INSTITUTE OF ECOLOGY OF NATURE RESEARCH CENTRE
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PHYTOPLANKTON AND ZOOPLANKTON COMMUNITY STRUCTURE AND CHANGE IN CHARACTERISTIC MESOTROPHIC LAKES OF LITHUANIA

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GAMTOS TYRIMŲ CENTRO EKOLOGIJOS INSTITUTAS
VILNIAUS UNIVERSITETAS

Daiva Kalytytė

PLANKTONO DUMBLIŲ IR VĖŽIAGYVIŲ BENDRIJŲ STRUKTŪRA IR KAITA CHARAKTERINGUOSE MEZOTROFINIUOSE LIETUVOS EŽERUOSE

Daktaro disertacijos santrauka
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INTRODUCTION

Most of the larger lakes of Lithuania are regarded as mesotrophic water bodies. 53.8% of the studied lakes were attributed to this type by J. Kavaliauskienė (1996). The trophic status of lakes is primarily estimated basing on the productivity of plankton community and its other parameters, that is why the processes occurring in it are of the utmost importance for the evaluation of the ecological status of lakes and the prediction of its possible changes under conditions of the global environmental change (McCormick, Cairns, 1994; Van Dam et al., 1994; Kavaliauskienė, 1996; Reynolds, 1998; Trifonova, 1998; Wetzel, 2001; Willén, 2001; Wehr, Sheath, 2003). In the Water Framework Directive 2000/60/EC, planktonic algae are classified as one of the bioindicators of the ecological status of lakes and rivers (Lepistö et al., 2006).

Since quite a number of Lithuanian lakes are regarded as mesotrophic, for the evaluation of the change trends of the status of such water bodies under local conditions, research should be made on the majority of these lakes, or the most typical representatives of their diversity should be selected for thorough studies. We have chosen the second solution – conducted research of the characteristic mesotrophic Lithuanian lakes. To cover a larger scope of mesotrophic lakes, we considered the information on zooplankton communities to be of great use. Lithuanian lakes are still inhabited by glacial relict crustaceans, including two planktonic calanoid species *Limnocalanus macrurus* (G. O. Sars) and *Eurytemora lacustris* Poppe. These calanoids dwell exclusively in mesotrophic lakes, moreover, they are never detected in the same locality (Grigelis, Arbačiauskas, 1996, 1997). Thus, according to zooplankton communities, Lithuanian mesotrophic lakes can be divided into three (characteristic) groups: lakes inhabited by *L. macrurus,* those inhabited by *E. lacustris* and lakes devoid of relict planktonic crustaceans. We assume that research on several lakes of each aforementioned group could provide sufficient information for the evaluation of the status of Lithuanian mesotrophic lakes. On the other hand, there was no research conducted to find out whether and to what extent plankton communities of the above-mentioned lake groups differ.

The current study focuses on the research of summer plankton, as summer is a suitable time for water quality assessment on the basis of phytoplankton due to comparatively stable environmental conditions typical of the lakes of the temperate climate zone (Eloranta, 1993; Padisák et al., 2006; Szeląg-Wasielewska, 2007). On the other hand, the majority of planktonic algae species spend just a certain part of their life cycle in the water column, the other part of it being resting stages (Padisák, 1992; Rengefors, 1997, Ståhl-Delbanco, 2004). Consequently, for the evaluation of the status of lakes, research on the seasonal dynamics of phytoplankton, as well as on regularities of cell activation from resting stages is also informative.

Due to human economic activity, eutrophication of lakes has been lately observed (Kirilova et al., 2010). Alongside, it could be partly caused by the climate change (Blenckner, 2005; Blenckner et al., 2007; De Senerpont Domis et al., 2007). Due to lake eutrophication resulting in the depletion of oxygen in the hypolimnion, glacial relict crustaceans are vanishing from some of the lakes (Сущеня, 1986; Plambeck, 2001 cit. from Kasprzak et al., 2005). That is why information on zooplankton and relict planktonic crustaceans in particular is very important for the evaluation of the present ecological status of Lithuanian mesotrophic lakes and the prediction of its development trends.

The aim of the present research was to identify defining characteristics of phytoplankton and zooplankton community structure and change in Lithuanian mesotrophic lakes, compare plankton communities in different lake groups, and to assess the trends of changes in Lithuanian mesotrophic lakes.

Tasks:

- to determine the abundance, diversity and species structure of phytoplankton, and distinguish its dominating species;
- to establish the succession of phytoplankton communities during the active vegetation period;
- to perform the tests on the impact of major environmental factors on the activation of phytoplankton resting stages;
- to study the abundance, diversity and structure of zooplankton species;
- to estimate the abundance of zooplankton glacial relict species and the status of their populations;
- to assess the trophic status of the lakes and the trends of its change.

Defensive statements:

- Phytoplankton and zooplankton communities of the studied lakes are characteristic of mesotrophic water bodies;
- The major factor for the activation of algae resting stages is light, though its effect on separate algae classes is not equally important;
- Significantly larger amount of algae activated from sediments of the deep part of the lake indicates the higher concentration of algae resting stages in these bottom sediments than in those of the shoreline;
- Relict planktonic crustaceans survived in those lakes which were previously reported for their presence;
- Interannual variation in relict calanoid *Limnocalanus macrurus* population density is greater than that of another calanoid *Eurytemora lacustris*. This difference suggests the increased probability of local *L. macrurus* population extinction.
- While comparing plankton communities of separate mesotrophic lake groups, significant differences for planktonic crustaceans were determined, whereas differences for phytoplankton were not ascertained except the peculiarities of seasonal dynamics.

Novelty of the study. In this study, complex analysis of phytoplankton and zooplankton structure was performed in mesotrophic lakes. Our data indicate the current status of Lithuanian mesotrophic lakes, and complement the information on phytoplankton and zooplankton in these water bodies. Phytoplankton and zooplankton communities were compared in different groups of mesotrophic lakes. For the first time interranual variation of population density of glacial relict crustaceans *Limnocalanus macrurus* and *Eurytemora lacustris* were compared. Higher interranual variability in the density of *L. macrurus*, comparing to *E. lacustris*, show higher *L. macrurus* sensibility to the changes of the environmental condition in hypolimnion.

For the first time in Lithuania, analysis of the activation factors of algae resting stages was conducted. Also, 32 new species of algae and cyanobacteria were identified and registered in the studied Lithuanian lakes.

Significance of the study. The current status of Lithuanian mesotrophic lakes was assessed. The data obtained complemented the information on plankton communities in these water bodies. The impact of environmental factors on the activation of phytoplankton resting stages was estimated. The obtained results are important for the evaluation of the ecological status of the lakes, and provide its environmental control tools.

Presentation of the results. The results of this study were presented at seven regional and international conferences: European large lakes symposium “Ecosystem changes and their ecological and socioeconomic impact” (2006); international young researchers’ symposium “Environment and the world” (2006); regional student conferences “Biodiversity and functioning of aquatic ecosystems in the Baltic Sea region” (2006, 2008, 2009); “Biodiversity and functioning of aquatic ecosystems” (2005, 2007).

Structure of the dissertation. The doctoral dissertation is written in Lithuanian and includes: introduction, literature review, characterization of water bodies, research material and methods, research results, discussion, conclusions, references (162 cited literature sources) and an appendix. The dissertation is illustrated with 36 figures and 13 tables. The volume of the dissertation is 139 pages (including appendix).

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MATERIALS AND METHODS

The research work was carried out during 2004-2005 in ten lakes. Lakes Baluošas, Šakarvai and Ūkojas are inhabited by *L. macrurus,* lakes Asveja, Baluošai and Daugai inhabited by *E. lacustris* and rest of lakes are devoid of glacial planktonic crustaceans.

Material for phytoplankton and zooplankton research was collected in July 2004 – 2006 in lakes Asveja, Baluošas, Baluošai, Daugai, Dusia, Plateliai, Seirijis, Šakarvai and Ūkojas. Material for the seasonal succession of phytoplankton was obtained in May and September 2006 from lakes Baluošas, Baluošai, Daugai, Šakarvai and Ūkojas, as well as in September from lakes Asveja, Dusia and Seirijis. The samples of phytoplankton for the research of the seasonal succession in Lake Nevardas were collected in April-

October 2005, and in May-October 2006. In May 2005 and June-July 2006, bottom sediment samples were collected for the research of the activation of algae resting stages. In total, 27 zooplankton, 51 phytoplankton and 218 algae resting stages test samples were analysed.

Water samples were collected with 2-litre water samplers in the deepest part of a lake. Integrated phytoplankton samples were taken from surface water, the depth that corresponded to the half of the Secchi depth; the depth adequate to the Secchi depth, and double the Secchi depth (Kavaliauskienė, 1996).

Water transparency (Secchi depth) was measured with a Secchi disk. Temperature, pH, dissolved oxygen and conductivity were measured *in situ* by selective electrodes of a universal portable WTW MultiLine F/Set 3 measuring instrument. Samples for chemical analyses were collected from surface and bottom water levels in April 2005 (spring overturn) and July 2006 (summer thermal stratification).

Phytoplankton samples were fixed with 40% formaldehyde solution (4% final concentration) and concentrated by the sedimentation method (Kavaliauskienė, 1996). Phytoplankton was analysed on a "Biolar" light microscope at ×600 magnification.

Algae abundance was determined using the Fuchs–Rosenthal counting chamber (volume 0.0032 mm^3). At least 500 units of algae were counted (Kavaliauskienė, 1996, HELCOM, 2008). The counting unit of filamentous cyanobacteria was 100 µm, colonial, coenobian algal species – colony or cenobium, of other – a cell (HELCOM, 2008). The total phytoplankton abundance was calculated according to Абакумова (1983). The dominating groups of algae and complexes of the prevailing species were ascertained according to Давидова (1986). The biomass was estimated from cell numbers and specific volumes (Olrik et al., 1998). Taxa of the highest order were presented according to Parker (cit. Саут, Уиттик, 1990). Chlorophyll *a* values were indicated spectrophotometrically by Porsons, Stricland (1963) and Jeffrey, Humphrey (1975), the values were calculated by SCOR-UNESCO (1966) suggested formula. The trophic state indices (TSI) were calculated according to Carlson (1977). The diversity of phytoplankton was evaluated by calculating the Shannon–Wiener diversity index (H') (Shanon, Wiener, 1949).

Test on algae activation from diapause. In Lake Nevardas on 18 May 2005 and on 4 June and 3 July 2006, bottom sediment samples were collected, including three samples both from 14-metre depth and the shoreline of 1.5-2 m depth. The samples were collected with a cylinder, and 2 cm of the sediment surface level were kept in cold (4°C) and in the dark. In 24 hours, 5 ml of bottom sediments were placed into 50 ml glass test-tubes and kept in 20 ml filtered (pore size 0.45 µm) lake water. Three glass test-tubes with bottom sediments from the shoreline, and three of them from the deep part of the lake were kept in the light (in natural photoperiod), in a thermostat under the temperature of 20°C. Correspondingly, three glass test-tubes with sediments from the bottom level and three – from the shoreline were kept in the dark (darkened test tubes) in the same thermostat under 20°C.

Later, every three 24 hours, the water was carefully removed for analysis, and the new filtered lake water of the same temperature was poured on the bottom sediments. The removed water was analysed in the Fuchs-Rosenthal counting chamber with a light microscope.

Zooplankton samples were collected by vertical hauling from the bottom to the surface using plankton net with a cone-shaped opening with a diameter of 25 cm. The samples were preserved in 4% formaldehyde solution and later analysed on a binocular microscope in Bogorov chamber. At least 100 individuals of the most abundant zooplankton species were counted (HELCOM, 2008; Gasiūnaitė, Arbačiauskas, 2009). The biomass (wet weight) was counted according to the allometric body length-weight relations (Салазкин et al., 1984; Gasiūnaitė, Arbačiauskas, 2009). The individual weight of a crustacean was calculated by dividing the crustacean biomass in a sample by the crustacean abundance.

