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Summer phytoplankton in deep Lithuanian lakes

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Summer phytoplankton of nine deep Lithuanian lakes was studied in 2004–2006, and the data were compared with data of the previous studies. A total of 157 algal and cyanobacterial taxa were registered in all lakes. Green algae were most abundant. Despite the fact that in some lakes the biomass of phytoplankton exceeds 1 mg/l, its average values are still typical of mesotrophic water bodies. Average biomass, the same as chlorophyll *a* values, during the study period was lowest in Lake Šakarva. The trophic state index (TSI) varied between 31.0 and 50.5. All the lakes studied currently may be characterized as mesotrophic.

Key words: phytoplankton structure, deep lakes, trophic state index, mesotrophy

INTRODUCTION

Algae and cyanobacteria produce the bulk of primary production in large lakes. 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). Also, they have short generation times and react rapidly to changes in the environment. 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 (Szeląg-Wasielewska, 2007).

The last investigations of large and deep Lithuanian lakes were performed more than a decade ago. The phytoplankton structure, abundance; chlorophyll *a* concentration in lakes Baluošas, Daugai, Dusia, Plateliai, Seirijis, Šakarva and Ūkojas have been periodically studied during 1970–1991 by J. Kavaliauskienė (1996; 1997); Lake Baluošas by J. Kasperovičienė in 1999 (2001). Lakes Plateliai and Seirijis were regarded as mesotrophic with oligotrophic traits, and Baluošas, Daugai, Dusia, Šakarva and Ūkojas – as mesotrophic water bodies (Kavaliauskienė, 1996). There are no previous data on the phytoplankton of lakes Asveja and Baluošai. Nowadays, eutrophication of lakes strongly depends on anthropogenic pollution (Frisk et al., 1999; Kango, 2005). The impact of climate warming may also be important (Blenckner, 2005; Blenckner et al., 2007; De Senerpont Domis et al., 2007). Thus, the recent ecological state of lakes was unclear.

Therefore, the purpose of this work was to study summer phytoplankton of nine lakes situated in different Lithuanian regions to verify the trophic state of these lakes.

STUDY AREA

The research work was carried out in Asveja, Baluošas, Baluošai, Daugai, Dusia, Plateliai, Seirijis, Šakarva and Ūkojas lakes in July 2004–2006. All lakes, except Daugai and Seirijis, are located in protected areas of Lithuania (national and regional parks). The location of the lakes is presented in Fig. 1. Almost all of the lakes belong to the deep lakes' group in which the water column is stratified in summer. Lakes Dusia and Seirijis belong to the thermally moderate deep lakes (Хомскис, 1969). The morphometric characteristics of the lakes are presented in Table 1.

MATERIALS AND METHODS

Water samples were collected with 2-litre water samplers in the deepest part of a lake. 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).

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. Phytoplankton samples were fixed with 40% formaldehyde solution (4% final concentration) and concentrated by the sedimentation method (Olrik et al., 1998). The phytoplankton was analysed on a "Biolar" light microscope at ×480 magnification. Algae abundance was determined using the Fuchs–Rosenthal counting chamber (volume 0.0032 mm^3). The counting unit of filamentous cyanobacteria was 100 µm and of other algae a cell. The dominating groups of algae and complexes of the prevailing species were ascertained according to Давидова (1986). Biomass was estimated from cell numbers and specific volumes (Olrik et al., 1998). To analyse chlorophyll *a*, 0.5–1 l of water was filtered onto 1.2 µm membrane filters. Pigments were extracted with acetone (90%) and quantified spectrophotometrically (Kavaliauskienė, 1996).

