagic areas, but considerably higher in the littoral areas (40%–60%).

Comprehensive benthic invertebrate material, including all the hypothetical depth zones usually distinguished from a lake bottom, were sampled from three basins (Pihlajavedenselkä, Kokonselkä and Väistönselkä, Fig. 1) in May and September. The sampling covered the littoral, soft bottom area partly covered with vegetation (1–3 m), the sublittoral zone (3–10 m), the upper profundal zone (10–20 m), and the deep profundal area (80%–100% of maximum depth). Only the deep profundal zone was sampled from five other basins of the lake in September.

The quantitative samples were taken with an Ekman grab (289 cm^3) and processed at the laboratory according to the Finnish standard SFS 5076 (sieve 0.5 mm). The biomass of the animals was measured as wet weight (WW). The number of grab samples needed in deep profundal area was estimated to be 10 (Veijola *et al.* 1996). In order to ensure high comparability of the results, the equivalent bottom area (10 grab samples) was studied from each depth zone (stratified random sampling). The total number of Ekman-samples was 290. The standard error of the mean density of benthos was relatively low, usually below 20%, while that of the mean biomass was somewhat higher.

The mobile zoobenthos was studied in sublittoral and profundal areas according to Bagge *et al.* (1996) using vertical net (mesh size 405 µm, area 0.56 m^2) and plexiglass traps with fish bait or a yellow luminance light stick. The number of vertical net replicates in a basin ranged from six to eight.

The phytoplankton trophic index (Järnefelt's EV/OV index, later expressed as PTI), showing the volume of eutrophic and oligotrophic taxa, was calculated according to Järnefelt (1952, 1956) and Järnefelt *et al.* 1963) including the modifications of Heinonen (1980). The zooplankton trophic index (Järnefelt's E/O index, ZTI), was calculated from species frequencies according to Järnefelt *et al.* (1963) and Hakkari (1978). Shannon's diversity index, H' (Shannon and Weaver 1949), and Simpson's diversity index, λ (Simpson 1949), were expressed as $e^{H'}$ and $1/\lambda$, which can be considered as the number of abundant and the number of very abundant species (*see* Hill's family of diversity numbers, Hill 1973). The communities were analysed with the principal components analysis (PCA, Euclidian distance measure) and detrended correspondence analysis (DCA) using Canoco-software (ter Braak 1988). The biological state of deep profundal areas was estimated by the Benthic Quality Index (BQI) based on the chironomid fauna (Wiederholm 1980).

Results

Phytoplankton

A total of 195 phytoplankton taxa were recorded (Appendix 1). The number of species was highest in the Chlorophyceae (63), Chrysophyceae (39) and Diatomophyceae (38). The species lists are given in the Finnish research report of the project (Hynynen *et al.* 1997).

The number of taxa was lowest at the beginning of the growing season ranging from 26–54 in the sites studied, and highest in August-September (37–72). The mean number of abundant and very abundant species were slightly higher in the littoral than in pelagic sites. Low values of the PTI indicated oligotrophy in all pelagic and littoral sites (Table 2).

The mean pelagic biomass varied from 460 mg m^{-3} to 580 mg m^{-3} (Fig. 2), and was almost equal in littoral areas (440–670 mg m^{-3}). The growing season biomass in the 0–4 m water layer was bimodal in Hirkivenselkä and Kokonselkä and unimodal in Väistönselkä, where the maximum biomass occurred in July–August. Although the phytoplankton biomass was relatively low, the mid-

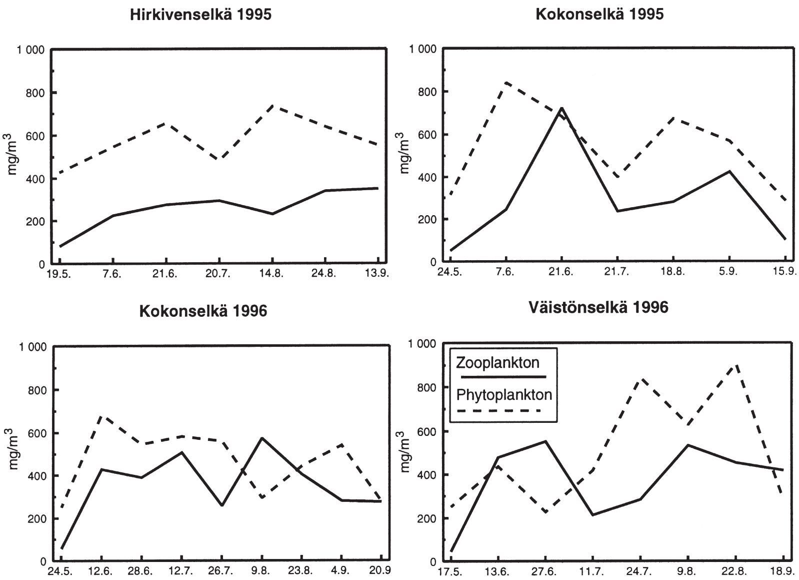

Fig. 2. Mean phytoplankton and zooplankton biomass (WW) in pelagial sites of Pihlajavesi in 1995 and 1996.

summer biomass in the pelagic stations indicated mesotrophy, early eutrophication, according to the classification of Heinonen (1980).

PCA ordination shows that the differences between the phytoplankton assemblages of pelagic and littoral sites were rather small (Fig. 3). The communities of Väistönselkä basin, however, differed to some extent from those of the other basins, which was indicated e.g. by a lower PTI value compared to the other areas. The differences between pelagic and littoral sites were small especially in the Väistönselkä. It is thus possible to distinguish two phytoplankton communities: one of the clear-water basin, and a second characteristic of the other basins. The correlation between the first ordination axis and the water quality parameters was high, and the factors having the strongest influence on phytoplankton communities were nutrient concentration and the colour of the water (Table 3). A weak habitat differentiation is found along the second ordination axis.

