Zooplankton indicators of trophy in Latvian lakes

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Abstract

Studies on the relationship between zooplankton taxonomic composition and environment characteristics are an important issue in the evaluation of the ecological quality of lakes. Data were collected in 1998 - 2004 in 113 lakes of different types. Zooplankton samples were taken simultaneously with the hydrochemical and phytoplankton samples, and field measurement of physical parameters. Redundancy Analysis was used to ordinate zooplankton abundance data against environmental variables, and General Linear Models and XY(Z) plots were used to test and visualize these relationships. A number of taxa increased in abundance with eutrophication, while results on using of zooplankton organisms as low trophy indicators were poor. However, an indirect adverse effect of increased nutrient concentrations through algal blooms was suggested.

Key words: high-trophy indicators, lake trophy, Latvia, low-trophy indicators, Redundancy Analysis, zooplankton.

Introduction

Zooplankton is an important component of lake ecosystems, the composition and abundance of which is related to many factors, such as water hydrochemistry, season, lake morphology, presence of macrophytes, predators etc., and, particularly, to the productivity of the lake – i.e. lake trophic condition (Wetzel 2001). The latter makes it very suitable and popular for monitoring programs devoted to record changes in the lake's ecological quality. Three groups of zooplankton organisms are usually used: rotifers, cladoceran crustaceans, and copepod crustaceans.

Various chemical and biological data on the ecological quality of the lakes have been collected in the period 1998 - 2004 by the Latvian Environment, Geology and Meteorology Agency during several state governed projects. These data included also zooplankton, covered a wide variety of lakes, but also had some shortages. Analyzes were made by different specialists with various levels of knowledge and experience, with taxa identified to various taxonomical levels (genus, species, subspecies, forms), and some possible identification errors. Another problem was the presence of taxonomically uncertain forms. Thus, *Daphnia* and bosminid cladocerans are taxonomically very complicated groups with many morphs, races with intermediate forms, and introgressive processes (Nilssen, Larsson 1980; Leider 1986; Taylor at al. 1996; Taylor et al. 2002). There are differences in identification even among different scientist groups – e.g. between the West European and Russian 'schools'. A third problem is finding the optimal taxonomical level for data used

for interpretation, since different closely related forms may have the same response to lake trophy, and their presence in one or an other lake may be due to other, not trophic factors, or simply by chance (Wetzel 2001).

Taking into account the above, the present study was devoted to identify easily-recognizable, more or less common taxa, not necessarily at the species level, with marked response to the lake trophy. Since zooplankton may respond not only to trophy, but also to many other parameters, including lake morphology or physical-chemistry, the latter were also taken into account.

Materials and methods

Sampling design
Sampling was carried out during summer stratification period from 2nd decade of July to the 3rd decade of August. Lakes covered all types available in Latvia, and were located in the whole territory of Latvia. Usually only one sample per lake was taken. In some cases, a lake was sampled several times in different years, or in different parts if they were well-separated by shore-line configuration and banks. A total of 113 lakes were surveyed, 144 samples processed. Zooplankton, phytoplankton and water chemistry samples were taken simultaneously, from the deepest part of a the lake, and from the epilimnion 0.5 m horizon, in mid-day.

Environmental variables
Relatively few variables with the potentially highest response of the zooplankton community were selected for the analysis. Lake morphology variables included area and average depth, and physical-chemistry variables were a temperature, pH, conductivity, and colour. The total phosphorus concentration (mg l^{-1}) was chosen as the most important productivity-limiting (trophy) factor in inland waters (Wetzel 2001). The total phytoplankton biomass (mg l^{-1}) and the percentage of cyanophyta were both also selected as trophy-related factors, having significant impact on zooplankton communities as food items (Wetzel 2001). These variables were used as predictors in zooplankton taxa ordination, and in subsequent taxa – variable relationship analysis.