The Carlson trophic state index (TSI) was calculated as (Carlson, 1977):

Fig. 1. Location of the study lakes

Table 1. **Morphometric and physicochemical characteristics of study lakes in mid-summer 2004–2006**

Lake name	Lake area, km²	Depth, m		Secchi depth, m	T, °C Surface / bottom level	pH surface	O_2, mg/l Surface / bottom level	Conductivity, µS cm $^{-1}$	Total N mg/l April 2005 / July 2006
		Maximum	Mean						
Asveja	9.78	50.2	14.9	2–3.3	21.3–23.1 / 6.7–6.9	8–8.5	13–8.4/ 6.2–6.7	347–358	1.23/1.12
Baluošas	4.27	33.7	10.9	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	37.5	12.5	2.5–3.6	20.9–22 / 5–8	8–8.5	8.5–8.8 / 2.94–5	341–348	0.72/1.26
Daugai	9.52	44.0	13.2	2.9–3.8	19–23 / 7.4–12	8–10.5	6–8.8 / 6	344	0.85/1.14
Dusia	23.16	32.4	14.6	5–5.3	17.4–22 / 11.6–11.9	7.5–8.9	8–8.9 / 2.09–4	340–343	0.78/1.34
Plateliai	12.04	46.0	10.4	6–7.4	19.4–21.8 / 6.1–8.9	7.2–8.7	7.5–9.19 / 6.2–8.71	201	0.63/0.74
Seirijis	5.01	19.2	7.9	4.5–6.1	17.5–22.8 / 12.4	7.5–8.9	7.5–10 / 0.85–1.7	265–298	0.72/1.16
Šakarva	2.1	40	16.5	3–6.6	21.9–23.7 / 4.4–7.8	8–8.3	7–9.03 / 1.2–3.1	333–338	0.57/1.02
Ūkojas	2.1	30.5	11.3	3–3.7	21.5–22.9 / 6.6–9.7	8.3–8.6	7.4–9.67 / 1.6–2.2	366–368	1.31/1.00

TSI (SD) = 60–14.41 ln Secchi disc (meters),

TSI (CHL) = 9.81 ln chlorophyll *a* (g/l) + 30.6.

The diversity of phytoplankton was evaluated by calculating the Shannon–Wiener diversity index (H') using the following formula (Shanon, Wiener, 1949):

$$H' = -\sum_{i=1}^{n} p_i \log_2 p_i,$$

where H' is the diversity index, p_i is the proportion of the i-th species and n is the number of species in a community.

Statistical analysis was done using the STATISTICA 6.0 software. Chlorophyll *a* data of the current study were compared with previous data (for the lakes for which information is available) using nested ANOVA.

RESULTS

Environmental parameters

During the study period, in 2004 surface water temperature ranged from 17 to 23.8 °C and in the bottom water level from 4.4 to 7.4 °C. In 2005 and 2006 the temperature was slightly higher

Table 2. **Phytoplankton species dominating by abundance (%) and biomass (%) in the study lakes in late July (2004–2006)**