Statistical analysis. One-way ANOVAs, nested ANOVAs, Kruskal-Wallis and Tukey HSD tests wer applied for the comparison of the abundance and biomass of phytoplankton and zooplankton communities, as well as other indices in separate lakes, lakes group and different research periods. Correlations were calculated according to Spearman Rank Order Correlations. Chlorophyll *a* data of the current study were compared with the previous data (for the lakes for which information is available) using nested ANOVA. Interannual density variation in populations of each relict species across studied lakes was estimated by the residual mean square error obtained from one-way ANOVAs and tested for significance of difference following Sokal and Rohlf (1995). The algae cell activation data were analysed by repeated measures ANOVAs.

The Bray-Curtis index of similarity was employed for the comparison of phytoplankton and zooplankton communities. It is calculated by applying the square root transformation to data on abundance. The data were analysed using different software: Statistica 6.0, Primer 5.2.3, Microsoft Excel.

GENERAL CHARACTERISTICS OF THE WATER BODIES

All investigated lakes, except Daugai, Nevardas and Serijis, are located in the protected areas of Lithuania. Lakes Asveja, Baluošai, Daugai, Plateliai, Šakarvai and Ūkojas belong to the deep lakes' group in which the water column is stratified in summer. Lakes Baluošas, Dusia and Seirijis belong to thermally moderate deep lakes (Chomskis, 1969). The studied lakes differ in morphology and land use of catchment area (Table 1). The major part of the catchment area (52-86%) of lakes Asveja, Daugai, Dusia, Plateliai, Seirijis and Ūkojas is used as agricultural land, and that of lakes Baluošas, Baluošai and Šakarvai is persisted by natural biotopes (77-88%) (Balevičienė et al., 2009).

Table 1. Morphometric characteristics of investigated lakes and land-use of their catchment.

Lake	Maximum depth, m	Mean dept, m	Area, ha	Volume, thousand. m³	Land-use of catchment area (Corine LC)		
					Villages	Agricultural land	Natural biotopes
Asveja	50.2	14.9	1015.1	148846.7	1.0	52.7	46.4
Baluošas	33.1	10.7	427.3	43991	0.6	11.3	88.1
Baluošai	37.5	12.5	251.6	31387	0	16.5	83.6
Dusia	32.6	15.4	2334.0	359000	5.5	68.0	26.5
Daugai	44.0	13.2	912.7	125836	2.1	86.6	11.3
Nevardas	21.0	12.0	4.8	–	–	–	–
Plateliai	46.0	11.4	1205.0	136400	2.7	60.8	36.5
Seirijis	19.2	7.9	501.2	39805	1.0	64.9	34.2
Šakarvai	40.0	16.5	79.5	13147.5	2.6	20.1	77.4
Ūkojas	30.5	11.3	210.0	23742.3	2.1	67.7	30.2

RESULTS AND DISCUSSION

During research in 2004, the surface water temperature ranged from 17 to 24°C, and in the bottom water level – from 4.4 to 7.4°C (Table 2). In 2005 and 2006, the temperature was slightly higher and varied between 6.5-12.4°C. Dissolved oxygen concentration in the surface water in all lakes ranged from 6 to 10.6 mg L^{-1}, while in the bottom water level of lakes Seirijis, Šakarvai, Baluošas and Ūkojas oxygen depletion was noted, i.e. oxygen concentration was less than 2 mg L^{-1}. Water transparency was the highest (7.4 m) in Lake Plateliai in 2004, and the lowest (2 m) – in Lake Asveja in 2005.

Table 2. Some hydrophysical and hydrochemical parameters of studied lakes in July of 2004-2006.

Lake	Secchi depth, m	T, °C surface/ bottom	pH surface	O_2,mg L^{-1} surface/ bottom	Conductivity, µS cm^{-1} surface	TN mg L^{-1} 2005 April/ 2006 July
Asveja	2.0-3.3	21.3-23.1/ 6.7-6.9	8.0-8.5	13.0-8.4/ 6.2-6.7	347-358	1.23/1.12
Baluošas	2.5-5.6	21.5-23.8/ 6.8-10	8.5	6.8-8.9/ 0.5-3.3	318-323	0.62/0.82
Baluošai	2.5-3.6	20.9-22.0/ 5.0-8.0	8.0-8.5	8.5-8.8/ 2.9-5.0	341-348	0.72/1.26
Daugai	2.9-3.8	19.0-23.0/ 7.4-12.0	8.0-10,5	6.0-8.8/ 6.0	344	0.85/1.14
Dusia	5.0-5.3	17.4-22.0/ 11.6-11.9	7.5-8.9	8.0-8.9/ 2.0-4.0	340-343	0.78/1.34
Nevardas	2.5-3.2	24.1/ 6.5-7.7	7.4-7.5	5.8-7.3/ 0	262-273	0.018/1.24
Plateliai	6.0-7.4	19.4-21.8/ 6.1-8.9	7.2-8.7	7.5-9.1/ 6.2-8.7	201	0.63/0.74
Seirijis	4.5-6.1	17.5-22.8/ 12.4	7.5-8.9	7.5-10.0/ 0.8-1.7	265-298	0.72/1.16
Šakarvai	3.0-6.6	21.9-23.7/ 4.4-7.8	8.0-8.3	7.0-9.0/ 1.2-3.1	333-338	0.57/1.02
Ūkojas	3.0-3.7	21.5-22.9/ 6.6-9.7	8.3-8.6	7.4-9.6/ 1.6-2.2	366-368	1.31/1.00

Water conductivity values which partly reflect the total concentration of dissolved salts and other chemical compounds in the studied lakes varied from 201 (in Lake Plateliai) to 368 µS cm^{-1} (in Lake Ūkojas).

Total nitrogen and phosphorus concentrations reflect the water quality in lakes. Lake trophicity depends on the concentration of biogenic materials (Wetzel, 2001). During the study period, total phosphorus (TP) did not exceed 0.02 mg L^{-1} in the surface water level of all lakes in spring overturn and summer stratification. Such values of one of the major biogenic elements are typical of mesotrophic lakes (Wetzel, 2001; Kilkus, 2005). Total nitrogen (TN) in the surface water level ranged from 0.57 to 1.34 mg L^{-1}. According to J. Kavaliauskienė (1996) the lakes in which total nitrogen concentration does not exceed 0.70 mg L^{-1} are attributable to mesotrophic with oligotrophic traits, and those with total nitrogen concentration 0.70-1.50 mg L^{-1} – to mesotrophic with eutrophic traits. Thus, basing on the data obtained, Lake Plateliai could be classified as mesotrophic with oligotrophic traits, whereas all remaining lakes – as mesotrophic with eutrophic traits. Comparing our data with the previously obtained results, it was revealed that total nitrogen and phosphorus concentrations have not markedly changed. Average total nitrogen concentration in lakes in 1970-1991 varied from 0.40 to 1.88 mg L^{-1}, and that of total phosphorus – from 0.02 to 0.15 mg L^{-1} (Kavaliauskienė, 1996). The total amount of nitrogen in lakes Baluošas, Dusia, Plateliai and Šakarvai decreased, in Lake Daugai remained similar, and in Lake Seirijis increased twofold.

Phytoplankton communities. During the study period, 258 taxa of algae and cyanobacteria were recorded in 10 lakes. A high diversity of species was most characteristic of Chlorophyceae – 95 species (37%). By the number of species, other classes were distributed as follows: Bacillariophyceae – 72 species (28%), Cyanophyceae – 32 (12%), Euglenophyceae – 26 (10%), Chrysophyceae – 23 (9%), Dinophyceae – 6 (2%), Cryptophyceae – 2 (1%) and Xantophyceae – 2 species (1%). 52 algae were described to genera.

Algae of these classes also prevail in phytoplankton of mesotrophic water bodies of other countries (Трифонова, 1990; Padisác, 1992; Trifonova, 1998). The highest diversity of species was found in mesotrophic with eutrophic traits Lake Nevardas – 186, and the lowest (65) – in Lake Dusia (Fig. 1). The different number of algae species was predetermined by different lakes' investigation level. According to the data obtained by J. Kavaliauskienė (1996), the number of algae species in Lithuanian mesotrophic lakes varies between 41 and 221.

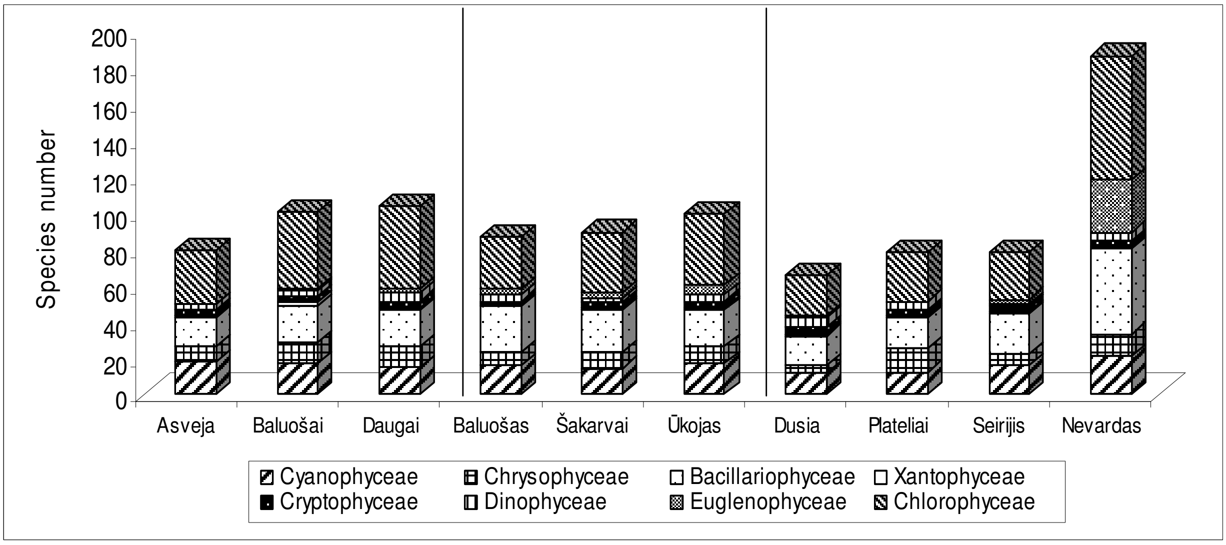

Fig. 1. Planktonic algae species richness in study lakes. Lake groups separated by vertical lines.

Nine algae species (green algae *Oocystis rhomboidea*, *Phacotus lenticularis*, *Tetraedron minimum*, diatoms *Asterionella formosa*, *Fragilaria crotonensis*, *Synedra acus*, golden-brown algae *Dinobryon divergens*, dinoflagellates *Ceratium hirundinella* and cyanobacteria *Aphanocapsa delicatissima*) were found in all investigated lakes.

Thirty two new algae species for Lithuanian freshwater ecosystems belonging to five classes were recorded. These are: cyanobacteria *Aphanothece nidulans*, *Gleothece subtilis*; golden-brown algae *Chromulina nebulosa*, *Mallomonas denticulata*, *Desmarella moniliformis*, *Dinobryon crenulatum*, *Dinobryon peliolatum*, *Dinobryon suecicum*, *Monosiga varians*, *Ochromonas mutabilis*, *Ochromonas pallida*, *Salpingoeca oblonga*, *Salpingoeca semiovata*, *Sphaleromantis ochracea*; diatoms *Amphiprora ornata*, *Cymatopleura turicensis*, *Cymbella tumida*, *Eunotia fallax*, *Neidium affine*; euglenoids *Euglena gracilis*, *Euglena hemichromata*, *Euglena polymorpha*, *Euglena variabilis*, *Lepocinclis elongata*, *Lepocinclis Steinii*, *Menoidium pellucidum*, *Rhabdomonas incurva*, *Trachelomonas rotunda* and green algae *Provasoliella sinica*, *Chloromonas acidophila*, *Asterococcus limneticus*, *Staurastrum mansfeldtii*. The majority of new species (21) were found in Lake Nevardas. Also, all euglenoid species were found in this lake.