Data on area and average depth of the lake were acquired from the on-line data base

Table 1. Environmental characteristics of surveyed sites (n = 144)

Variable	Range	Average ± SD	Median
Area (ha)	0.5 - 5765	366 ± 936	49.9
Average depth (m)	0.3 - 16.5	4.7 ± 3.5	3.5
Temperature (°C)	14.6 - 27.9	21.9 ± 2.9	22.2
pH	4.1 - 9.4	7.7 ± 1.2	8.03
Conductivity (µS cm^{-1})	9 - 793	232.5 ± 140.4	244
Colour (mg Pt° l^{-1})	5 - 610	88.2 ± 108.4	50
P total (mg l^{-1})	0.003 - 0.180	0.034 ± 0.030	0.022
Phytoplankton biomass (mg l^{-1})	0.010 - 122.14	4.1 ± 13.2	0.762
Proportion of *Cyanophyta* (%)	0 - 99.8	29.81 ± 31.55	17.6

(http://www.ezeri.lv). Most of the physical-chemistry parameters – temperature, pH (both ± 0.1), conductivity (µS cm^{-1}) were measured on site with a multi-parameter field meter (WTW, Germany). Total phosphorus (mg l^{-1}) and water colour (mg Pt° l^{-1}) analysis was carried out with standardized methods in a laboratory accredited by the Latvian National Accreditation Bureau. Water samples for chemistry and phytoplankton were taken with a bathometer. Phytoplankton samples were preserved with the addition of the Lugol solution, then concentrated and cells were counted in a counting chamber with inverse light microscopy; biomass was calculated from the cell biovolume (Keskitalo, Salonen 1994). Statistical summary of the environmental variables is given in Table 1.

Zooplankton
Sampling was made by filtering of 100 l of water through a plankton net with mesh size of 65 µm. Samples were preserved by addition of 2 - 4 % solution of formaldehyde. During
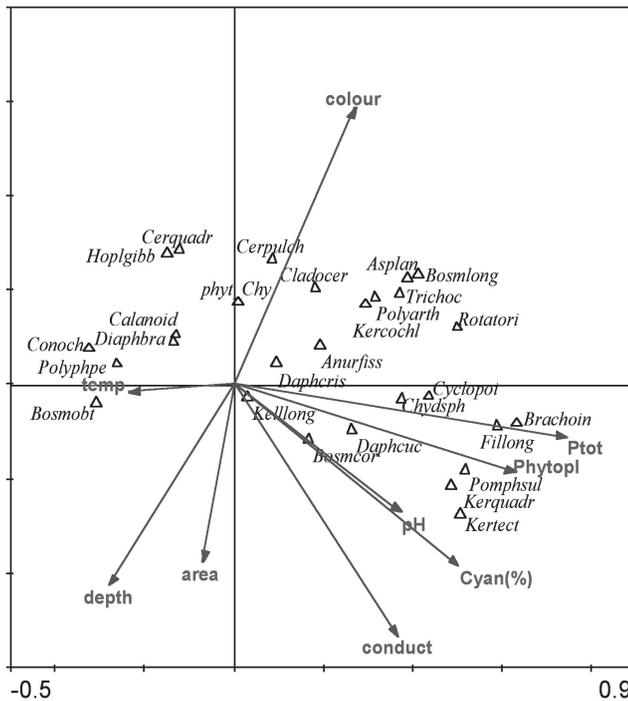

Fig. 1. RDA ordination plot for zooplankton taxa and environmental variables. Taxa in RDA plot indicated with triangles instead of arrows. Anurfiss – *Anuraeopsis fissa*, Asplan – *Asplanchna*, Bosmcor – 'humped' *Eubosmina*, Bosmlong – *Bosmina longirostris*, Bosmobt – non-humped *Eubosmina*, Brachoin – *Brachionus*, Calanoid – calanoid copepods, Cerpulch – *Ceriodaphia pulchella*, Cerquadr – *Ceriodaphnia* cf. *quadrangula*, Chysph – *Chydorus sphaericus*, Cladocer – cladocerans, Conoch – *Conochilus*, Cyclopoi – cyclopoid copepods, Daphcris – *Daphnia* cf. *cristata*, Daphcuc – *Daphnia* cf. *cucullata*, Diaphbra – *Diaphanosoma bracyurum*, Fillong – *Filinia longiseta*, Hoplgibb – *Holopedium gibberum*, Kellong – *Kellicottia longispina*, Kercochl – *Keratella cochlearis* typical forms, Kertect – *Keratella cochlearis* cf. *tecta*, Kerquadr – *Keratella quadrata*, phyt_Chy – phytophilous *Chydoriidae*, Polyarthr – *Polyarthra*, Polyphpe – *Polyphemus pediculus*, Pomphsul – *Pompholyx sulcata*, Rotatori – rotifers, Trichoc – *Trichocerca*.

the counting process, they were sub-sampled and counted twice, and the average was used for calculating the organism density expressed as thousands of per m³.