Lake	Dominating species by abundance	Dominating species by biomass
Asveja	*Asterionella formosa* Hassal (30.2%), *Oocystis rhomboidea* Fott (22.7–23.5%), *Cyclotella* cf. *comensis* (18.2%)	*Peridinium* sp. (51.9%), *Asterionella formosa* Hassal (47.9%), *Dinobryon sociale* Ehrenberg (26.9%), *Fragilaria crotonensis* Kitton (22,5%), *Tetraedron minimum* (A. Braun) Hansgirg (12.7%)
Baluošas	*Cyclotella* cf. *comensis* (11.6–77.4%), *Planktothrix agardhii* Anagnostidis & Komàrek (44,9%), *Oocystis rhomboidea* Fott (26.1%)	*Planktothrix agardhii* Anagnostidis & Komàrek (45.9%), *Cyclotella* cf. *comensis* (32.5%), *Gymnodinium* sp. (17.8%), *Ceratium hirundinella* (O. F. Muller) Schrank (15.2%), *Chlamydomonas* sp. (11.6%)
Baluošai	*Cyclotella* cf. *comensis* (10.1–38.5%), *Oocystis rhomboidea* Fott (17.6–28.4%), *Phacotus lenticularis* (Ehrenberg) A. Stein (16.8%), *Cryptomonas* sp. (10.7%)	*Peridinium* sp. (18.8–31%), *Phacotus lenticularis* (Ehrenberg) A. Stein (15.5–28.2%), *Chlamydomonas* sp. (22.4%), *Ceratium hirundinella* (O. F. Muller) Schrank (13.6%), *Dinobryon divergens* Imhof (10.9%), *Asterionella formosa* Hassal (10.2%)
Daugai	*Cyclotella* cf. *comensis* (36.2%), *Chrysophyceae* undet (29%), *Phacotus lenticularis* (Ehrenberg) A. Stein (27.5%), *Asterionella formosa* Hassal (25.8%), *Salpingoeca* sp. (24.4), *Oocystis rhomboidea* Fott (19%)	*Peridinium* sp. (40.9%), *Asterionella formosa* Hassal (34.2%), *Chrysophyceae* undet (28,71%), *Phacotus lenticularis* (Ehrenberg) A. Stein (22.4%), *Rhizosolenia longiseta* Zacharias (20.8%), *Dinobryon sociale* Ehrenberg (15.4%)
Dusia	*Oscillatoria* sp. (30.2%), *Oocystis* sp. (26%), *Asterionella formosa* Hassal (24.2%), *Limnothrix redeckei* (Van Goor) Meffert (18,6%), *Cryptomonas* sp. (12.6%), *Dinobryon bavaricum* Imhof (12%)	*Dinobryon bavaricum* Imhof (33.6%), *Cryptomonas* sp. (32.6%), *Chlamydomonas* sp. (32.5%), *Peridinium* sp. (12.9–18%), *Limnothrix redeckei* (Van Goor) Meffert (15,6%), *Asterionella formosa* Hassal (12.7%)
Plateliai	*Oocystis rhomboidea* Fott (14.3–22.1%), *Fragilaria crotonensis* Kitton (16.3%), *Cyclotella* cf. *comensis* (13.1%)	*Peridinium* sp. (13.8–24.2%), *Dinobryon divergens* Imhof (19.9%), *Chlamydomonas* sp. (18.9%), *Fragilaria crotonensis* Kitton (10.1%), *Cyclotella* cf. *comensis* (10.1%)
Seirijis	*Phacotus lenticularis* (Ehrenberg) A. Stein (12.5–26.3%), *Asterionella formosa* Hassal (23.5%), *Cyclotella* cf. *comensis* (13.7–23.5%), *Fragilaria crotonensis* Kitton (11.3%)	*Ceratium hirundinella* (O. F. Muller) Schrank (62%), *Asterionella formosa* Hassal (20.2%), *Phacotus lenticularis* (Ehrenberg) A. Stein (17.6%), *Fragilaria crotonensis* Kitton (10.6%)
Šakarva	*Phacotus lenticularis* (Ehrenberg) A. Stein (25.8%), *Fragilaria crotonensis* Kitton (11.3–19.5%), *Oocystis rhomboidea* Fott (15.5–17.4%), *Cyclotella* cf. *comensis* (13.9%)	*Phacotus lenticularis* (Ehrenberg) A. Stein (20.2–37%), *Fragilaria crotonensis* Kitton (21.8–36.8%), *Rhizosolenia longiseta* Zacharijas (10.8%)
Ūkojas	*Oocystis rhomboidea* Fott (17.6–32.7%), *Phacotus lenticularis* (Ehrenberg) A. Stein (27.2–32.3%), *Cyclotella* cf. *comensis* (12.8–17.6%), *Fragilaria crotonensis* Kitton (10.4%)	*Peridinium* sp. (13–48.4%), *Phacotus lenticularis* (Ehrenberg) A. Stein (19.3–25.3%), *Sphaerocystis* sp. (20.1–24.9%)