The Shannon–Wiener diversity index revealed the heterogeneity of phytoplankton community. The diversity index in all lakes ranged between 1.4 and 4.4. The lowest value was found in Lake Baluošas in 2006. The prevalence of *Cyclotella comensis* (77% of the total phytoplankton abundance and 32.5% of the total biomass) was associated with the lowest diversity in this lake. The highest value of diversity was found when three species prevailed in phytoplankton and made up 9.9-24.6% of the total abundance. The highest index variation during three years' time was determined in lakes Baluošas and Nevardas. In lakes Asveja, Dusia, Plateliai, Seirijis and Šakarvai, the values' variation was negligible. The values of the Shannon–Wiener diversity index in different lakes were not statistically different (H': KW-H (9.29) = 10.73, p = 0.29).

In the studied lakes, the abundance of phytoplankton varied from 0.25 mln. units L^{-1} in Lake Plateliai in 2005 up to 1.83 mln. units L^{-1} in Lake Asveja in 2004. Variation in the total abundance of phytoplankton during three years' time was the highest in lakes Asveja, Baluošas and Ūkojas, whereas in the rest of the lakes its variation was low (Fig. 2).

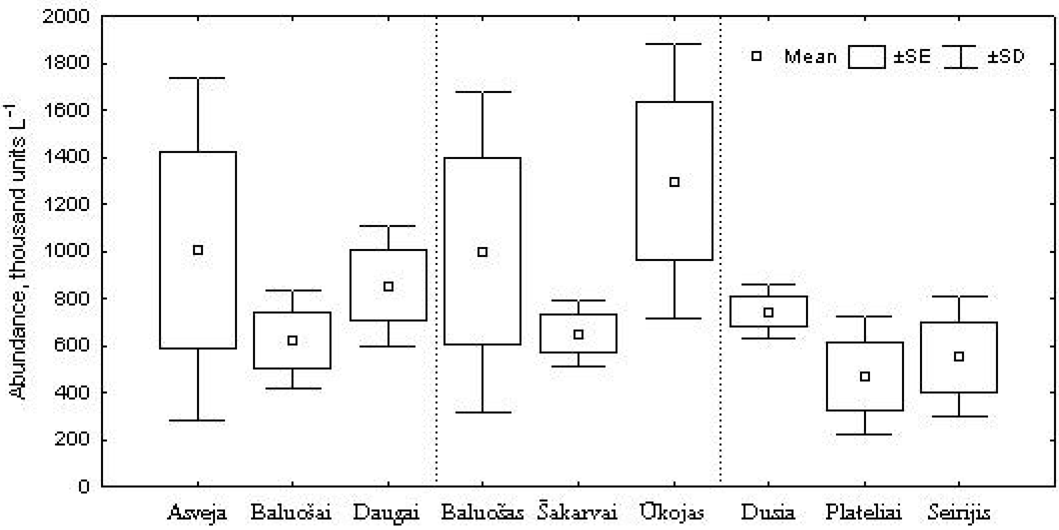

Fig. 2. Variation in phytoplankton abundance in study lakes in July during 2004-2006.

The phytoplankton biomass in the studied lakes varied from 0.11 mg L^{-1} in Lake Plateliai in 2005 up to 1.20 mg L^{-1} in Lake Ūkojas in 2006. The highest variation in phytoplankton biomass was determined in lakes Asveja and Ūkojas, the lower variation – in lakes Baluošai, Dusia and Plateliai, and the variation in lakes Seirijis and Šakarvai was negligible (Fig. 3). Despite the fact that in some lakes the biomass of phytoplankton exceeds 1 mg L^{-1}, the average values are still typical of mesotrophic water bodies (Kavaliauskienė, 1996).

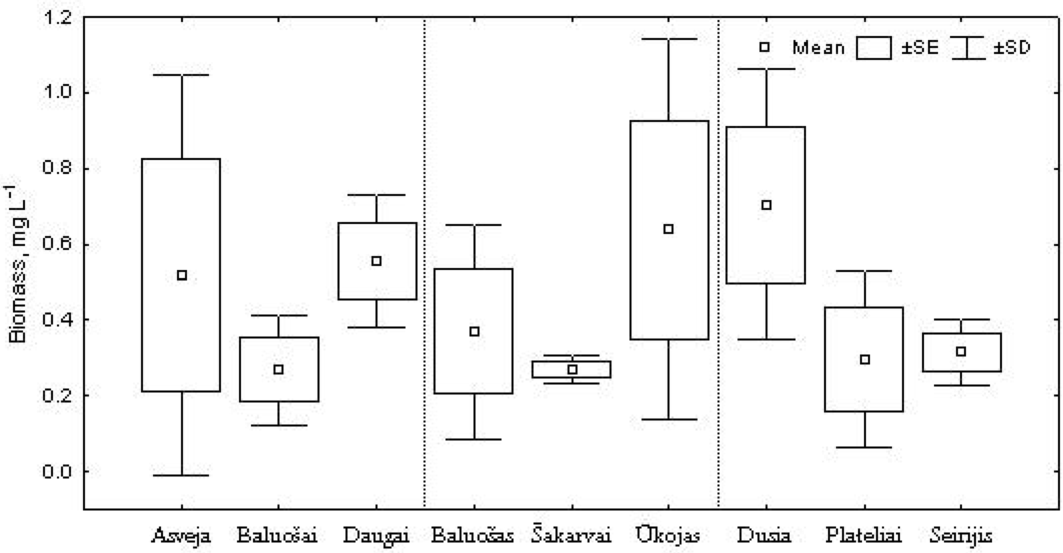

Fig. 3. Variation in phytoplankton biomass in study lakes in July during 2004-2006.

Phytoplankton abundance and biomass in separate lakes and in different study years was not statistically different (one-way ANOVA: lake effect: $F_{8,18}$=1.17; p=0.36 and $F_{8,18}$=0.90; p=0.53 and period effect: $F_{2,24}$=0.35; p=0.70 and $F_{2,24}$=1.74; p=0.19, correspondingly). Comparing phytoplankton abundance and biomass between separate lake groups, reliable differences were not ascertained either (nested ANOVA: group effect: $F_{2,18}$=1.98, p=0.16 and $F_{2,18}$=0.01, p=0.98, correspondingly).

Since different taxonomic groups and species have different requirements and tolerance ranges for various environmental factors, phytoplankton provides a good tool for lake classifications (Reynolds, 1998; Trifonova, 1998, Wetzel, 2001). Summer phytoplankton communities in temperate lakes are generally regarded as quite stable as a result of the environmental stability. Consequently, late summer is a good time for water quality assessment (Eloranta, 1993; Kavaliauskienė, 1996; Padisák et al., 2006; Szeląg-Wasielewska, 2007).

Green algae *Oocystis rhomboidea*, *Phacotus lenticularis* prevail in lakes Asveja, Baluošai, Plateliai and Ūkojas. *Sphaerocystis* sp. prevails according to biomass. Development of *Oocystis* and *Sphaerocystis* algae are typical of many clear water bodies (Трифонова, 1990). *Phacotus* is an alga of stagnant inland waters of various morphometric and ecological status: from deep stratified oligotrophic lakes to shallow polymictic hypertrophic waters (Schlegen et al., 1998). Diatoms, which were abundant in lakes, are common in mesotrophic water bodies. *Cyclotella comensis* made up to 77% of the total phytoplankton abundance in Lake Baluošas in 2006. *Fragilaria crotonensis* were abundant in Lake Šakarvai, *Asterionella formosa* – in lakes Asveja, Daugai, Dusia and Seirijis. Usually, the diatom genera *Asterionella* and *Fragilaria* are characteristic of eutrophic waters (Reynolds, 1998; Kavaliauskienė, 1996; Трифонова, 1990). Some researchers indicate the diatom *Asterionella formosa* as a species typical of mesotrophic or even oligotrophic lakes (Rosen, 1981; Happey-Wood, 1988). Cyanobacteria *Planktothrix agardhii* made up to 45% of the total phytoplankton abundance and biomass in Lake Baluošas in 2004. This species is an indicator of organic matter in a lake. The emergence of this species is associated with anthropogenic eutrophication of a water body (Rosen, 1982; Kavaliauskienė, 1999; Kango & Noges, 2003; Kango et al., 2005). The development of *Planktothrix agardhii* had been recorded in earlier years

(Kavaliauskienė, 1996), but in 2005–2006, no intensive development of this species was noted.

Together with biomass, to calculate the trophic status of lakes chlorophyll *a* concentration is frequently used, because this parameter is an indicator of phytoplankton productivity (Трифонова, 1990; Kavaliauskienė, 1996; Щербак и др., 2006; Aponasenko et al., 2007; French, Petticrew, 2007). With the increase of biogenic elements in water (eutrophication), phytoplankton undergoes rapid development, and the increase of chlorophyll *a* is observed (Бульон, 1983).

In summer of 2004-2006, chlorophyll *a* concentration in the studied lakes varied from 1.3 to 7.6 µg L^{-1} (Fig. 4). In Lake Nevardas in 2005 and 2006, the average chlorophyll *a* in the vegetation season was 6.04 and 8.4 µg L^{-1}, respectively.

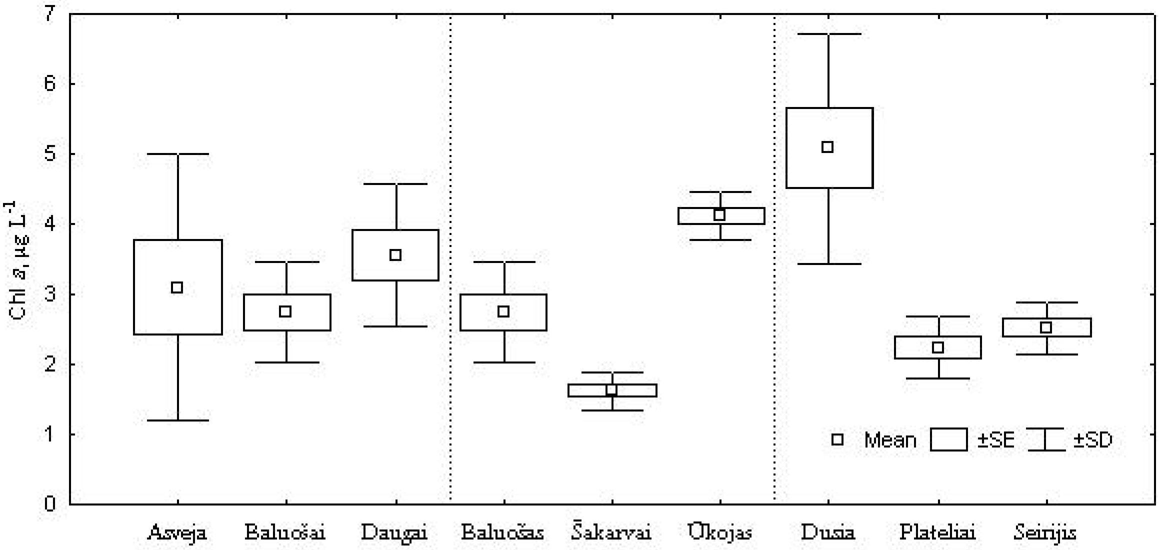

Fig. 4. Variation in chlorophyll *a* concentration in study lakes in July during 2004-2006.

Correlation between phytoplankton biomass and chlorophyll *a* concentration in our study was moderate (r_2=0.310, r=0.557, p=0.003). Also, the correlation between chlorophyll *a* and proportion of the agricultural land in a lake catchment was established (r^2=0.17, r=0.41, p=0.03). When comparing chlorophyll *a* concentration, significant differences between lakes were determined, whereas differences between lake groups were absent (nested ANOVA, lake group effect: $F_{2,63}$=1.31, p<0.27; lake effect: $F_{6,63}$=11.26, p<0.001).