The phytoplankton biomass of Hirkivenselkä and Kokonselkä consisted mainly of Cryptophyceae, Chrysophyceae and Diatomophyceae, and a major part of the pelagic biomass in Väistönselkä consisted of chrysophyceans, which are typical of oligotrophic waters. Diatoms were abundant in littoral sites (Appendix 1). The most abundant taxa in all sites were *Cryptomonas* sp., *Rhodomonas lacustris* Pashcher and Ruttner, *Chrysochromulina* sp., *Uroglena* sp., *Pseudopedinella* sp., and *Rhizosolenia longiseta* Zach. *Aphanizomenon flos-aquae* (L.) Ralfs, *Asterionella formosa* Hassall and *Tabellaria fenestrata* (Lyng.) Kütz. were occasionally abundant in Hirkivenselkä and Kokonselkä. The biomass of blue-green algae was very low in Väistönselkä, while some taxa characteristic to oligotrophic waters such as *Quadri-*

Table 2. Characterization of pelagic phytoplankton assemblages in three basins of Pihlajavesi in 1995–1996; mean values for growing season.

	Hirkivenselkä	Kokonselkä	Väistönselkä
Number of taxa	103	106	103
No. of abundant taxa	14.6	15.6–18.4	17.0
No. of very abundant taxa	8.2	10.0–11.6	11.7
Biomass (mg m^{-3})	580	440–540	500
Phytoplankton Trophic Index	0.31	0.23–0.50	0.19

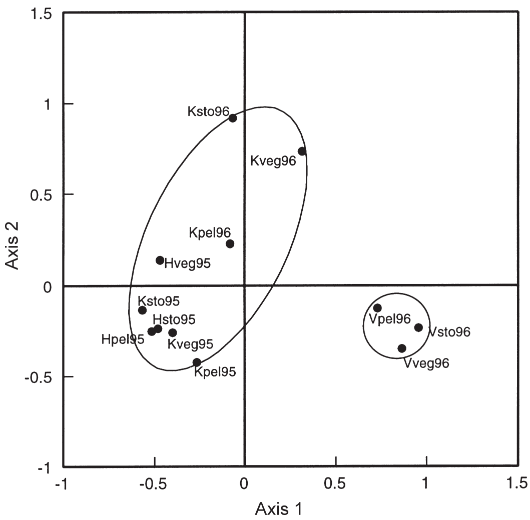

Fig. 3. Ordination (PCA) for the phytoplankton of Pihlajavesi based on mid and late summer (second half of July–end of September 1995–1996) mean biomass (logarithmic transformation). Abbreviations of sampling sites: H = Hirkivenselkä basin, K = Kokonselkä basin, V = Väistönselkä basin; pel = pelagial, sto = stony shore, veg = vegetation shore. Axis 1 was considered as oligotrophy-eutrophy axis. The percentage variance accounted by the first axis was 40% and by the first and second axis 47%.

gula pfitzeri (Schröder) G. M. Smith and *Cyclotella kuetzingiana* Thwaites were more abundant there than in the other sites.

Table 3. Correlation between water quality parameters and species axes 1 and 2 in the ordination (PCA) analysis for phytoplankton (mean biomass of the second half of July–end of September). * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

	Axis 1	Axis 2
Alkalinity (mmol l^{-1})	0.878***	–0.346
pH	0.575**	0.091
Colour (mgPt l^{-1})	–0.894***	0.287
COD (mg O_2 l^{-1})	–0.888***	0.316
Conductivity (mS m^{-1})	0.843***	–0.436
$NO_2 + NO_3$ (µg l^{-1})	–0.880***	0.221
Total nitrogen (µg l^{-1})	–0.902***	0.280
Total phosphorus (µg l^{-1})	–0.888***	0.399

Zooplankton

A total of 87 zooplankton taxa were recorded of which 59 were found in Hirkivenselkä, 62 in Väistönselkä and 80 in Kokonselkä. The higher number of taxa in Kokonselkä was at least partly due to two years of sampling. The mean number of very abundant species varied from four to eight and the mean number of abundant species from 5–12 (Table 4). The ZTI varied between 0.22–0.40 in pelagic sites (Table 4), which, according to Hakkari (1978), indicates an oligotrophic state (< 0.5).

Pelagic zooplankton biomass was highest in the 0–5 m depth zone, and the biomass of the 10–20 m depth zone was markedly lower than that of the 0–10 m depth zone (Fig. 4). The mean biomass at 0–20 m varied between 280–360 mg m^{-3}, of which copepods comprised 40%–50%. The mean biomass was usually 200–400 mg m^{-3} in littoral areas, and the proportion of cladocerans and rotifers was higher than in pelagic areas (Table 4).

Based on the PCA ordination the pelagic and the littoral sites could be clearly distinguished from each other (Fig. 5), but no marked differences were found in the littoral communities between stony and vegetated sites. The dominant species in pelagic communities were *Daphnia cristata* Sars and *Eudiaptomus* spp. *Daphnia* in particular is known to be abundant in areas dominated by small sized alga, as in the northern part of Lake Saimaa (Karjalainen *et al*. 1993). *Acroperus harpae* (Baird), *Alona* spp., *Alonella nana* (Baird), *Alonopsis elongata* Sars, *Ceriodaphnia* spp., *Eurycercus lamellatus* (O.F.M.), *Peracantha truncata* (O.F.M.), *Sida crystallina* (O.F.M.) and *Diacyclops bicuspidatus* (Claus) were found only in littoral areas.

Temporal variation in the pelagic phytoplankton and zooplankton biomasses was synchronous with a certain delay in the development of the zooplankton. An increasing phytoplankton biomass in spring was followed by an increase in zooplankton, which in turn caused a decrease in phytoplankton biomass. Following the decline in the amount of food the zooplankton biomass dropped and the phytoplankton biomass began to rise again (Fig. 2).