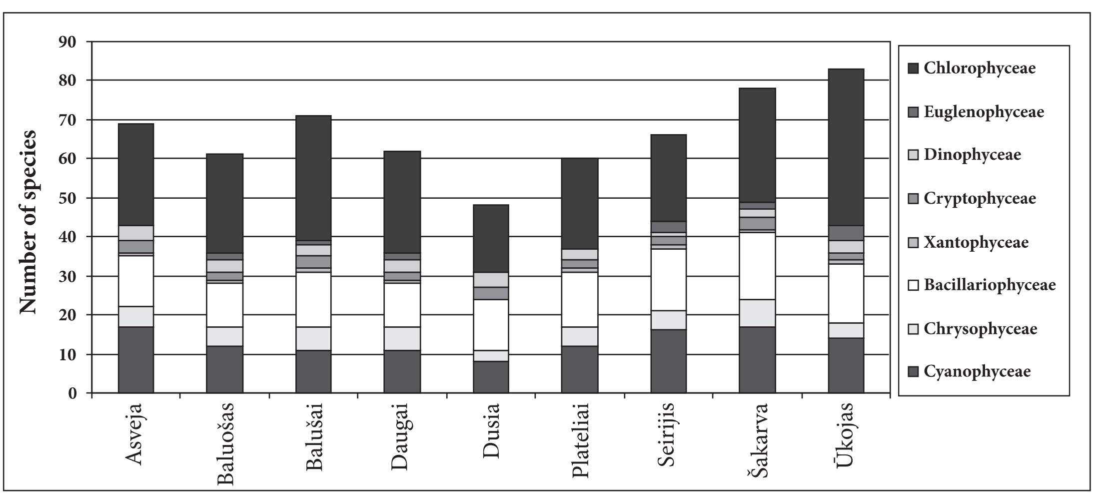

Fig. 2. Phytoplankton species richness diversity in the lakes in late July (2004–2006)

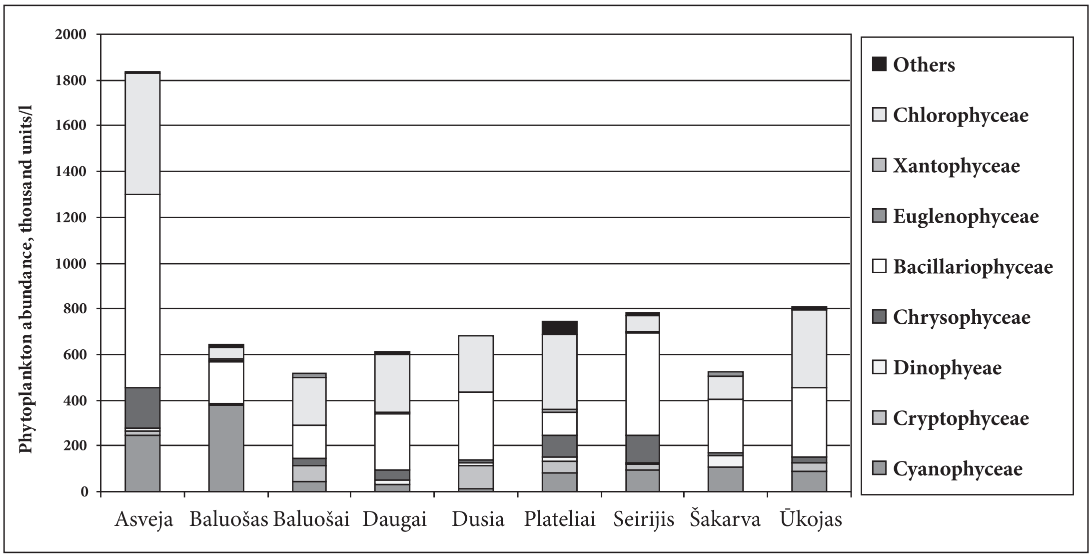

Fig. 3. Phytoplankton abundance in lakes in late July (2004)