Forms similar to *Keratella cochlearis* all were pooled into two groups – (a) typical (including *K. irregularis*, *K. c. hispida*) with a rear spine, and (b) cf. *tecta* (including *K. serrulata*) without a rear spare. *Ceriodaphnia* were treated as: *pulchella* – with a clump of hairs proximally from a row of small teeth on postabdomen, and cf. *quadrangula* – taxa without this feature. All bosminid species and forms were pooled into three groups: (a) *Bosmina longirostris* (subgenus *Bosmina*); (b) non-humped forms of the genus or subgenus *Eubosmina* (*B. obtusirostris*, *B. longispina*, *B. crassicornis*, *B. coregoni* sensu stricto etc.); (c) humped forms of *Eubosmina* (*B. gibbera*, *B. thersites*, *B. lilljeborgii*). *Daphnia* were treated as: cf. *cristata* with 1 + 1 hairs on branches of the second antennae, and cf. *cucullata* – with 2 + 1 hairs on the second antennae.

Other rotifer and cladoceran taxa were analyzed at species or genus level, rare taxa present in few samples were not treated separately. Phytophilous cladocerans of the *Chydoriidae* family (*Acroperus*, *Alona*, *Camptocercus*, *Graptoleberis* etc.) were not rare, but their composition even at the genus level strongly varied from sample to sample, therefore they all were pooled together. Calanoid and cyclopoid copepods were recognized at suborder level. Total densities of all rotifers and all cladocerans (including rare, not separately treated taxa) were also used.

Statistics

Detrended Correspondence Analysis (DCA) was performed to test linear versus unimodal response of the data. The gradient length of the first axis was 2.4, suggesting a linear response. Therefore, Redundancy Analysis (RDA) was chosen as the method for ordination of absolute abundance data against environmental variables (Van den Brink et al 2003). RDA was performed using inter-species correlations, dividing by the standard deviation, and log transformation of the data. The Monte Carlo permutation test was performed under 999 permutations. General Linear Models (GLM) and XY(Z) plots were used to test and visualize taxa relationships with selected environmental variables. All statistics were performed on CANOCO for Windows 4.5.

Results

Eigenvalues of the 1st and 2nd RDA axis were 0.156 and 0.027 respectively, and the cumulative percentage variation of first two axes was 73 %, sum of all canonical eigenvalues 0.252; and consequently, percentage of explained variation was relatively low – 25 %. The Monte Carlo test in all cases was < 0.05. Conditional effect of environmental variables in all cases was significant at p < 0.05. The first axis in the ordination can be explained mostly by a trophy gradient, the second by physical-chemistry and lake morphology (Fig. 1). Among environmental variables, the two closest to trophy axis were total phosphorus and phytoplankton biomass, to physical-chemistry axis – colour and conductivity. Area and average depth well characterized lake morphology. These variables were used as pairs of predictors in GLM analysis to verify the response of the taxa to trophy, physical-chemistry, and lake morphology (Table 2). XY(Z) plots with symbol coding were created to visualize all the data for finding threshold values not revealed by GLM.

A group of taxa at the eutrophic end of the ordination had a positive correlation with

Table 2. Statistically significant [(*) p < 0.05; (**) p < 0.01; (***), p < 0.001] regression coefficients (T) for GLM for taxon and environmental variable relationships