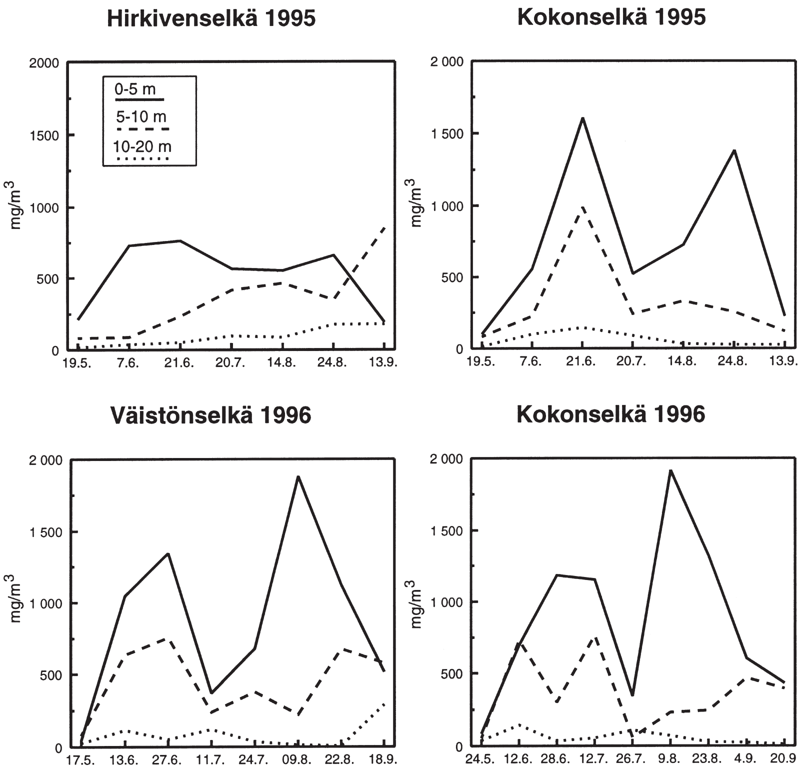

Fig. 4. Zooplankton biomass (WW) in the pelagial areas of Hirkivenselkä, Kokonselkä and Väistönselkä in 1995 and 1996.

Benthic invertebrates

The combined soft bottom material comprised 168 taxa and included 62 dipteran species, mainly chironomids. The rest of the fauna was composed of Acari (33 taxa), Trichoptera (20), Oligochaeta (13), Sphaeriidae (10), Gastropoda (8), Ephemeroptera (7), Crustacea (5), Hirudinea (3) and other invertebrate groups, such as Turbellaria, Coleoptera and Megaloptera represented by a few species. Detailed data on the mean density, mean biomass and biotic indices at the different sampling sites are given in Appendices 2 and 3. The species level data are presented in the research report (Hynynen *et al.* 1997).

The species richness of snails and mussels was highest in the littoral zone of Väistönselkä (six species of snails and eight species of mussels). In addition to molluscs mayflies and caddis flies were typical inhabitants of the littoral zone. The most abundant mayfly species were *Ephemera vulgata* L., *Caenis horaria* (L.) and *Centroptilum luteolum* (Müll.). The bathymetric distribution of these species was clearly wider than that of the other mayfly species. *Cyrnus* spp., *Molanna* spp., *Athripsodes* spp. and *Mystacides* spp. were the most abundant caddis flies.

Four relict crustacean species were caught from the area. The large sized, cold-stenothermal and oxybiontic *Relictacanthus lacustris* Sars, found only from few lakes in Finland (Särkkä *et al.* 1990), occurred in all the studied basins. However, the species was rare in the clear-water Väistönselkä basin. *Pallasea quadrispinosa* Sars was found in all the studied basins and was frequent also in the littoral zone. The oxybiontic *Monoporeia affinis* Lindstr., was not found in the shallowest basin (Hirkivenselkä), but was numerous in other basins, even in the sublittoral zone. The abundance of *Mysis relicta* Lovén, the most abundant relict crustacean in Finland (Särkkä *et al.* 1990), varied considerably between the basins,

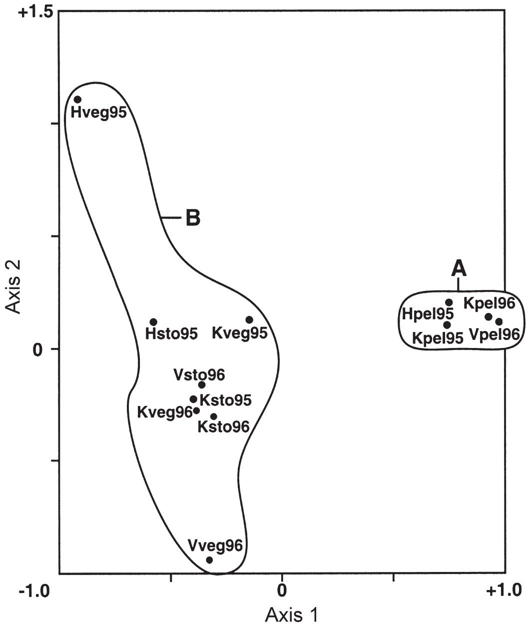

Fig. 5. Ordination (PCA) for the zooplankton of Pihlajavesi (mean biomasses of the growing season, logarithmic transformation). Abbreviations of sampling sites in Fig. 3. Axis 1 was explained as pelagial-littoral axis. The percentage variance accounted by the first axis was 40% and by the first and second axis 60%.

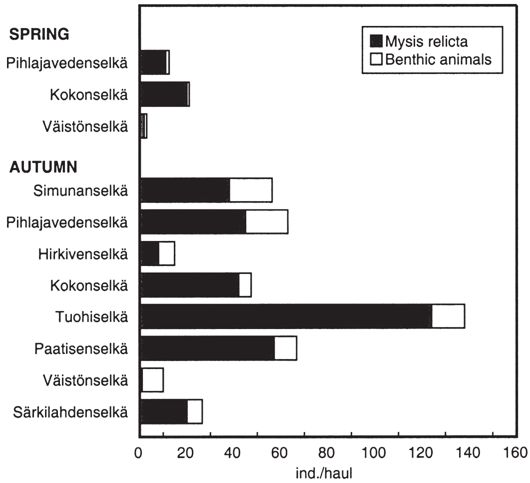

Fig. 6. Proportion of *Mysis relicta* and benthic animals in vertical net samples (sample = 0.56 m^2) in the basins of Pihlajavesi in May and September 1996.

and it was rare in the clear-water Väistönselkä basin (Fig. 6).