We compared the data on chlorophyll *a* concentration in 1987-1991 in lakes Baluošas, Daugai, Plateliai, Seirijis and Šakarvai obtained by J. Kavaliauskienė with our data and found no significant difference (nested ANOVA, lake effect: $F_{4,14}$ = 4.5, p=0.015; period effect: $F_{5,14}$ =1.3, P=0.33).

From chlorophyll *a* levels and Secchi depth it is possible to estimate the trophic state index (TSI). In the studied lakes, the TSI (SD) ranged from 31 to 50 and the TSI (Chl) from 34.7 to 50.5, and those values are associated with mesotrophy (Carlson, 1977). As compared with the data calculated by J. Kavaliauskienė in 1987-1991, the TSI values in lakes Šakarvai and Plateliai remained similar, while in Lake Daugai in 1987 they were slightly higher. In Lake Seirijis, the TSI (SD) was notably higher, but the TSI (Chl) was lower. The TSI (SD) values between lakes significantly varied (one-way ANOVA, $F_{8,18}$=4.85, p=0.025), whereas the TSI (Chl) values were not statistically different ($F_{8,18}$=2.38, p=0.59).

Thus, our results suggest that all studied lakes with respect to chlorophyll *a*, phytoplankton biomass and trophic state index still may be characterized as mesotrophic lakes.

Seasonal dynamics of phytoplankton communities. With the change of environmental conditions in water bodies during the year, abundance, diversity and biomass of phytoplankton species undergo changes as well. In 2006, in lakes selected for the study of seasonal dynamics of phytoplankton, its abundance in May varied from 0.29 to 1.01 mln. units L^{-1}, and its biomass – from 0.26 to 0.63 mg L^{-1} (Fig. 5). In July phytoplankton abundance varied from 0.49 to 1.92 mln. units L^{-1}; biomass – from 0.13 to 1.20 mg L^{-1}. In September phytoplankton abundance varied from 0.13 to 0.92 mln. units L^{-1}, biomass – from 0.10 to 0.26 mg L^{-1}.

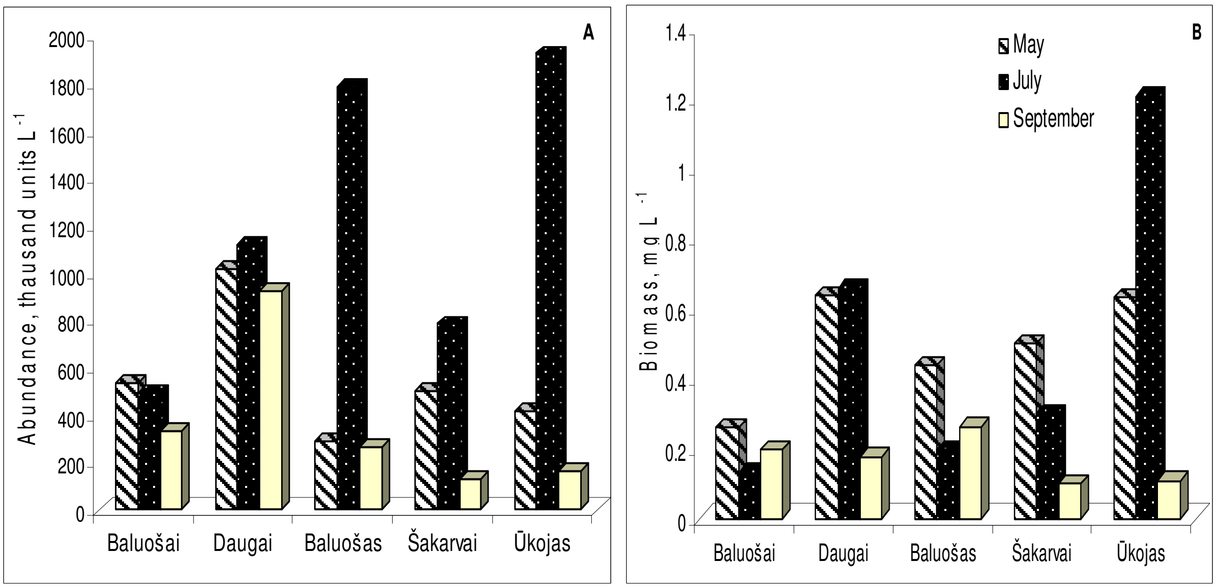

Fig. 5. Phytoplankton abundance (A) and biomass (B) in study lakes in May, July and September in 2006.

The peak of phytoplankton abundance was observed in July (one-way ANOVA: month effect: $F_{2,12}$=5.97, p=0.016; HSD test: difference between summer and spring p=0.09, difference between summer and autumn p=0.014), and of biomass – in May (in lakes Baluošas, Baluošai and Šakarvai) and July (in lakes Daugai and Ūkojas). The highest abundance and biomass of phytoplankton was found in Lake Ūkojas.

Peculiarities of seasonal dynamics in phytoplankton structure were predetermined by the changes in most abundant species of the prevailing algae classes – golden-brown algae, diatoms, green algae and cyanobacteria in 2006. In spring, the lakes were dominated by golden-brown algae (*Dinobryon divergens*, *D. sociale*) and diatoms (*Cyclotella* sp.) except Lake Daugai which was dominated by cyanobacteria *Limnothrix redekei*. Diatoms are characterized by photoadaptive features which enables their development under conditions of low and variable light intensity in lakes in spring and autumn. Besides, they are tolerant to low water temperatures (Round et al., 1990; Willén, 1991). Golden-brown algae substitute diatoms in case of decreased concentrations of silicon and calcium in water (Kavaliauskienė, 1996; De Hoyos et al., 1998). In summer, diatoms persisted in lakes Baluošas and Daugai, cyanobacteria – in Lake Dusia, and green algae – in lakes Šakarvai and Ūkojas. In autumn, Lake Dusia was dominated by cyanobacteria, and Lake Daugai – by green algae.

According to J. Kavaliauskienė (1996), during earlier studies (1987), Lake Daugai was dominated by diatoms, and Lake Seirijis – by dinoflagellates, diatoms and cyanobacteria. In summer of 1979, Lake Šakarvai was dominated by cyanobacteria, and in spring – by diatoms. After a ten-year period, diatoms, dinoflagellates and cyanobacteria were the most abundant in it.

During research, the tendency that in lakes inhabited by relict crustacean *L. macrurus* phytoplankton is dominated by golden-brown algae and diatoms in spring and green algae in summer was observed. In autumn, dominating diatom species are supplemented by cyanobacteria or cryptophytic algae. In lakes inhabited by *E. lacustris*, diatom biomass in phytoplankton remains high during the whole vegetation season. Another important phytoplankton group is that of green algae which supplement diatoms in spring or autumn.

The more extensive research on seasonal dynamics was conducted in Lake Nevardas. In 2005, the peak phytoplankton abundance in this lake was observed in spring (up to 2.4 mln. units L^{-1}), and that of biomass – at the end of summer (up to 3.16 mg L^{-1}) (Fig. 6).

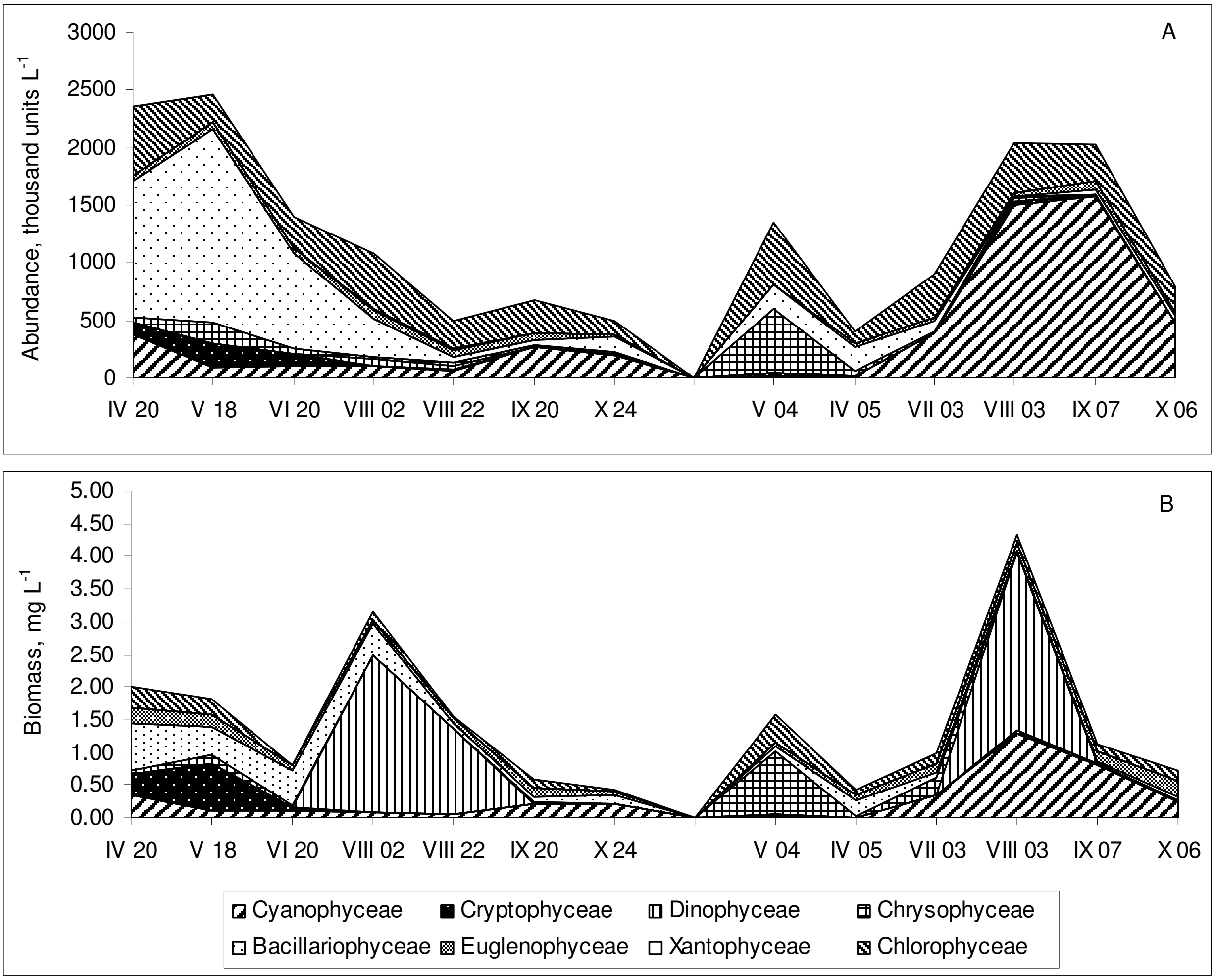

Fig. 6. Phytoplankton abundance (A) and biomass (B) in Lake Nevardas during 2005 – 2006.

Diatoms prevailed (up to 60%) in the lake during spring and early summer. Later they were substituted by green algae (up to 42%), and in autumn, phytoplankton was dominated by cyanobacteria (up to 29%). The increased concentration of nutrients in water at the end of the vegetation season has an effect on the development of cyanobacteria as well.

Alongside, in 2006, the fast development of phytoplankton was observed in August-September (about 2 mln. units L^{-1}), and the peak of the biomass (4.3 mg L^{-1}) as in previous years – in August which was caused by not numerous but of large individual weight dinoflagellates. In spring, plankton was dominated by golden-brown algae (38.9% of the total phytoplankton abundance), in June – by diatoms (52.8%), in July – by cyanobacteria (43%) together with green algae (41%), and since August – by cyanobacteria (even as much as 77% of the total phytoplankton abundance). The seasonal dynamics in Lake Nevardas in 2006 was similar to that determined in 1984 by J. Kavaliauskienė (1996). In that year, cyanobacteria (there are no data on dominant species) comprised from 66 up to 98% of the total phytoplankton abundance which varied between 0.9 and 6.5 mln. ind. L^{-1}. Despite the prevalence of cyanobacteria, the lake was attributed to mesotrophic water bodies.