Taxon	Trophy		Physical-chemistry		Morphology	
	Ptot	Phytoplankton	Colour	Conductivity	Area	Depth
Anuraeopsis fissa	ns	ns	2.43*	-0.96*	ns	ns
Asplanchna	4.13***	5.75***	2.63*	0.21*	ns	ns
Brachionus	-1.74***	13.13***	ns	ns	ns	ns
Conochilus	ns	ns	ns	ns	ns	ns
Filinia longiseta	1.39***	4.51***	ns	ns	ns	ns
Kellicottia longispina	ns	ns	ns	ns	ns	ns
Keratella cochlearis typical forms	1.64**	2.07**	4.40***	1.62***	ns	ns
Keratella cochlearis cf. *tecta*	2.21**	1.53**	ns	ns	5.10***	-1.92***
Keratella quadrata	3.15**	-0.35**	0.72*	2.67*	ns	ns
Polyarthra	4.32***	-0.90***	2.58*	2.08*	ns	ns
Pompholyx sulcata	4.99***	3.71***	0.95***	4.08***	ns	ns
Trichocerca	ns	ns	ns	ns	ns	ns
Bosmina longirostris	2.97*	-0.97*	3.29**	0.33**	ns	ns
non-humped *Eubosmina*	ns	ns	ns	ns	ns	ns
'humped' *Eubosmina*	3.51**	-1.11**	ns	ns	ns	ns
Chydorus sphaericus	ns	ns	ns	ns	ns	ns
Phytophilous *Chydoridae*	ns	ns	ns	ns	ns	ns
Ceriodaphnia pulchella	ns	ns	ns	ns	-1.22*	-2.16*
Ceriodaphnia cf. *quadrangula*	ns	ns	1.51***	-3.59***	ns	ns
Daphnia cf. *cristata*	3.06**	-1.69**	ns	ns	ns	ns
Daphnia cf. *cucullata*	ns	ns	0.98***	4.09***	ns	ns
Diaphanosoma brachyurum	ns	ns	ns	ns	ns	ns
Holopedium gibberum	ns	ns	4.68***	-2.88***	ns	ns
Polyphemus pediculus	ns	ns	ns	ns	ns	ns
rotifers	6.48***	8.04***	2.55***	3.56***	ns	ns
cladocerans	2.48*	-0.83*	ns	ns	-1.54*	-1.80*
calanoid copepods	ns	ns	ns	ns	ns	ns
cyclopoid copepods	7.11***	-0.45***	3.96***	3.67***	ns	ns

the trophy variables. Some of them had better positive correlation with total phosphorus (*Keratella cochearis* typical forms, *Keratella cochlearis* cf. *tecta*, *Keratella quadrata*, *Polyarthra*, *Bosmina longirostris*, cyclopoid copepods), some with phytoplankton biomass (*Brachionus*, *Filinia longiseta*), and others good with both (*Asplanchna*, *Pompholyx sulcata*, a total of rotifers). Some of the taxa located more in the middle position in ordination (humped *Eubosmina*, *Daphnia* cf. *cristata*, cladocerans in total), also had positive correlations with total phosphorus, but were probably strongly hindered by high algae biomass (Table 2). XY(Z) plots did not reveal any threshold values below which the eutrophic taxa would
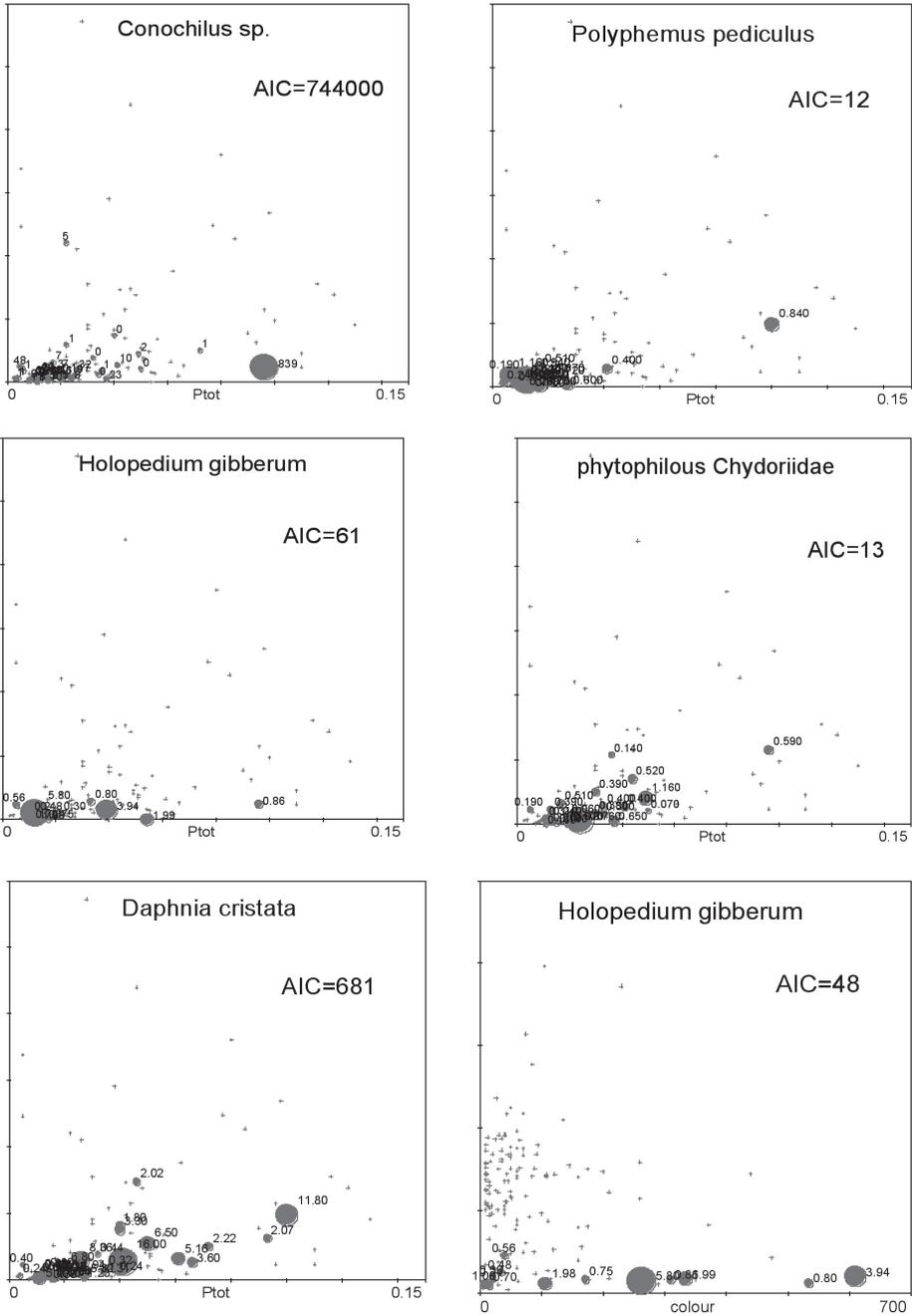
Fig. 2. XY(Z) plots for taxa densities (Z) with significant environment – determined thresholds; abbreviations on axes: Phytopl – phytoplankton, Ptot – total phosphorus concentrations (mg l^{-1}), conduct – conductivity (µS cm^{-1}), colour – colour (mg Pt° l^{-1}); AIC – Akaike information criterion; size of the dot corresponds to the density of taxa in sample, crosses indicate samples where the taxon was absent.