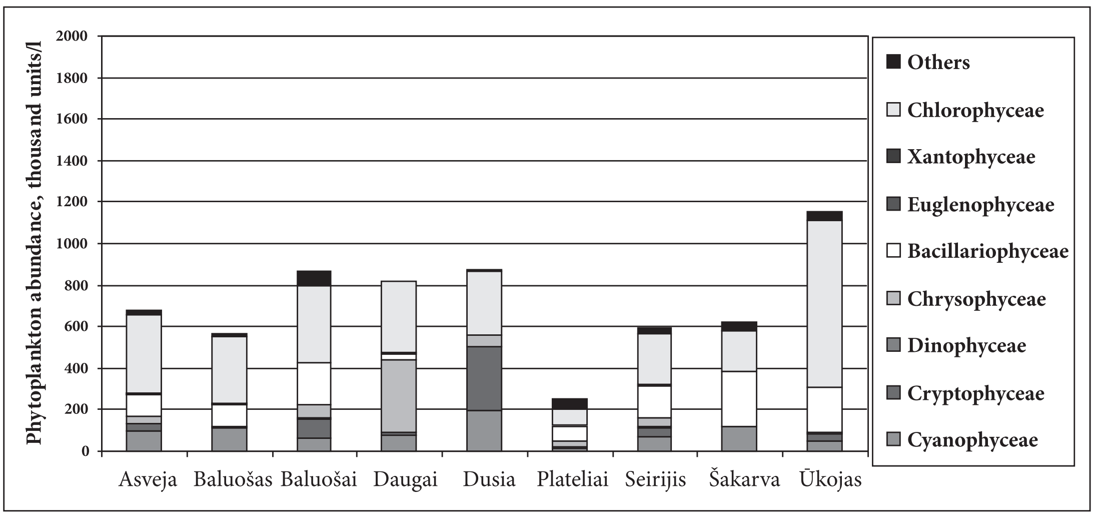

Fig. 4. Phytoplankton abundance in lakes in late July (2005)

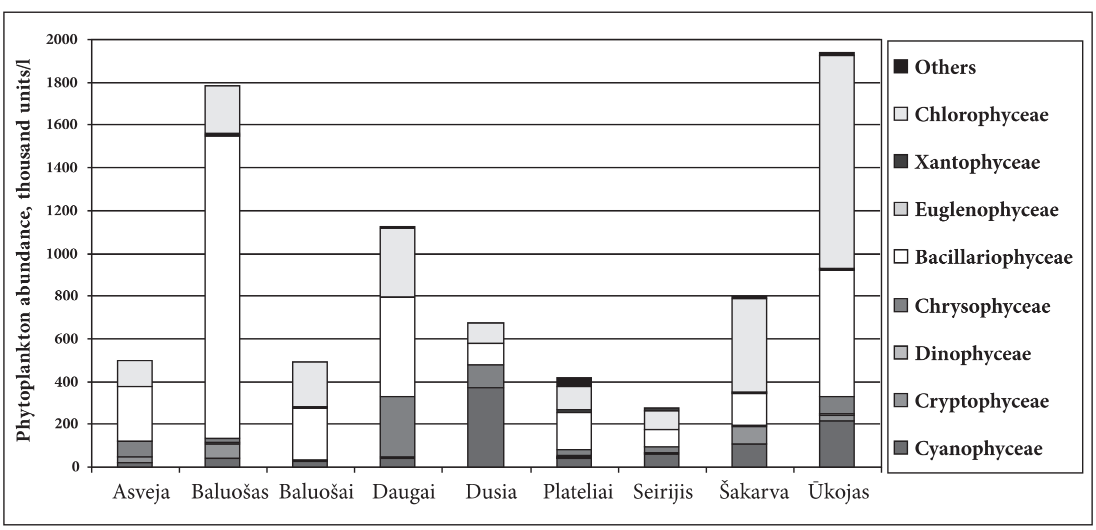

Fig. 5. Phytoplankton abundance in lakes in late July (2006)

and varied between 6.5–12.4 °C. Dissolved oxygen concentration in surface water in all lakes ranged from 6 to 10.6 mg/l, while in the bottom water level of the lakes Seirijis, Šakarva, Baluošas and Ūkojas oxygen depletion was noted, i. e. oxygen concentration was less than 2 mg/l. Water transparency (7.4 m) was the highest in Lake Plateliai in 2004.