I. Trifonova (1998) emphasizes that the seasonal succession of phytoplankton of mesotrophic lakes is characterized by the prevalence of diatoms and golden-brown algae, whereas with the increase of the trophic level of the lake, the dominance is taken over by cyanobacteria, euglenoids or green algae.

The seasonal dynamics of phytoplankton is predetermined by numerous abiotic and biotic factors. One of the abiotic factors regulating the development of planktonic algae is temperature. Algae of separate classes develop under different water temperature conditions, however, our data did not indicate statistically significant correlation (Spearman Rank) between separate algae classes and changes of water temperature.

One of the major biotic factors affecting the development of phytoplankton is zooplankton. Phytophags select small flagellate green algae, golden-brown and cryptophytic algae species (Gervais, 1998). The abundance of these species in phytoplankton highly depends on the abundance and species composition of zooplankton (Riemann et al., 1993; Bronmark, Hansson, 1998; Graham, Wilcox, 1999; Olden, 2000). In the studied lakes, suitable for consumers planktonic algae (<50 μm) comprised 26-99% of the total phytoplankton biomass. The largest amount (0.56±0.42 mg L^{-1}) of such phytoplankton was in Lake Ūkojas, and the smallest – in lakes Šakarvai and Seirijis (0.14±0.07 mg L^{-1} and 0.15±0.07 mg L^{-1}, respectively). For comparison, in mesoeutrophic Lake Gulbinas, phytoplankton suitable for zooplankton nutrition made up 67% of the total phytoplankton biomass (Krevš et al., 2004). Comparing the biomass of suitable for consumers planktonic algae between lakes, significant differences were not ascertained (nested ANOVA: $F_{2,18}=0.04$; $p=0.95$).

Besides zooplankton, development of phytoplankton could be affected by viruses- and fungi-induced diseases which could cause a sudden loss of the whole population (Graham, Wilcox, 1999). Viruses are especially harmful to large species which do not persist in the diet of zooplankton (Tijdens, et al., 2008).

Effect of environmental factors on the activation of resting stages. During the tests on activation of algae resting stages performed in 2005-2006, the following algae groups were detected in experimental samples: diatoms, green algae, euglenoids, golden-brown algae, cryptomonads, dinoflagellates and cyanobacteria. Diatoms were the most abundant. The highest richness and abundance of algae were found in samples kept in the light.

Repeated measures ANOVA indicated that light is not equally important for separate algae classes. Significant light effect was determined for diatoms, green algae and cyanobacteria, whereas for euglenoids and dinoflagellates light effect was not ascertained. Sediment sampling locality (shoreline or deep waters) was important for green algae, diatoms and cyanobacteria in June 2006, whereas in July 2006 – for green algae, euglenoids and dinoflagellates. Detection of abundant euglenoids in samples kept both in the light and in the dark could be explained by their capability to assimilate organic materials (Trifonova, 1990).

Table 3. Results of repeated measures ANOVAs testing for the effect of environmental factors (light, sediment sampling depth and time of exposure) on the activation of resting stages of different algae classes. Significant probabilities are in bold.

	Light		**Depth**		**Time**	
May 2005	**F**	**p**	**F**	**p**	**F**	**p**
Cyanophyceae	2.23	0.18	0.002	0.97	-	-
Bacillariophyceae	2.21	0.18	0.87	0.38	-	-
Chlorophyceae	4.94	0.06	0.001	0.98	-	-
Euglenophyceae	0.08	0.78	4.42	0.07	-	-
June 2006						
Cyanophyceae	59.55	**<0.01**	36.89	**<0.01**	0.81	0.50
Bacillariophyceae	711.57	**<0.01**	422.53	**<0.01**	38.22	**<0.01**
Chlorophyceae	113.33	**<0.01**	56.43	**<0.01**	23.55	**<0.01**
Euglenophyceae	2.56	0.148	1.86	0.21	16.32	**<0.01**
July 2006						
Cyanophyceae	9.22	**<0.05**	0.30	0.60	2.72	0.067
Bacillariophyceae	56.99	**<0.01**	1.09	0.33	2.36	0.10
Chlorophyceae	28.72	**<0.01**	45.71	**<0.01**	4.40	**<0.05**
Euglenophyceae	2.09	0.19	17.11	**<0.05**	16.14	**<0.01**
Dinophyceae	4.07	0.08	5.93	**<0.05**	0.77	0.40

Reliably more cells activated from resting stages in samples collected from deep waters of the lake and kept in the light, whereas the difference between samples from the shoreline kept in the light and in the dark was negligible (Fig. 7). Our findings suggest that the deep part of the lake is regarded as a potential bank of resting stages of planktonic algae, where under favourable environmental conditions the phytoplankton community undergoes regeneration. Field studies conducted by foreign researchers show that the cells return to water mass primarily from the shoreline because of more favourable temperature and light regimes, and more intensive water circulation (Karlsson-Elfgren et al., 2004, Rengefors et al., 2004). From the deep part of the lake, the cells are capable of returning to the water column under natural environmental conditions during spring and autumn water circulation.

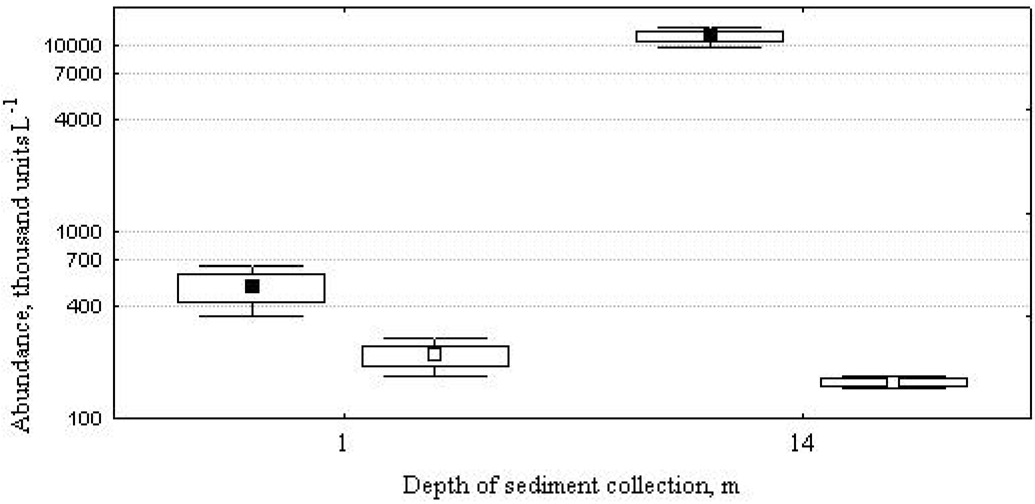

Fig. 7. Average abundance of algae in resting stages activation experiments with lake sediments collected at 1 and 14 m depths and kept in light (filled symbols) or dark (open symbols) at 20°C. Note logarithmic scale.

Algae species composition in activation experiment did not correspond to the species prevailing in lake phytoplankton during experimental study, and exhibited the prior species composition of algae community species structure in the water column. For instance, diatoms *Synedra acus* prevailed in phytoplankton in April and May, whereas in samples of phytoplankton of June merely single items were detected.

To sum up, the test on activation of algae resting stages indicates that the deep part of the lake is a potential bank of phytoplankton resting stages which enables regeneration of phytoplankton community under favourable environmental conditions. The results obtained also showed the importance of light for emergence from diapause of particular algae groups.

Zooplankton communities. During research, 25 metazooplankton species were recorded, including 15 species of Cladocera and 10 of Copepoda. The highest number of planktonic crustacean species (13 cladocerans and 6 copepods) was detected in Lake Daugai, and the lowest species diversity was determined in Lake Plateliai (8 cladoceran and 6 copepod species) (Fig. 8). For comparison, in mesotrophic Lake Piaseczno (Poland), in total 24 crustacean species were detected, among which 6 cladoceran and 4 copepod species were found in the pelagial (Adamczuk, 2004). Lake Wigry (Poland) was reported to contain 20 crustacean species: 13 cladocerans and 7 copepods (Czeczuga, Kozłovska, 2002). In Lake Volos (Belarus) which is also inhabited by the relict crustacean *L. macrurus*, 17 cladocerans and 11 copepod species were detected in the pelagial (Galkovskaya et al., 2006).

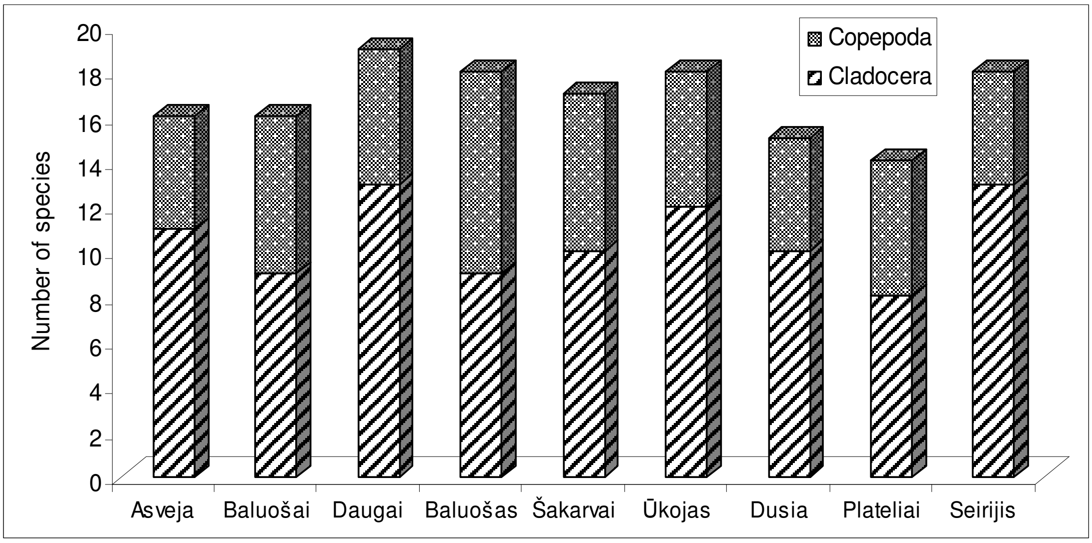

Fig. 8. Number of crustaceans species in study lakes in July during 2004-2005.

The abundance of planktonic crustaceans in studied lakes varied from 28.49 to 118.46 ind. L^{-1} (Fig. 9). The highest abundance variation was determined in lakes Dusia and Seirijis. The effect of individual lake and lake groups on the abundance of planktonic crustaceans were significant (nested ANOVA: lake effect: $F_{6,17}=8.72$, $p<0.001$; lake group effect: $F_{2,17}=10.89$, $p<0.001$).