be absent, and all of them were present in small numbers at least in some samples with low P total concentrations (< 0.025 mg l^{-1}) and algae biomass (< 2 mg l^{-1}). Species at the oligotrophic end of the gradient did not show significant negative correlation with the trophy variables. However, among them several taxa (*Conochilus*, *Holopedium gibberum*, *Polyphemus pediculus*), as well as some others of 'indifferent' (phytophilous *Chydoriidae*, *Daphnia* cf. *cristata*) taxa had marked threshold values for phytoplankton biomass, above which they were absent (Fig. 2).

Several taxa were more abundant in a lake type in respect to their physical-chemistry. Colour and conductivity had opposite vectors in ordination, therefore a positive correlation with one and negative with the other should be interpreted with caution. One taxa (*Holopedium gibberum*) had a marked threshold for conductivity, it was found only in soft-water lakes (< 100 μS cm^{-1}), and XY(Z) plots revealed that its 'preference' for brown and soft water lakes (e.g. acid bog lakes) indicated by GLM was coincidental.

Relationships with lake morphology were least significant. Although some taxa (*Ceriodaphnia pulchella*, a total of cladocerans) were somewhere more abundant in smaller lakes, only one (*Keratella cochlearis* cf. *tecta*) had a significant preference for lakes with larger size and smaller average depth.