Based on the DCA ordination the water depth and related parameters, such as bottom quality, were the most important factors affecting animal assemblages, since the separate Ekman grab samples were distributed according to the sampling depths along the ordination axis 1. An example of this is shown in Fig. 7. This indicates that the species composition changes gradually with increasing depth, the rate of the change being highest in

Table 4. Characterization of pelagic and littoral zooplankton in Pihlajavesi (ranges of seasonal means).

	Pelagic	Stony littoral	Vegetation littoral
Number of species			
Rotaroria	21–28	21–24	18–26
Cladocera	12–15	10–17	13–19
Copepoda	9–10	5–7	5–11
Total	49–51	43–52	46–58
No. of abundant taxa	9.7–11.5	7.4–8.6	5.2–10.5
No. of very abundant taxa	6.2–8.1	5.3–6.7	3.8–8.1
Zooplankton Trophic Index (E/O)	0.22–0.40	0.38–0.48	0.06–0.70
Biomass (mg m^{-3})			
Rotaroria	40–70	10–110	10–110
Cladocera	90–140	60–140	40–2100
Copepoda	140–170	40–50	10–110
Total	280–360	120–280	240–2300
Biomass (%)			
Rotaroria	15–21	11–48	3–48
Cladocera	29–40	26–52	18–93
Copepoda	43–52	14–38	4–34

littoral area. When the benthic samples were combined according to the four hypothetical depth zones these were clustered separately in the DCA (Fig. 8), interpreted here as different soft bottom communities of the lake, the littoral, sublittoral, upper profundal and deep profundal communities. One of the profundal sites studied, the Simunanselkä basin, differed from the other basins to such an extent that it can be considered to form a distinct community of its own.

The littoral zone of the clear-water Väistönselkä basin differed from the other areas (but not along the axis 1, "the depth axis") due to the mass occurrence of oligochaetes *Tubifex* spp., *Limnodrilus hoffmeisteri* Clap. and *Spirosperma ferox* (Eisen) (Fig. 8). Littoral and sublittoral communities in all basins were dominated by large insect larvae, molluscs, oligochaetes and also chironomids especially in the sublittoral zone. The great variation in population parameters such as individual density and benthic biomass was typical of littoral communities, but the key taxa of the communities were comprised of the same species in all the studied basins (Table 5). The number of abundant and very abundant species was higher in the littoral and sublittoral zones than in profundal communities.

The profundal community in the Simunanselkä basin was typical of mesotrophic basins, and the number of taxa, individual density and values of diversity indices were somewhat higher than those in the other areas (Table 6). The key taxa in Simunanselkä, *Sergentia coracina* (Zett.) and *Stictochironomus rosenscholdi* Zett. are indicators of mesotrophy, while the indicators of oligotrophy, such as *Micropsectra* spp. were frequent in the other profundal areas. The ultraoligotrophic midge, *Heterotrissocladius subpilosus* (Kieff.), was found in four basins (Pihlajavedenselkä, Kokonselkä, Särkilahdenselkä and Hirkivenselkä). The variation in the BQI was quite small between the basins, excluding Simunanselkä (3.16) and Särkilahdenselkä (4.80). The BQIs were unexpectedly low (3.95 and 3.79) in the clear-water basins of Väistönselkä and Paatisenselkä in relation to their low nutrient level.

Individual density, biomass and species richness were highest in the littoral zone (1–3 m) and lowest in the upper profundal zone from 10–20 m. The greatest variation in the abundance was observed in the vegetated littoral zone, from ca. 3 000 to 7 700 ind. m^{-2} (Fig. 9). The mean sublittoral and littoral biomass ranged from 2.7 to 8.3 g m^{-2} in the clear water Väistönselkä basin, while in other areas the biomass was much lower (ca. 0.9–3.2 g m^{-2}). The mean biomass in the upper profundal zone (10–20 m) was low throughout the study area, 0.13–0.64 g m^{-2} (Fig. 9). The profundal individual density and biomass shown in Fig. 10, were low in all the basins (225–695 ind. m^{-2} and 0.22–1.0 g m^{-2}), the biomass ranging from 0.32 to 0.76 g m^{-2} in spring and from 0.22 to 1.0 g m^{-2} in autumn.

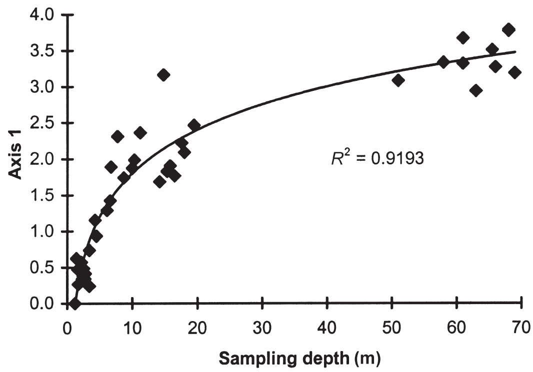

Fig. 7. Relationship between the sampling depth of zoobenthos and axis 1 of the DCA ordination in the Kokonselkä basin in May 1996.

Discussion

Pihlajavesi is in many respects comparable to Päijänne, another large Finnish lake, which was heavily loaded by effluent from wood-processing industry and municipal waste water in the 1960s–1970s, and has recovered from the loading during the past 20 years (*see* Meriläinen and Hamina 1993).

The present state of the planktonic and zoobenthic communities in Pihlajavesi is typical of oligotrophic, boreal lakes and considered to be quite close to the natural state, which forms a good basis for the protection of the endemic population of the Saimaa ringed seal.