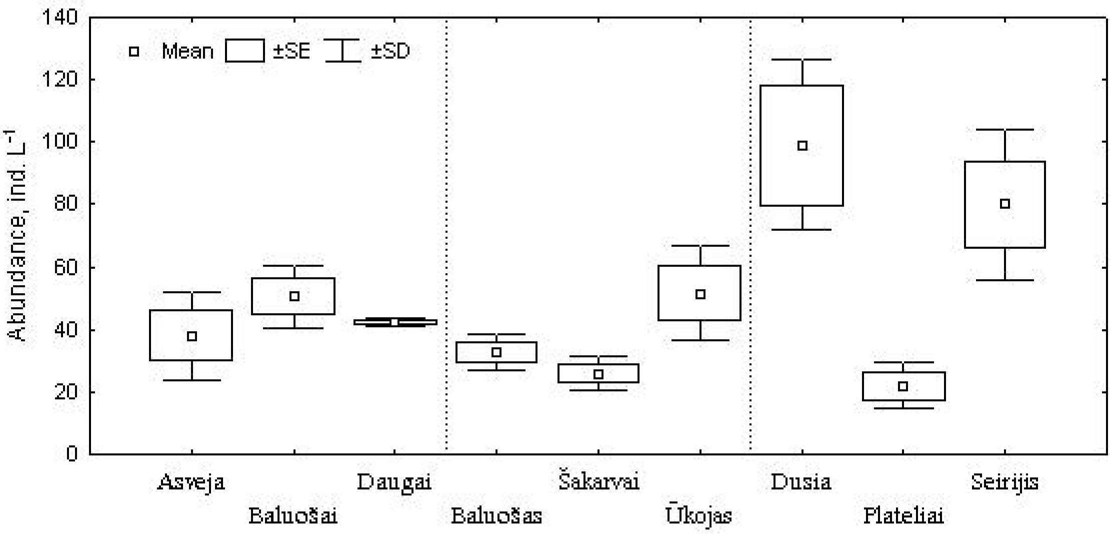

Fig. 9. Variation in zooplankton abundance in study lakes in July during 2004-2006. Lake groups separated by vertical lines.

In the studied lakes, the biomass of planktonic crustaceans varied from 0.42 to 3.13 mg L^{-1}, such values being typical of mesotrophic water bodies (Maniukas, Virbickas, 1975). The highest variation in zooplankton biomass was recorded in lakes Dusia, Seirijis and Ūkojas, whereas in other lakes it exhibited negligible variation (Fig. 10). As for abundance, effects of lake and lake group on planktonic crustacean biomass was significant differed (nested ANOVA: $F_{6,17}=5.14$, $p=0.003$ and $F_{2,17}=4.43$, $p=0.028$, respectively).

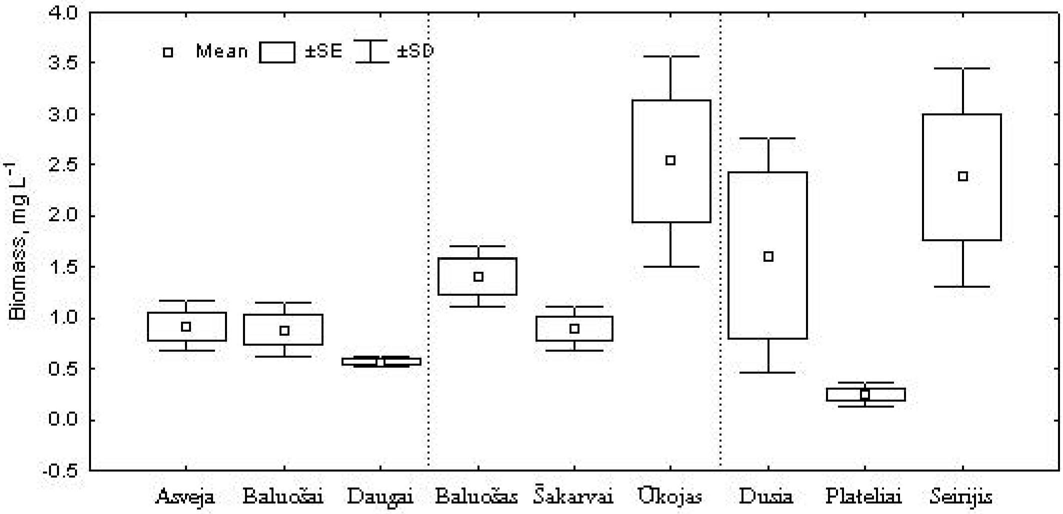

Fig. 10. Variation in zooplankton biomass in study lakes in July during 2004-2006.

The southern boundary of distribution range of glacial relict crustaceans stretches through Lithuania. These crustaceans are important not only for the understanding of the regularities of formation of the fauna of Northern Europe and the Baltic Sea, as well as its adaptation to changing environmental conditions, but also for economic purposes, as they make a major component in the diet of common whitefish. They also belong to environmentally important species being highly susceptible to anthropogenic impact (Grigelis, Arbačiauskas, 1996). Due to lake eutrophication resulting in the depletion of oxygen in the hypolimnion, these relict crustaceans are vanishing from some of the lakes (Сущеня, 1986; Plambeck, 2001 cit. from Kasprzak et al., 2005).

In our studied lakes, the abundance of *Limnocalanus macrurus* varied from 0.43 to 7 ind. L^{-1}, and its biomass – from 0.19 to 2.35 mg L^{-1} (Fig. 11). Correspondingly, the biomass of *L. macrurus* in Lake Ūkojas comprised 81-96% of the total metazooplankton biomass, in Lake Baluošas – 81-87%, and in Lake Šakarvai – 42-77%. The abundance of *Eurytemora lacustris* varied from 0.13 to 2.93 ind. L^{-1}, and the biomass – from 0.008 to 0.10 mg L^{-1}. Correspondingly, the biomass of *E. lacustris* in Lake Daugai made up 17.91-22.46% of the total metazooplankton biomass, in Lake Asveja – 1.76-3.42%, and in Lake Baluošai – 4.86-14.35%.

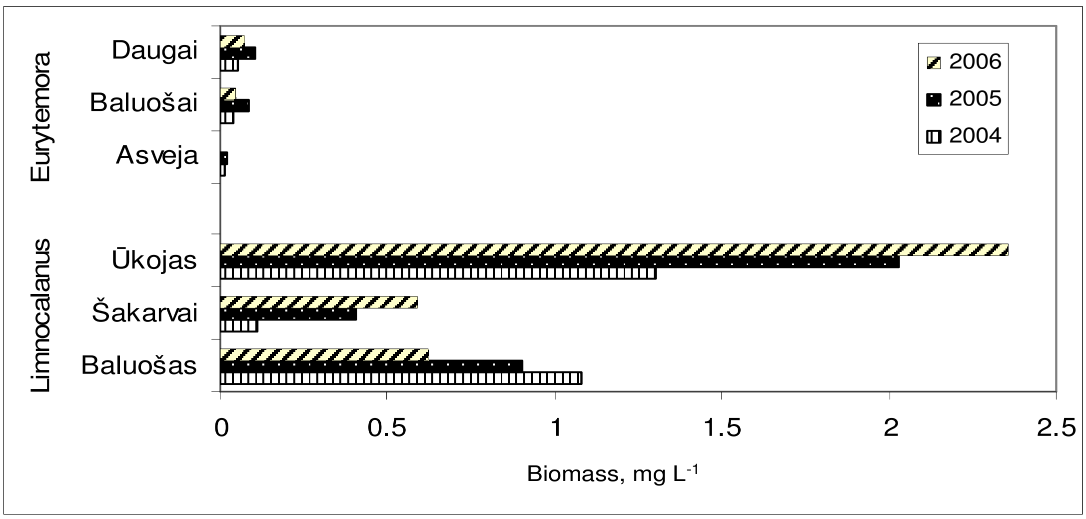

Fig. 11. Biomass of relict crustaceans *E. lacustris* and *L. macrurus* in study lakes in July during 2004-2006.

The research conducted by L. Blyžaitė (2007) in 2003 indicated that *L. macrurus* comprised 45% of the total biomass in Lake Baluošas, in Lake Ūkojas – 26%, and in Lake Šakarvai – 22%. *E. lacustris* had a markedly smaller share in the crustacean biomass making only 3% of its total biomass in Lake Daugai, and equally 2% – in Lake Baluošai and Lake Asveja.

The longest data sets (4-5 years) on the relict species density showed that interannual variability of density for *L. macrurus* was higher than that for *E. lacustris* (Fig. 12). The estimates of interannual variation in the density of relict species across lakes were derived from ANOVAs testing for lake effect. It was not significant for *L. macrurus* ($F_{4,13}$=2.55, p=0.089), but significant for *E. lacustris* ($F_{3,11}$=7.05, p=0.006). A comparison of variation between species further showed that interannual variability in the density of *L. macrurus* was significantly higher than that in the other calanoid species ($F_{13,11}$=14.196, P<0.001). Such a pattern further imply that *L. macrurus* is more sensitive than *E. lacustris* to environmental alterations in lake hypolimnion and consequently probability of extinction of local populations of the first species is higher.

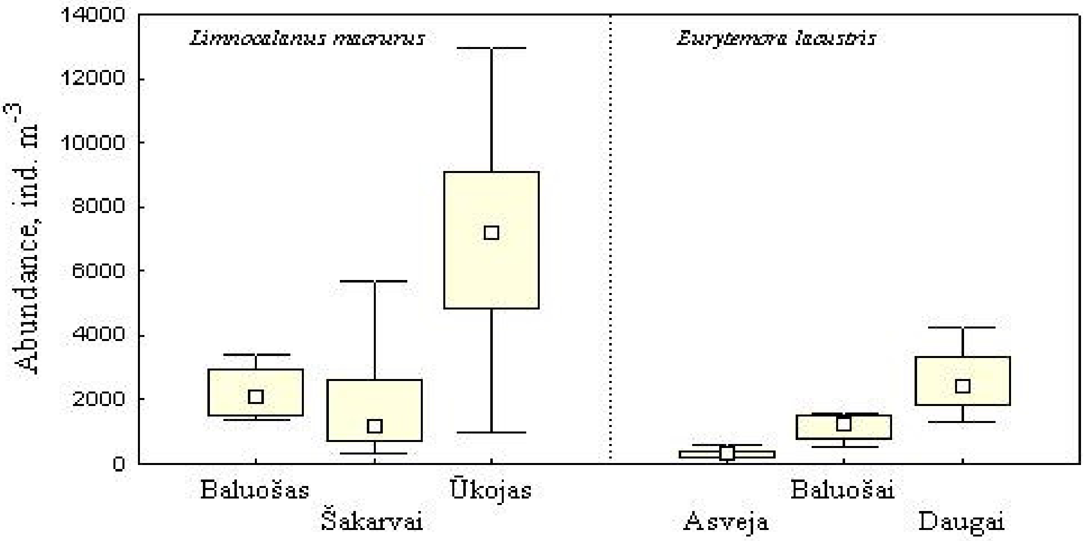

Fig. 12. Interannual density variation (median, quartiles and range) of *L. macrurus* and *E. lacustris*.

While comparing the studied lakes with respect to the abundance of zooplankton groups (i. e. Daphnia, Bosmina, Cyclopoida etc. Bray-Curtis similarity), the following lake groups were distinguished (Fig.13): lakes inhabited by the relict crustacean *Limnocalanus macrurus* (A) and those inhabited by *Eurytemora lacustris* (B). Lakes Plateliai, Seirijis and Dusia which are devoid of relict crustaceans made up a separate cluster. The most similar were the adjoining zooplankton communities of lakes Asveja and Baluošai, as well as those of lakes Šakarvai and Baluošas.

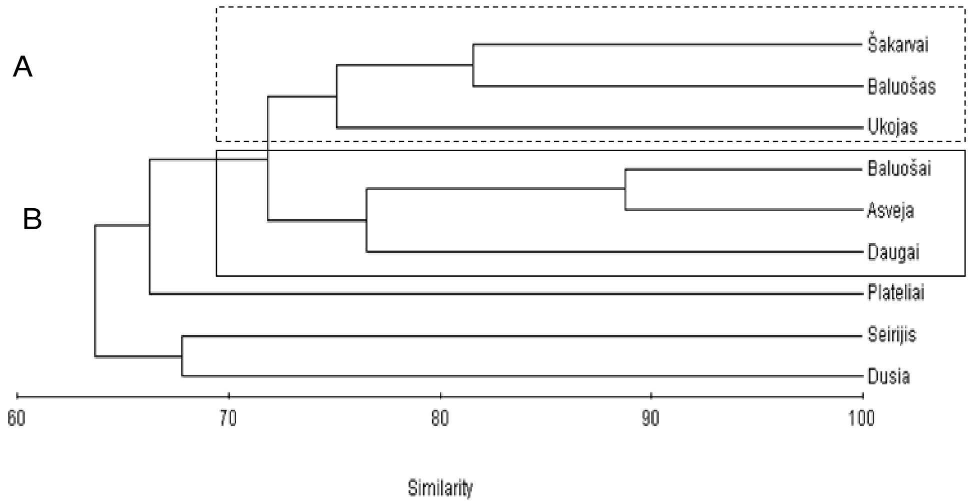

Fig. 13. Comparison of lake zooplankton communities according to the Bray-Curtis Index of Similarity.