Discussion

A number of taxa had increased in abundance with eutrophication. Rotifers in general are better indicators than crustaceans, as they are less affected by the summer algae blooms, which in the present study were associated to mass development of blue-green algae. Some taxa (*Brachionus*, *Filinia longiseta*) probably even have an advantage under such conditions. Presumably, they are less or not susceptible to toxic influence of blue-green algae and consume mostly bacteria (Kirk, Gilbert 1992; Agasild, Noges 2005). Presence in the group of high-trophy indicators of taxa such as *Keratella cochlearis* cf. *tecta*, *Keratella quadrata*, *Brachionus*, *Filinia longiseta*, *Pompholyx sulcata*, and total rotifer abundance, was expected from studies in other countries (Hakkari 1972; Maemets 1983; Karabin 1983, 1985; Bērziņš, Pejler 1989). The presence of some other taxa is not so unequivocal. The typical form of *Keratella cochlearis* is usually not regarded as a high-trophy indicator, and various *Polyarthra* species are indicated as preferring different trophy levels (Hakkari 1972; Maemets 1983; Karabin 1985; Bērziņš, Pejler 1989). In the present study, they usually formed the bulk of the rotifer individuals in the samples. The density increased with increasing productivity of the ecosystem. However, they did not dominate in samples from highly eutrophic lakes with clear water colour. One species of *Asplanchna* (i.e. *A. herricki*) is indicated as more characteristic for low trophy conditions (Hakkari 1972; Maemets 1983; Bērziņš, Pejler 1989). However, it was rare in the present study. *Asplanchna* are raptors, and their densities should be higher in more productive ecosystems. Notable was that all of these 'high-trophy' indicator taxa can be present at small numbers in low-trophy conditions as well.

In crustaceans, it is likely that even high trophy indicators are adversely affected by the summer phytoplankton blooms. Cyclopoid copepods were more abundant in brown-water lakes with low transparency and lower algae biomass. Among cladocerans, the relationship with phytoplankton biomass was negative even in some taxa more characteristic of higher trophy conditions – *Bosmina longirostris* and 'humped' *Eubosmina*.

There are probably no good low trophy indicators among the zooplankton taxa – no taxa located in the low trophy area of the ordination had significant negative correlations with trophy variables. High levels of total phosphorus lacked direct adverse impact on any taxa (Table 2; with the exception of probably an occasional correlation with *Brachionus*). However, there was an indirect effect through the algal blooms. Thus, rotifer *Conochilus*, cladocerans *Polyphemus pediculus, Holopedium gibberum* were absent above threshold values of 5 - 6 (former two, except the one case for *Conochilus*) to 2 (the latter) mg of algae per liter. Phytophilous cladocerans disappeared also at summer phytoplankton biomass above 6 mg l^{-1}, which was probably associated with a decline of macrophyte vegetation due to the shift from clear-water to turbid state of lake (Wetzel 2001). Large algae-feeding cladocerans of the *Daphnia* genus can be susceptible to the domination of toxic or filamentous blue-green algae (Ghadouani et al 1998; Kurmayer 2001). The present survey indicates possible differences in the susceptibility among taxa, as *Daphnia* cf. *cristata* was absent at algae biomass above 8 mg l^{-1}, but *Daphnia* cf. *cucullata* had relatively high densities even at about 30 mg l^{-1}. In Nordic countries, *Daphnia cristata* is regarded as an oligotrophy indicator versus eutrophy indicator *Daphnia cucullata* (Bērziņš, Bertilsson 1989; Lyche 1990). However, in the present study such a pattern was not observed for samples with an algal biomass below 8 mg l^{-1}.

The remaining surveyed taxa, although some of them occasionally are indicated as low (*Kellicottia longispina*) or high trophy (*Anuraeopsis fissa*, *Chydorus sphaericus*) indicators, should be regarded as 'indifferent' taxa with a wide spectrum of ecological tolerance, sometimes rare or absent at extreme ends of the trophy gradient.

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Zooplankons kā trofiskā stāvokļa indikators Latvijas ezeros

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Kopsavilkums

Pētījumi, kuros zooplanktona taksonomiskais sastāvs tiek saistīts ar vides parametriem, ir būtiski, novērtējot ezeru ekoloģisko kvalitāti. Dati ievākti no 1998. līdz 2004. gadam 113 dažāda tipa ezeros. Zooplanktona paraugi ņemti vienlaicīgi ar ūdens ķīmijas un fitoplanktona paraugiem, paraugu ņemšanas vietā veikti ūdens fizikāli-ķīmisko parametru mērījumi. Zooplanktona taksonu izvietošanai (ordinācijai) attiecībā pret vides rādītājiem izmantota dublēšanas analīze, bet sakarību pārbaudē un vizualizēšanā lietota vispārīgā lineārā analīze un XY(Z) diagrammas. Vairāku taksonu blīvums pieauga ar ezera eitrofikācijas rādītāju pieaugumu, savukārt, saistība ar zemas trofijas rādītājiem nebija pārliecinoša. Domājams, ka barības vielu blīvuma pieaugumam ezera ir netiešs negatīvs efekts, izraisot aļģu masveida ziedēšanas parādību.