In terms of phytoplankton biomass and the phytoplankton trophic index, PTI, Pihlajavesi is at present more oligotrophic than the cleanest

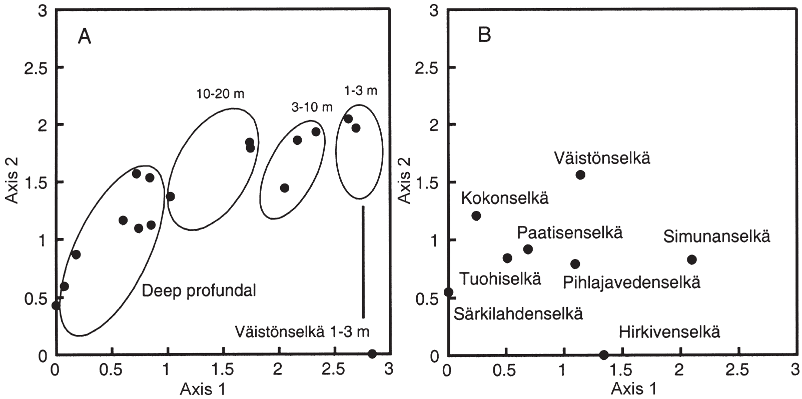

Fig. 8. DCA ordination for the depth zone combined data of zoobenthos of Pihlajavesi (a) (Axis 1 was considered as depth axis), and for the profundal samples (b) (no transformation, downweighting for rare species). Axis 1 was explained as eutrophy axis.

basins of the Päijänne area (e.g. Tehinselkä) and the adjacent watercourse, Southern Saravesi. The zooplankton biomass and the zooplankton trophic index, ZTI, were also lower in Pihlajavesi compared to those in northern Päijänne (Table 7) (Granberg 1993, Palomäki *et al*. 1998a, 1998b). According to Hakkari and Veijola (1985) the mean pelagic zooplankton biomass in Puruvesi in 1980–1983 was somewhat higher (340–660 mg m^{-3}) than that in Pihlajavesi. The variation in the mean biomass was even greater, from 330 to 3 200 mg m^{-3}, in littoral areas of the Saimaa lake complex, the highest pelagic biomasses being found in those years (1980–1983) when the water levels were exceptionally high.

The profundal benthic communities of Pihlajavesi were dominated by the same indicator species of oligotrophy, *Micropsectra* spp. and *Heterotrissocladius subpilosus* as the cleanest parts of Päijänne (Table 8). The *Sergentia–Stictochironomus* community in the mesotrophic basin, Simunanselkä, resembles that found in the northern and central parts of Päijänne, which are recovering from wood-prosessing effluent loading. As a consequence of decreasing point loading, many polluted Finnish lakes have recovered during the 1980s and 1990s (Fig. 11) (Meriläinen and Hamina 1993). However, some of the large lakes suffering from heavy diffuse loading from forestry and agriculture, such as Lappajärvi in Western Finland, have not recovered despite a considerable decrease in point loading into the lake (Hynynen *et al*. 1997).

Development of the communities during the past two decades

Although the nutrient concentration in Pihlajavesi has decreased during the last two decades, the

Table 5. Characterization of littoral, sublittoral and upper profundal benthic communities of Pihlajavesi in 1996.

	Littoral (1–3 m)	Sublittoral (3.1–10 m)	Upper profundal (10.1–20 m)
Mean density (ind. m^{-2})	3 023–7 656	572–1649	173–320
Mean biomass (g m^{-2})	3.01–8.30	0.88–2.56	0.13–0.64
No. of taxa	69–83	37–86	24–30
No. of abundant taxa	10.0–20.3	9.5–19.5	4.1–12.8
No. of very abundant taxa	5.6–14.0	6.3–12.2	2.4–10.5
BQI	.	.	3.64–4.16
Key taxa	*Asellus aquaticus* (L.)	*Ephemera vulgata* L.	*Pallasea quadrispinosa* Sars
	Pisidium spp.	*Cladotanytarsus* spp.	*Heterotanytarsus apicalis* (Kieff.)
	Limnodrilus hoffmeisteri Clap.	*Heterotanytarsus apicalis* (Kieff.)	*Heterotrissocladius marcidus* (Walk.)
	Spirosperma ferox (Eisen)	*Heterotrissocladius marcidus* (Walk.)	*Monodiamesa bathyphila* (Kieff.)
	Sialis spp.	*Mesocricotopus thienemanni* (Goetgh.)	
	Cyrnus spp.		
	Caenis spp.		
	Gastropoda		

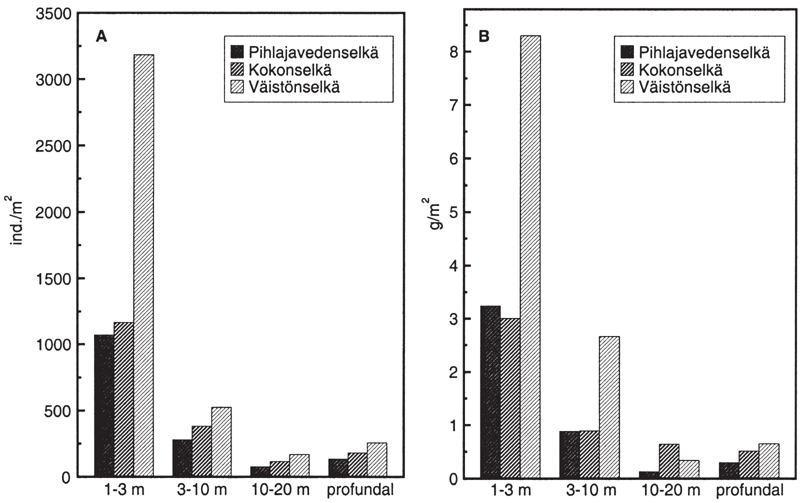

Fig. 9. Mean zoobenthic density (a) and mean biomass (WW) (b) in littoral, sublittoral, upper profundal and deep profundal areas in Pihlajavedenselkä, Kokonselkä and Väistönselkä.

present phytoplankton biomass was slightly higher than that in the least polluted area near Savonlinna in the 1970s (250–350 mg m^{-3}) (Jumppanen 1976). Also the PTI of pelagic areas observed in this study (0.41–1.45) was higher compared to those observed by Jumppanen (1976) in the least polluted area in the 1970s (0.04–0.78 unit). The changes in the phytoplankton community and the decrease in phosphorus concentration seem to contradict each other. This is probably due to the improved purification of the effluent from the wood-processing industry resulting in a decrease in the amount of organic matter and inhibitive chlorine compounds in the recipient. The same phenomenon has also been observed in Päijänne (Granberg *et al*. 1995).