Total phosphorus (TP) did not exceed 0.010 mg/l in the surface water level of all lakes in spring overturn and summer stratification, while total nitrogen (TN) in the surface water level ranged within 0.58–1.31 mg/l in 2005 and 0.74–1.34 mg/l in 2006.

Phytoplankton composition

A total of 157 algal and cyanobacterial taxa were registered in nine lakes. A high diversity of species was most characteristic of green algae (*Chlorophyceae*) – 67 species (43%). By the number of species, other classes were distributed as follows: diatoms (*Bacillariophyceae*) – 35 species (22%), cyanobacteria (*Cyanophyceae)* – 30 (19%), golden-brown algae (*Chrysophyceae*) – 10 (6%), dinoflagellates (*Dinophyceae*) – 7 (3%), euglenoids (*Euglenophyceae*) – 5 (3%), cryptomonads (*Cryptophyceae*) – 3 (2%) and yellow-green algae (*Xantophyceae*) – 1 species (1%). The number of species varied from 48 in Lake Dusia to 83 in Lake Ūkojas (Fig. 2). About half of the species (40) found in Lake Ūkojas belonged to green algae. Eight alga species (green algae *Oocystis rhomboidea*, *Phacotus lenticularis*, diatoms *Asterionella formosa*, *Fragilaria crotonensis*, *Synedra acus, Cyclotella* cf. *comensis*, golden-brown algae *Dinobryon divergens*, dinoflagellates *Ceratium hirundinella*) were found in all lakes.

The Shannon–Wiener diversity in all lakes ranged between 1.4 and 4.4. The lowest value was found in Lake Baluošas in 2006. The highest value of diversity was found in Lake Daugai in 2004, but in 2005–2006 this value was only 3.1. In Lake Plateliai, phytoplankton diversity in all years fluctuated around 4 (4.0–4.3).

Phytoplankton abundance and biomass

The smallest amount of phytoplankton (514.3 thousand units/l) and biomass (0.25 mg/l) was registered in Lake Baluošai in July 2004 and the largest one (1.84 million units/l and 1.25 mg/l) in Lake Asveja. In all lakes, diatoms and green algae prevailed. Cyanobacteria were more abundant only in Lake Baluošas (Fig. 3). In this lake, *Planktothrix agardhii* made up to 45% of the total phytoplankton abundance and biomass (Table 2).

In July 2005, the amount of phytoplankton (252.1 thousand units / l) and biomass (0.14 mg/l) was smallest in Lake Plateliai and the greatest (1.15 million units/l and 0.85 mg/l) in Lake Ūkojas. In most of the lakes green algae prevailed. Green and golden-brown algae prevailed in Lake Daugai and green algae with cryptophytes in Lake Dusia. Diatoms prevailed in Lake Šakarva (Fig. 4).

In July 2006, the amount of phytoplankton (252.1 thousand units / l) and biomass (0.14 mg/l) was smallest in Lake Seirijis and greatest (1.93 million units/l and 1.39 mg/l) in Lake Ūkojas. In all lakes various species of diatoms and green algae prevailed. In Lake Dusia cyanobacteria were more abundant (Fig. 5). *Oscillatoria* sp. and *Limnothrix redeckei* dominated.

The (0.23–0.33 mg/l) biomass of phytoplankton during the whole study period was smallest in Lake Šakarva. In lakes Asveja and Ūkojas, phytoplankton biomass varied in a wide range and sometimes exceeded 1 mg/l. In 2004, the highest (7.6 mg/m^3) chlorophyll *a* concentration was found in Lake Dusia and the lowest (1.3–1.8 mg/m^3) in lakes with the highest transparency (Baluošas, Šakarva and Plateliai). In 2005, chlorophyll *a* concentration varied from 1.7 in Lake Šakarva to 4.5 mg/m^3 in Lake Dusia. In 2006, the highest (5.5 mg/m^3) chlorophyll *a* concentration was found in Lake Baluošai and the lowest (1.5 mg/m^3) in Lake Asveja.