In lakes Asveja, Baluošas, Baluošai and Daugai, copepods and their copepodite stages prevailed, whereas in lakes Dusia and Šakarvai, cladocerans dominated. The ratio between of cladocerans and copepods most often increases in eutrophic lakes if fish is not abundant (Hessen et al., 1986; Mayer et al., 1997). The species which are encountered in eutrophic waters (*Daphnia cucullata*, *Bosmina coregoni*) developed in the studied lakes, as well as those typical of oligomesotrophic waters (*Daphnia cristata*, *Bythotrephes longimanus*) (Zingel, Haberman, 2008). *Chydorus sphaericus* and *Bosmina longirostris* are considered eutrophication indicators (Vijverberg, Boersma, 1997; Jeppesen et al., 2000). Similar complexes of dominating crustaceans (*Diaphanosoma brachyurum*, *Bosmina coregoni*, *Bosmina longirostris*, *Daphnia cucullata* and *Eudiaptomus graciloides*, *Mesocyclops leuckarti*) have prevailed in mesotrophic Lake Piaseczno (Adamczuk, 2004).

The average weight of individual in the studied lakes varied between 0.009 and 0.06 mg, the largest weight being found in lakes Ūkojas and Baluošas (ANOVA, $p<0.05$), and the smallest – in lakes Plateliai and Daugai, which were dominated by *Daphnia*, *Eudiaptomus* and copepod crustacean nauplii. Differences between lake groups were significant (nested ANOVA lake group effect $F_{2,18}=26.7$, $p<0.001$).

It was suggested that with the increase in lake trophicity smaller crustaceans (*Bosmina* spp., *Chydorus sphaericus*) become more abundant than large daphnia (Vijverberg, Boersma, 1997). However, our data do not support that pattern. Mean individual weight of individuals was the smallest in lakes Plateliai and Daugai, and the largest – in lakes Ūkojas and Baluošai, which were dominated by large relict crustaceans *L. macrurus*.

For the evaluation of the trophic status of lakes, the ratio between Cyclopoida and Cladocera biomass was calculated. Its values varied from 0.09 in Lake Seirijis to 0.88 in Lake Baluošai (Fig. 14). While comparing lake groups, this ratio was significantly affected by lake group (nested ANOVA, $F_{2,18}=12.3$, $p<0.01$), and the lowest values were observed in lakes inhabited by *L. macrurus*. As another indicator of lake trophic level the proportion of Cyclopoida in the total crustacean biomass may be applied. Representatives of that group comprised from 3.9 up to 27.4% of biomass in the studied lakes. Significant differences were also ascertained between lake groups (nested ANOVA: $F_{2,18}=44.5$, $p<0.01$). Consequently, according to zooplankton indices all studied lakes could be characterized as mesotrophic lakes.

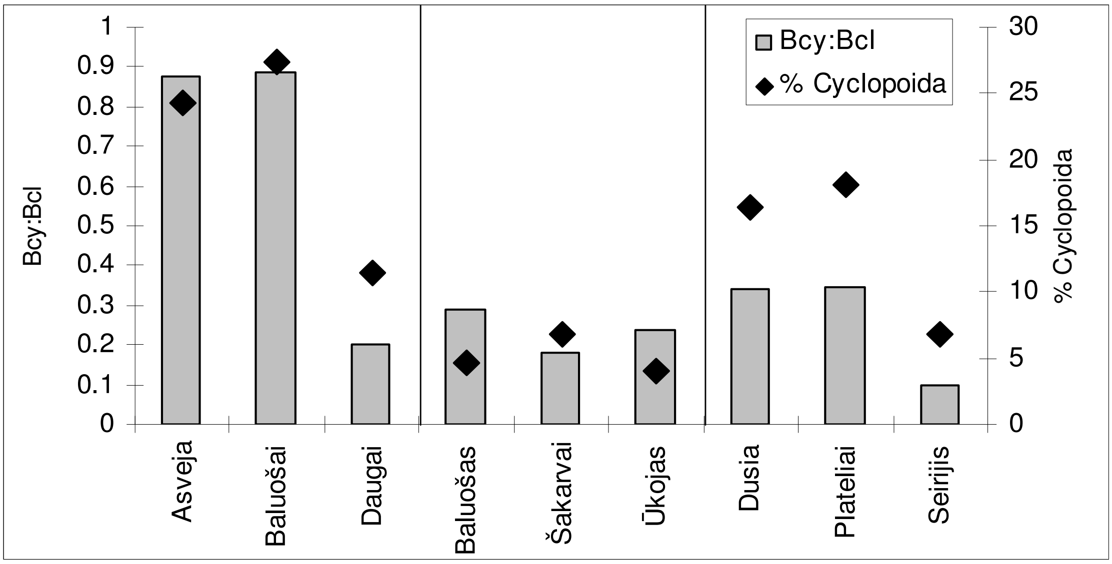

Fig. 14. Ratio between Cyclopoida biomass and Cladocera biomass (B_{Cy}:B_{Cl}) and proportion of Cyclopoida in crustacean biomass (% Cyclopoida) in study lakes. Lake groups separated by vertical lines.

Our results also testify that environmental conditions in most Lithuanian lakes inhabited by glacial relict crustaceans are still sufficient for their survival, and global environmental change, at least until now, has a slight impact on parameters of studied lakes. That was a prerequisite for the still abundant populations of these crustaceans in the discussed lakes. However, further anthropogenic impacts and climate change may induce certain changes in lakes, primarily oxygen depletion in the hypolimnion, and those could cause the decrease or even extinction of populations of these organisms.

CONCLUSIONS

1. All the studied lakes according to chlorophyll *a*, phytoplankton and zooplankton biomass values, as well as complexes of dominating species and trophic indices could be regarded as mesotrophic lakes.
2. During the study period, 258 taxa of algae and cyanobacteria, and 25 taxa of planktonic crustaceans were recorded in 10 lakes. Algae were ascribed to four phyla and eight classes. The highest species richness is characteristic of the Chlorophyceae and Bacillariophyceae classes.
3. 32 new algae species for Lithuanian freshwater ecosystems belonging to five classes were detected. Chrysophyceae was represented by 12, Euglenophyceae – 9, Bacillariophyceae – 5, Chlorophyceae – 4 and Cyanobacteria – 2 species.
4. Peculiarities of the seasonal dynamics in phytoplankton structure in mesotrophic lakes were predetermined by the changes in most abundant species of the prevailing algae classes. Species of Bacillariophyceae, Chlorophyceae, Cyanophyceae. Bacillariophyceae and Chrysophyceae prevail in spring, those of Chlorophyceae – in summer, and the species of Bacillariophyceae or Cyanophyceae – in autumn.
5. Light is an important factors for the activation of resting stages of Cyanophyceae, Bacillariophyceae and Chlorophyceae, whereas for the activation of Dinophyceae and Euglenophyceae resting stages effect of light was not established. The composition of algae species activated from diapause corresponds the prior species composition of algae community in the water column.
6. Significantly larger amount of algae activated from sediments of the deep part of the lake indicates the higher concentration of algae resting stages in these bottom sediments than in those of the shoreline.
7. Abundant populations of the glacial relict calanoid *Limnocalanus macrurus* still inhabit lakes Baluošas, Šakarvai and Ūkojas, and those of *Eurytemora lacustris* harbour lakes Asveja, Baluošai and Daugai.
8. Interannual variation of *L. macrurus* population density is substantially higher than that in *E. lacustris*. Such a pattern suggest that although *L. macrurus* is more widespread in Lithuanian lakes, this species is more sensitive to environmental alterations, and consequently, the probability of extinction of its local populations may be higher.
9. While comparing plankton communities of separate mesotrophic lake groups, significant differences were determined for planktonic crustaceans, whereas variation for phytoplankton was not ascertained, except for some difference in seasonal dynamics of dominating algae groups.

ĮVADAS

Darbo aktualumas. Dauguma didesnių Lietuvos ežerų yra priskiriami mezotrofinių vandens telkinių tipui. J. Kavaliauskienė (1996) šiam tipui priskyrė 53,8 % tirtų ežerų. Ežerų trofinė būklė visų pirma vertinama pagal planktono bendrijos produktyvumą ir kitus jos parametrus, todėl procesai vykstantys šioje bendrijoje yra išskirtinės svarbos vertinant ežerų ekologinę būklę ir prognozuojant galimus pokyčius globalios aplinkos kaitos sąlygomis (McCormick, Cairns, 1994; Van Dam et al., 1994; Kavaliauskienė, 1996; Reynolds, 1998; Trifonova, 1998; Wetzel, 2001; Willén, 2001; Wehr, Sheath, 2003). Bendrosios vandens politikos direktyvoje (Water Framework Directive, 2000/60/EC) planktoniniai dumbliai reglamentuojami kaip vienas iš ežerų ir upių ekologinės būklės biotinių vertinimo rodiklių (Lepistö et al., 2006).

Lietuvoje mezotrofiniams priskiriamų ežerų yra gana daug, todėl vertinant šio tipo vandens telkinių būklės pokyčių tendencijas mūsų krašto sąlygomis reikėtų ištirti daugumą tokių ežerų arba pasirinkti tyrimams tokius ežerus, kurie visumoje galėtų reprezentatyviai atspindėti šio tipo ežerų įvairovę. Mes pasirinkome antrą kelią – ištirti charakteringus mezotrofinius Lietuvos ežerus. Mūsų nuomone, siekiant apimti platesnį mezotrofinių ežerų spektrą galima panaudoti informaciją apie ežerų zooplanktono bendrijas. Lietuvoje iki šiol gyvena ledynmečio reliktiniai vėžiagyviai, tarp kurių yra dvi planktono irklakojų vėžiagyvių rūšys, *Limnocalanus macrurus* (G. O. Sars) ir *Eurytemora lacustris* Poppe. Šie irklakojai gyvena tik mezotrofiniuose ežeruose, be to, niekad neaptinkami kartu (Grigelis, Arbačiauskas, 1996, 1997). Taigi, Lietuvos mezotrofinius ežerus pagal zooplanktono bendrijas galima suskirstyti į 3 (charakteringas) grupes: ežerus, kuriuose gyvena tik *L. macrurus,* ežerus su *E. lacustris* ir ežerus be reliktinių planktono vėžiagyvių. Ištyrus po kelis skirtingų grupių ežerus, mūsų nuomone, gali būti gauta informacija leidžianti vertinti Lietuvos mezotrofinių ežerų būklę. Antra vertus, niekad nebuvo tirta, ar ir kiek skiriasi aukščiau paminėtų ežerų grupių planktono bendrijos.

Pagrindinis dėmesys darbe skiriamas vasaros planktono tyrimams, nes vasara yra tinkamas laikas vertinti ežerų vandens kokybę pagal fitoplanktoną, dėl šiuo metu vidutinės klimato juostos ežerams būdingų palyginti stabilių aplinkos sąlygų (Eloranta, 1993; Padisák et al., 2006; Szeląg-Wasielewska, 2007). Antra vertus, dauguma planktono dumblių rūšių tik tam tikrą gyvenimo ciklo dalį praleidžia vandens storymėje, o likusį laiką būna ramybės stadijose (Padisák, 1992; Rengefors, 1997, Ståhl-Delbanco, 2004), todėl vertinant ežero būklę informatyvūs yra ir sezoniniai fitoplanktono kaitos tyrimai bei ląstelių aktyvacijos iš ramybės stadijų dėsningumai.