Jumppanen (1976) reported disturbances at benthic communities in the vicinity of the town of Savonlinna in the 1970s. The *Chironomus* community, which indicates strong eutrophy, occurred frequently in the waters around Savonlinna at that time. The profundal fauna in Simunanselkä and Pihlajavedenselkä indicated mesotrophy and was inhabited by a *Sergentia-Stictochironomus* community. The results of the palaeolimnological study of Pihlajavedenselkä and Väistönselkä basins (O. Sandman unpubl.) were consistent with those of Jumppanen and the present study. It was showed that the environmental changes have been small in these basins during the past two centuries, although the biological state of Pihlajavedenselkä was affected to some extent by effluent water in the 1960s and 1970s (O. Sandman unpubl.). Changes were not observed in the eastern basin

Table 6. Characterization of profundal benthic communities in different basins of Pihlajavesi in September 1996.

	Simunanselkä (28–31 m)	Other basins (28–67 m)
Mean density (ind. m^{-2})	443	118–695
Mean biomass (g m^{-2})	0.40	0.25–1.01
No. of taxa	40	18–33
No. of abundant taxa	443	4.1–8.5
No. of very abundant taxa	0.40	2.4–7.8
No. of relict crustaceans	4	4
BQI	3.16	3.79–4.80
Key taxa	*Stictochironomus rosenscholdi* (Zett.) *Sergentia coracina* (Zett.)	*Micropsectra* spp. *Heterotrissocladius subpilosus* (Kieff.) *Stictochironomus rosenscholdi* (Zett.) *Heterotrissocladius* spp. *Zalutschia zalutschicola* Lipina

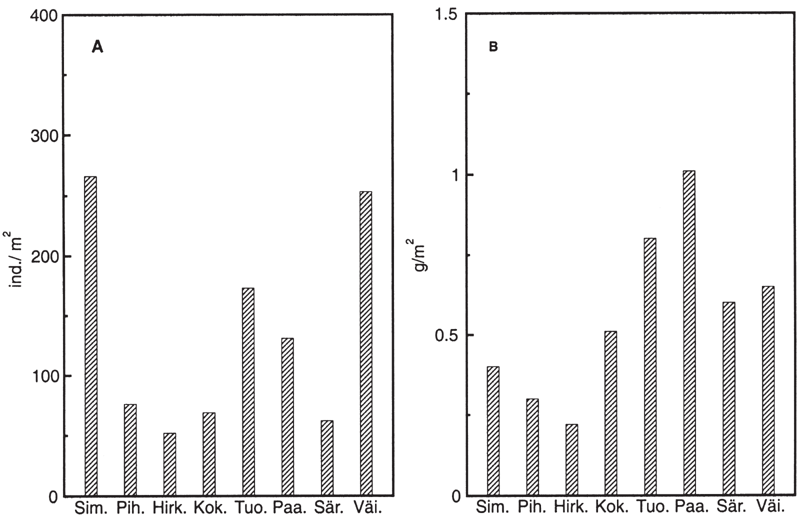

Fig. 10. Zoobenthic density (a) and biomass (b) in deep profundal sites in Pihlajavesi. Simunanselkä (Sim), Pihlajavedenselkä (Pih), Hirkivenselkä (Hirk), Kokonselkä (Kok), Tuohiselkä (Tuo), Paatisenselkä (Paa), Särkilahdenselkä (Sär) and Väistönselkä (Väi).

(Väistönselkä), far from the pollution source. A slight trend towards more mesotrophic conditions in the area near Savonlinna at that time was evidenced by an increase in some diatom taxa, e.g. *Asterionella formosa*, *Aulacoseira italica* (Ehr.) Simonsen, *Fragilaria capucina* Desmazières and *Fragilaria ulna* (Nitzsch) Lange-Bert, and a decrease in the BQI (from ca. 4.2 to 3.8) (Jumppanen 1976, O. Sandman unpubl.)

Special features in communities of the nutrient-poor, clear-water basins

The Väistönselkä-Hirvolanselkä area with low water colour (approx. 10 mg Pt l^{-1}) and low surface phosphorus concentration (5–6 µg l^{-1}) compared to other areas of the lake, had rather high phytoplankton biomass in relation to the nutrient concentration and a species composition typical

Table 7. Total phosphorus concentration (summer; 0–2 m), chlorophyll-*a* concentration (0–2 m) and biomass and trophic indices of phytoplankton (0–2 m; Tehiselkä basin 0–10 m) and zooplankton (0–20 m) of Pihlajavesi (pelagic) compared to some basins of Päijänne area (.. = no data).

	Year	Tot. P (µg l^{-1})	Chl. *a* (µg l^{-1})	Phytoplankton		Zooplankton	
				Biomass (mg m^{-3})	Trophic index	Biomass (mg m^{-3})	Trophic index
Hirkivenselkä basin	1995–96	8	4.0	570	0.31	280	0.27
Kokonselkä basin	1995–96	8	3.8	470	0.37	180	0.32
Väistönselkä basin	1995–96	6	3.5	440	0.19	160	0.22
Puruvesi, Saimaa	1980	5	3.2	..	..	340	0.24
Lake Vatia	1997	24	10	1780	6.8	..	..
Northern Leppävesi	1997	16	6.8	1440	6.1	..	..
Southern Saravesi	1997	11	4.3	840	0.83	..	..
Poronselkä basin, Päijänne	1994	17	6.5	1000	3.9	680	0.86
	1997	19	6.8	1030	2.7	..	..
Ristiselkä basin, Päijänne	1992	14	3.8	930	2.5	500	0.98
	1997	15	5.1	830	1.2	..	..
Lehtiselkä basin, Päijänne	1997	13	4.5	780	1.0	..	..
Tehinselkä basin, Päijänne	1992	8	2.6	720	1.3	..	..

of oligotrophic waters. The high transparency of the water allows effective phytoplankton growth in the studied water layer (0–4 m). In the clear-water and nutrient-poor Puruvesi, the next basin upstream from Väistönselkä, the productive layer reaches down to 10–12 m, which makes the area highly productive in spite of the low nutrient concentrations (Huttunen *et al.* 1991). In these circumstances the maximum biomass and chlorophyll-a concentration can occur even deeper than in the 0–4 m water layer, so that the routine sampling depth (0–2 m) can seriously underestimate the amounts of chlorophyll-a and phytoplankton.