DISCUSSION

Nitrogen and phosphorus are nutrients that often limit the concentration of algae in a lake; the higher the concentration of these nutrients, the more eutrophic a lake. TP values in the study lakes are characteristic of mesotrophic lakes (Wetzel, 2001; Kilkus, 2005). According to J. Kavaliauskienė (1996), lakes in which TN is 0.700–1.500 mg/l are ascribable to mesotrophic ones. Thus, all the study lakes according to the content of main nutrients are mesotrophic.

A total of 157 algal and cyanobacterial taxa were identified during the study. The composition of phytoplankton is very often an excellent indication of the trophic state of a water body (Rosen, 1981; Reynolds, 1998). Green algae *Oocystis rhomboidea*, *Phacotus lenticularis* prevail in lakes Asveja, Baluošai, Plateliai, 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 states: from deep stratified oligotrophic lakes to shallow polymictic hypertrophic waters (Schlegen et al., 1998). Diatoms, which were abundant in lakes, are common in mesotrophic lakes. *Cyclotella* cf. *comensis* made up to 77% of the total phytoplankton abundance in Lake Baluošas in 2006. *Fragilaria crotonensis* was abundant in Lake Šakarva, *Asterionella formosa* in lakes Asveja, Daugai, Dusia, 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 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.

The Shannon–Wiener (H') index varies with both the number of species and the relative abundance of species. The prevalence of *Cyclotella* cf. *comensis* (77% of total phytoplankton abundance and 32.5% of total biomass) was associated with the lowest diversity (1.4) in Lake Baluošas in 2006.

Despite the fact that in some lakes the biomass of phytoplankton exceeds 1 mg/l, the average values are still typical of mesotrophic water bodies (Fig. 6). Together with biomass, chlorophyll *a* concentration is often used to assess the trophic state of lakes as chlorophyll *a* is an indicator of phytoplankton productivity (Трифонова, 1990;

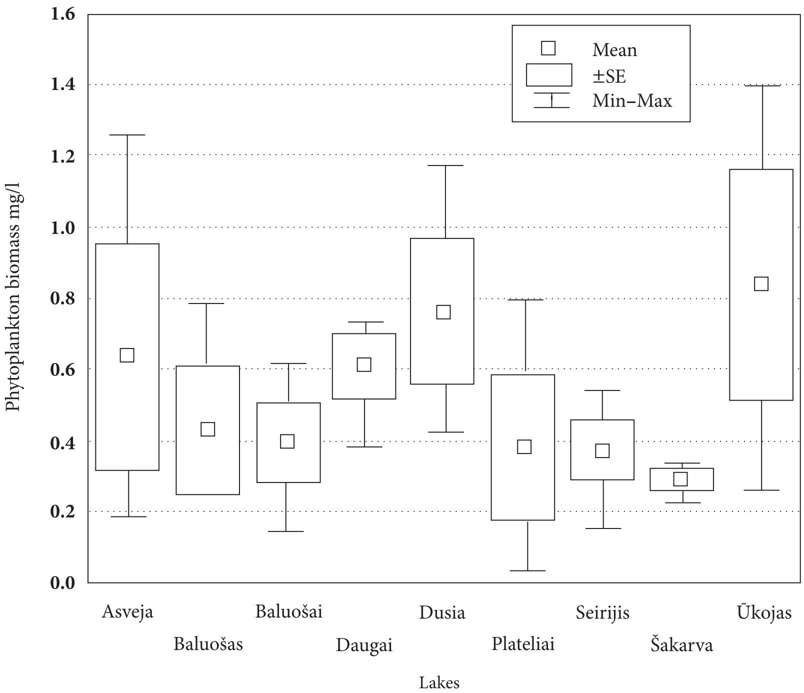

Fig. 6. Phytoplankton biomass in study lakes in late July (2004–2006)