Dėl žmonių ūkinės veiklos pastaruoju metu vyksta ežerų eutrofikacija (Kirilova et al., 2010). Antra vertus, eutrofikacijos priežastimi tam tikra dalimi gali būti ir klimato kaita (Blenckner, 2005; Blenckner et al., 2007; De Senerpont Domis et al., 2007). Vykstant ežerų eutrofikacijai ir susidarant deguonies trūkumui hipolimnione, dalyje ežerų ledynmečio reliktiniai vėžiagyviai nyksta (Сущеня et al., 1986; Plambeck, 2001 cit. iš Kasprzak et al., 2005). Todėl informacija apie zooplanktoną ir ypač reliktinius planktono vėžiagyvius yra svarbi vertinant dabartinę Lietuvos mezotrofinių ežerų ekologinę būklę ir prognozuojant jos raidos tendencijas.

Darbo tikslai: Nustatyti charakteringų mezotrofinių Lietuvos ežerų planktono dumblių ir vėžiagyvių bendrijų struktūrą ir kaitą, palyginti šias bendrijas skirtingose ežerų grupėse ir įvertinti Lietuvos mezotrofinių ežerų kitimo tendencijas.

Darbo uždaviniai:

- Nustatyti fitoplanktono rūšių sudėtį, įvairovę ir gausumą, išskirti vyraujančias fitoplanktono rūšis;
- Nustatyti fitoplanktono bendrijų sukcesiją aktyvios vegetacijos periodu;
- Eksperimentiškai ištirti pagrindinių aplinkos veiksnių įtaką fitoplanktono ramybės stadijų aktyvacijai;
- Ištirti zooplanktono rūšių sudėtį, įvairovę ir gausumą;
- Įvertinti zooplanktono ledynmečio reliktinių rūšių gausumą ir jų populiacijų būklę;
- Įvertinti ežerų trofinį lygį ir jo kitimo tendencijas.

Darbo naujumas:

- Atlikti kompleksiniai mezotrofinių ežerų fitoplanktono ir zooplanktono struktūros tyrimai, įvertinta dabartinė mezotrofinių ežerų būklė. Gauti rezultatai papildo mokslinę informaciją apie mezotrofinių Lietuvos ežerų fitoplanktoną ir zooplanktoną;
- Pirmą kartą palyginta ledynmečio reliktinių vėžiagyvių *Limnocalanus macrurus* ir *Eurytemora lacustris* tarpmetinė populiacijų gausumo variacija. Nustatyta, kad *L. macrurus* gausumas skirtingais metais stipriai keičiasi, o tai rodo šios rūšies didesnį, palyginus su *E. lacustris*, jautrumą aplinkos sąlygų kaitai hipolimnione.
- Palygintos fitoplanktono ir zooplanktono bendrijos skirtingose mezotrofinių ežerų grupėse;
- Pirmą kartą Lietuvoje atlikti dumblių ramybės stadijų aktyvacijos veiksnių tyrimai;
- Aptiktos 32 naujos Lietuvai gėlų vandenų dumblių rūšys.

Mokslinė ir praktinė darbo reikšmė:

- Įvertinta dabartinė Lietuvos mezotrofinių ežerų būklė;
- Gauti rezultatai papildo mokslinę informaciją apie mezotrofinių ežerų planktono bendrijas;
- Įvertintas aplinkos veiksnių poveikis fitoplanktono ramybės stadijų aktyvacijai;
- Gauti rezultatai svarbūs vertinant ežerų ekologinę būklę, prognozuojant kitimo tendencijas ir numatant gamtosaugines priemones užtikrinant mezotrofinių ežerų gerą ekologinę būklę.

Ginamieji teiginiai:

- Tirtų ežerų fitoplanktono ir zooplanktono bendrijos atitinka mezotrofinį vandens telkinių tipą;
- Svarbiausias veiksnys dumblių aktyvacijai iš ramybės stadijų yra šviesa, tačiau jos įtaka skirtingoms dumblių klasėms nėra vienodai reikšminga.
- Reikšmingai didesnis iš giluminės ežero dalies sedimentų aktyvuotų dumblių kiekis rodo kad dumblių ramybės stadijų koncentracija šiose dugno nuosėdose yra didesnė nei priekrantėje.

- Reliktiniai planktono vėžiagyviai iki šiol išliko tuose ežeruose, kuriuose gyveno ir anksčiau.
- Reliktinio irklakojo *Limnocalanus macrurus* populiacijų gausumo tarpmetinė variacija yra didesnė nei kito reliktinio irklakojo *Eurytemora lacustris*. Šis skirtumas leidžia teigti, kad pirmosios rūšies atskirų populiacijų išnykimo tikimybė yra didesnė.
- Palyginus skirtingų mezotrofinių ežerų grupių planktono bendrijas reikšmingi skirtumai nustatyti planktono vėžiagyviams, tuo tarpu fitoplanktono skirtumų nerasta, išskyrus sezonines kaitos ypatumus.

Rezultatų pristatymas ir aprobavimas. Darbo rezultatai paskelbti 2 straipsniuose ir 7 mokslinių pranešimų tezėse. Disertacijos tema perskaityti 7 pranešimai mokslo renginiuose: VIII – joje Lietuvos jaunųjų hidroekologų konferencijoje „Vandens ekosistemų įvairovė, funkcionavimas ir kaita“ (Anykščiai, Lietuva, 2005); Tarptautiniame jaunųjų tyrėjų simpoziume “Aplinka ir pasaulis” (Šiauliai, Lietuva, 2006); Europos didžiųjų ežerų simpoziume „Ekosistemų kaita ir jos ekologiniai bei socioekonominiai poveikiai“ (Tartu, Estija, 2006); II – joje regioninėje studentų konferencijoje „Baltijos jūros regiono vandens ekosistemų bioįvairovė ir funkcionavimas (Klaipėda, Lietuva, 2006); X – joje Lietuvos jaunųjų hidroekologų konferencijoje „Vandens ekosistemų įvairovė, funkcionavimas ir kaita“ (Molėtai, Lietuva, 2007); III – joje tarptautinėje studentų konferencijoje „Baltijos jūros regiono vandens ekosistemų bioįvairovė ir funkcionavimas“ (Klaipėda, Lietuva, 2008); IV – joje tarptautinėje studentų konferencijoje „Baltijos jūros regiono vandens ekosistemų bioįvairovė ir funkcionavimas“ (Dubingiai, Lietuva, 2009).

Disertacijos struktūra ir apimtis: Disertacija parašyta lietuvių kalba, ją sudaro šie skyriai: įvadas, literatūros apžvalga, medžiaga ir tyrimų metodai, tyrimų rezultatai, apibendrinimas ir išvados. Literatūros sąraše cituoti 162 literatūros šaltiniai. Pateiktas publikacijų disertacijos tema sąrašas. Disertacijos apimtis – 121 puslapis (be priedų), 13 lentelių ir 36 paveikslai.

Padėka.

Už suteiktą galimybę ir sąlygas studijuoti doktorantūroje dėkoju Gamtos tyrimų centro Ekologijos instituto vadovybei. Nuoširdžiai dėkoju: darbo vadovui dr. Kęstučiui Arbačiauskui už rūpestį, kantrybę, vertingus patarimus ir pagalbą per visus ketverius doktorantūros metus bei rengiant disertaciją; draugams ir kolegoms: dr. Simonai Smilgevičienei, dr. Audronei Matusevičiūtei, Laurai Andreikėnaitei, Giedrei Višinskienei, Vytautui Rakauskui, dr. Aleksandrui Rybakovui, dr. Vaidui Palinauskui, dr. Astai Kryžanauskienei ir kolegoms iš KU Baltijos pajūrio aplinkos tyrimų ir planavimo instituto už draugiškumą ir visokeriopą pagalbą; Hidrobiontų ekologijos ir fiziologijos laboratorijos darbuotojams už pagalbą vykdant mokslinius tyrimus; Hidrobotanikos laboratorijos darbuotojams už vertingas konsultacijas ir pagalbą vykdant mokslinius tyrimus; savo šeimai už kantrybę, paramą ir palaikymą; draugams už moralinę paramą.

Darbą 2005 metais parėmė Lietuvos valstybinis mokslo ir studijų fondas.

IŠVADOS

1. Visi tirti ežerai pagal chlorofilo *a*, fitoplanktono ir zooplanktono biomases, vyraujančių rūšių kompleksus ir trofiškumo indeksus atitinka mezotrofiniam vandens telkinių tipui.
2. Tyrimų laikotarpiu dešimtyje mezotrofinių Lietuvos ežerų aptiktos 258 dumblių ir melsvabakterių rūšys ir 25 planktono vėžiagyvių rūšys. Fitoplanktone rastos rūšys priklauso 4 skyriams ir 8 klasėms. Didžiausia rūšių įvairove išsiskyrė Chlorophyceae (95) ir Bacillariophyceae (72) klasės.
3. Aptiktos 32 naujos Lietuvos ežerams dumblių rūšys, priklausančios 5 klasėms. Chrysophyceae klasei priklauso 12, Euglenophyceae – 9, Bacillariophyceae – 5, Chlorophyceae – 4, Cyanophycea – 2 rūšys.
4. Mezotrofinių ežerų fitoplanktono sezoninę kaitą lėmė vyraujančių dumblių klasių Bacillariophyceae, Chlorophyceae, Cyanophyceae, bei jų gausiausių rūšių kaitos ypatumai. Pavasarį fitoplanktone vyrauja Bacillariophyceae ir Chrysophyceae klasės atstovais. Vasarą vyrauja Chlorophyceae, o rudenį vėl Bacillariophyceae arba Cyanophyceae klasės rūšys.
5. Cyanophyceae, Bacillariophyceae ir Chlorophyceae klasių rūšių ląstelių aktyvacijai iš ramybės stadijų vienas iš pagrindinių faktorių yra šviesa, tuo tarpu Dinophyceae ir Euglenophyceae klasių ramybės stadijų aktyvacijai statistiškai patikimos šviesos įtakos nenustatyta. Aktyvacija iš ežero giluminės dalies nuosėdų buvo intensyvesnė. Iš diapauzės aktyvuotų dumblių rūšių kompleksas skiriasi nuo fitoplanktone tuo metu vyraujančių rūšių ir atspindi prieš tai vandens masėje buvusios dumblių bendrijos rūšinę sudėtį.
6. Reikšmingai didesnis iš giluminės ežero dalies sedimentų aktyvuotų dumblių kiekis rodo kad dumblių ramybės stadijų koncentracija šiose dugno nuosėdose yra didesnė nei priekrantėje.
7. Santykinai gausios ledynmečio reliktinių irklakojų vėžiagyvių *Limnocalanus macrurus* populiacijos iki šiol gyvena Baluošo, Šakarvų ir Ūkojo ežeruose, o *Eurytemora lacustris* – Asvejos, Baluošų ir Daugų ežeruose.
8. *L. macrurus* populiacijų tarpmetinis kintamumas yra didesnis. Dėl šios priežasties galima prognozuoti, kad nors lyginant su *E. lacustris* rūšis *L. macrurus* yra plačiau paplitusi Lietuvos ežeruose, jos lokalių populiacijų išnykimo tikimybė yra didesnė.
9. Palyginus skirtingų mezotrofinių ežerų grupių planktono bendrijas reikšmingi skirtumai nustatyti planktono vėžiagyviams, tuo tarpu fitoplanktono skirtumų nerasta, išskyrus sezonines kaitos ypatumus.

LIST OF PUBLICATIONS ON DISSERTATION TOPIC
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6. **Kalytytė D.** 2008. Seasonal dynamics of phytoplankton of deep Lithuanian lakes. 3rd International student conference „Biodiversity and functioning of aquatic ecosystems in the Baltic Sea region", Klaipėda (Juodkrantė): p. 29-30.
7. **Kalytytė D.** 2009. Summer metazooplankton in deep Lithuanian lakes. 4th International student conference „Biodiversity and functioning of aquatic ecosystems in the Baltic Sea region", Dubingiai: p. 20.

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