The high primary productivity also results in a high benthic biomass. The mean littoral and sublittoral benthic biomass at 1–10 m was 2.5 times higher in Väistönselkä (5.43 g m^{-2}) than in other areas of the lake (Table 5), and 2.9 times higher than the average biomass in the other basins of the Saimaa lake complex (Meriläinen 1985). The exceptionally high biomass in Väistönselkä consisted mainly of molluscs, oligochaetes, mayflies and midges. The highly productive vegetated littoral zone of this clear-water area is wide and reaches deeper than in other areas, which enables grazers to be very abundant in the whole littoral and sublittoral zone.

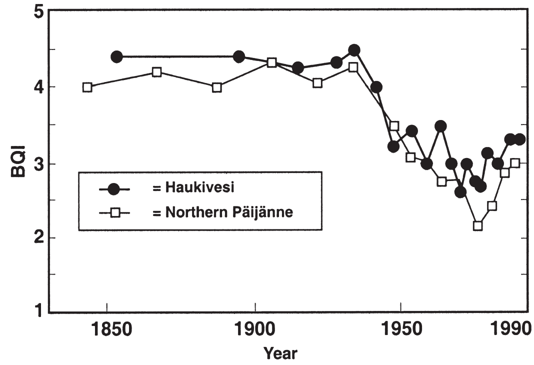

Fig. 11. Benthic Quality Index in Lake Haukivesi and Northern Päijänne during the past 150 years (Meriläinen and Hamina 1993, Simola *et al.* 1996).

The high transparency causes some special features also in the profundal communities. The profundal benthos of Paatisenselkä and Väistönselkä had low BQI values (3.95 and 3.79) in relation to the low nutrient level of the basins. This phenomenon was also observed in the nutrient-poor Puruvesi basin (Meriläinen 1992). The explanation for this is high phytoplankton production with respect to the hypolimnetic volume, since high production increases the organic sedimenta-

Table 8. Wiederholm's BQI in deep profundal areas in some Finnish lake basins. [1)] has been estimated from the water quality monitoring data of L.Vatia, according to which the water quality of the lake was poor already in the 1960s (strong hypolimnetic anoxia) (.. = no data).

Years	1960–1970	1971–1980	1981–1985	1986–1990	1991–1997
Pihlajavedenselkä	4.00–3.80[2]	3.80[2]	4.00–4.30[2]	4.30–4.40[2]	4.35
Väistönselkä	4.00–4.20[2]	4.00–4.20[2]	4.00–4.20[2]	4.00–4.20[2]	3.95
Other basins in Pihlajavesi	..	..	..	..	3.16–4.80
Lake Vatia	0[1]	0	0	0.13–2.50	0.50–1.50
Lievestuoreenjärvi	0	0	0	..	3.00
Leppävesi	..	..	..	1.90–3.00	2.75–3.00
Poronselkä, Päijänne	2.38	2.15–2.60	2.97	2.91–3.20	2.95–3.07
Ristiselkä, Päijänne	3.00	..	3.04	3.37–4.10	3.49–3.90
Souselkä–Vanhanselkä, Päijänne	..	..	3.42	3.80	4.22
Tiirinselkä, Päijänne	0	0	0	0	2.02–2.52
Lehtiselkä, Päijänne	..	0	2.80	2.84	3.09–3.43
Judinsalo–Tehinselkä, Päijänne	..	..	3.81–4.00	4.00	3.98
Asikkalanselkä, Päijänne	4.00–4.20[2]	4.00–4.30[2]	4.00–4.20[2]	4.00–4.20[2]	4.03
Lappajärvi	2.00–3.30[2]	1.80–2.50[2]	1.60–2.20[2]	1.70–2.00[2]	1.70–2.00[2]

[1] Estimated values
[2] Paleolimnological data (O. Sandman unpubl.)

tion and oxygen consumption in the hypolimnion. The hypolimnetic oxygen concentration varies annually and is highly dependent on the weather conditions and especially on the temperature of the hypolimnion during the formation of the ice cover. The temporarily low oxygen concentration in the hypolimnion (32%–78% in 1963–1991) is probably partly responsible for the scarcity of the oxybiontic relict crustaceans in the Väistönselkä basin. The scarcity of *Mysis relicta*, which is quite eurytopic (Särkkä *et al*. 1990) and also inhabits polluted areas, can not be explained by the lowered hypolimnetic oxygen concentration. Another possible explanation could be selective predation pressure by fish. Large-sized, actively moving invertebrates can obviously be observed and caught more easily in clear than in brown-coloured water. Relict crustaceans are known to form a remarkable part of the food of many fish species in some Finnish clear-water lakes (e.g. Bagge 1992).

Conclusions

Based on the results of this study the following guidelines for the future monitoring programs in the Pihlajavesi ecosystem are suggested.

1. *Phytoplankton*: The structure of phytoplankton communities in Pihlajavesi is mainly determined by the water quality parameters such as nutrient concentrations and the colour of the water. We therefore recommend that the monitoring program should include at least two pelagic sites, one clear-water basin and one basin near Savonlinna town, which receives the main effluent loading. The sampling depth for phytoplankton and chlorophyll-a should be greater in the clear-water basins than usually recommended (e.g. 0–5 m instead of 0–2 m).
2. *Zooplankton*: Monitoring should be carried out in the same basins as that for phytoplankton. It is notable that there are considerable differences between the littoral and pelagic communities.
3. *Zoobenthos*: The water depth and related parameters, such as bottom quality are the most important factors affecting the benthic communities. We recommend that the monitoring program should be carried out in the nearest basin of Savonlinna town and in at least one site in a clear-water area of the lake. The littoral communities should be included in the monitoring at least in the basin near Savonlinna town. Five Ekman replicates are recommended for littoral communities and 10 for studies in profundal areas (e.g. Veijola *et al*. 1996).

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Appendix 1. Number of taxa and mean biomass of phytoplankton groups in Pihlajavesi in 1995–1996. (Pel = pelagic site, sto = stony shore, veg = vegetation shore)

	Hirkivenselkä 1995			Kokonselkä 1995			Kokonselkä 1996			Väistönselkä 1996		
	Hpel	Hsto	Hveg	Kpel	Ksto	Kveg	Kpel	Ksto	Kveg	Vpel	Vsto	Vveg
	Number of taxa											
Cyanophyceae	9	13	11	9	9	13	11	13	12	10	10	10
Cryptophyceae	3	3	4	3	3	3	3	3	3	3	3	3
Dinophyceae	2	4	4	4	4	4	4	5	8	4	6	5
Prymnesiophyceae	1	1	1	1	1	1	1	1	1	1	1	1
Chrysophyceae	25	23	26	25	26	29	30	29	27	31	28	28
Diatomophyceae	24	26	27	26	27	27	21	28	26	13	19	17
Tribophyceae	1	–	1	1	–	–	–	1	–	1	–	–
Raphidophyceae	1	–	1	1	–	–	–	–	–	–	–	–
Euglenophyceae	1	–	1	1	2	1	1	3	–	–	2	1
Prasinophyceae	1	2	2	1	2	1	1	2	2	1	1	2
Chlorophyceae												
Volvocales	3	3	3	3	3	3	1	3	3	2	1	2
Tetrasporales	2	2	2	–	2	1	1	–	2	1	2	–
Chlorococcales	23	27	20	21	21	22	22	30	20	21	24	23
Ulotrichales	2	1	1	1	1	3	4	2	2	3	2	4
Conjugatophyceae	1	3	3	3	2	5	2	6	4	5	5	8
Craspedomonadina	2	1	2	2	2	1	3	–	–	2	–	–
Zooflagellata	2	2	2	1	1	1	1	1	1	1	–	–
Total	103	111	111	103	106	115	106	127	111	103	98	104
	Biomass (mg m^{-3})											
Cyanophyceae	27	35	63	23	29	34	56	97	69	18	12	17
Cryptophyceae	181	182	192	151	101	203	132	315	114	97	66	88
Dinophyceae	11	11	9.3	11	8.4	13	8.4	24	33	15	36	37
Prymnesiophyceae	11	8.3	12	8.5	9.6	17	15	10	16	19	25	39
Chrysophyceae	182	161	169	152	108	199	147	129	184	241	208	185
Diatomophyceae	133	179	178	155	143	151	76	142	106	64	166	99
Tribophyceae	0.1	–	0.2	0.1	–	–	–	0.08	–	0.2	–	–
Raphidophyceae	0.6	–	0.6	0.6	–	–	–	–	–	–	–	–
Euglenophyceae	0.6	–	1.3	0.3	1.6	1.4	1.6	3.3	–	–	2.9	1.4
Prasinophyceae	0.2	0.7	0.9	0.02	0.6	–	0.8	0.05	0.04	0.6	–	0.05
Chlorophyceae	36	32	37	32	33	36	22	27	40	41	51	54
Conjugatophyceae	1.6	3.8	2.1	3.3	1.2	7.5	3.8	7.7	1.9	2.9	5.2	7.5
Craspedomonadina	0.7	0.6	0.2	0.8	0.5	0.6	0.4	–	–	0.3	–	–
Zooflagellata	0.8	1.2	1.4	0.3	0.2	1.1	0.6	0.7	0.5	0.2	–	–
Total	577	615	667	537	437	664	464	561	565	499	571	529

Appendix 2. Characterization of zoobenthos in different depth zones in three basins of Pihlajavesi.

	Pihlajavedenselkä				Kokonselkä				Väistönselkä			
Depth (m)	1–3	3.1–10	10.1–20	50–67	1–3	3.1–10	10.1–20	51–69	1–3	3.1–10	10.1–20	43–50.5
Mean density (ind. m^{-2})	3000	570	170	360	3600	970	320	400	7700	1650	250	810
Mean biom (g m^{-2})	3.24	0.88	0.13	0.30	3.01	0.89	0.64	0.51	8.30	2.66	0.34	0.65
N. of abund. taxa	17.1	12.3	7.6	5.7	14.2	17.5	6.5	4.7	17.6	18.2	11.0	6.6
N. of very ab. taxa	10.7	8.9	5.5	4.4	11.0	11.0	7.9	7.1	9.8	9.9	5.5	2.8
BQI	–	–	4.16	4.35	–	–	3.64	4.26	–	–	4.00	3.95

Appendix 3. Characterization of profundal benthos in eight basins of Pihlajavesi. Simunanselkä (Sim), Pihlajavedenselkä (Pih), Kokonselkä (Kok), Tuohiselkä (Tuo), Hirkivenselkä (Hirk), Paatisenselkä (Paa), Särkilahdenselkä (Sär) and Väistönselkä (Väi) (data from autumn samples).

Depth (m)	Sim 28–31	Pih 50–67	Kok 51–69	Tuo 42–50	Hirk 28–31	Paa 36–38	Sär 43–50	Väi 43–50.5
Mean density (ind. m^{-2})	440	260	240	700	120	400	220	590
Mean biom. (g m^{-2})	0.40	0.28	0.25	0.80	0.22	1.01	0.60	0.64
N. of abundant taxa	17.1	3.9	7.0	6.0	6.5	8.4	8.1	4.7
BQI	3.16	4.00	4.00	4.00	4.33	3.79	4.80	3.93

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