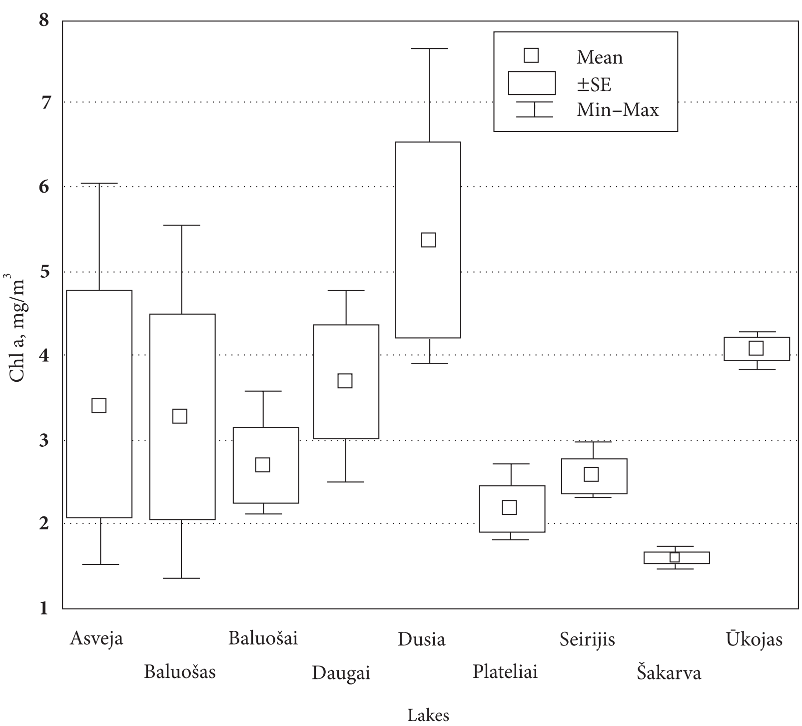

Fig. 7. Chlorophyll a concentration in study lakes in late July (2004–2006)

Kavaliauskienė, 1996). The average chlorophyll *a* values during the study period were lowest in Lake Šakarva (Fig. 7). In some lakes, chlorophyll *a* values fluctuated in a wide range, but the average values were also characteristic of mesotrophic lakes.

Researchers indicate a correlation between phytoplankton biomass and chlorophyll *a* concentration (Трифонова, 1990; Kavaliauskienė, 1996). This correlation in our study was moderate ($r^2 = 0.3101$, $r = 0.5568$, $p = 0.0026$). We compare data on chlorophyll *a* concentration in 1987–1991 in lakes Baluošas, Daugai, Plateliai, Seirijis, Šakarva with our data and found no essential difference (nested ANOVA, lake effect $F_{4.14} = 4.5$, $p = 0.015$; study 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). Trophic state index values are grouped into trophic state classifications. Its values less than 30 are associated with oligotrophy and between 30 and 50 with mesotrophy. The index values greater than 50 are associated with eutrophy (Carlson, 1977). In all study lakes, the TSI (SD) ranged from 31 to 50 and the TSI (Chl) from 34.7 to 50.5. As compared with data calculated by J. Kavaliauskienė in 1987–1991, the TSI values in lakes Šakarva 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.

Thus, our results suggest that all study lakes with respect to chlorophyll *a*, phytoplankton biomass and trophic state index still may be characterized as mesotrophic. This status is also supported by some characteristics of phytoplankton assemblage, such as the development of diatoms, *Cyclotella* and *Asterionela,* green algae *Oocystis* which may be regarded as bioindicators of the mesotrophic status.

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Daiva Kalytytė

VASAROS FITOPLANKTONAS GILIUOSE LIETUVOS EŽERUOSE

Santrauka

Darbe analizuojami fitoplanktono tyrimų rezultatai, gauti 2004–2006 m. intensyvios vasaros vegetacijos laikotarpiu 9 giliuose Lietuvos ežeruose, ir lyginami su anksčiau ežeruose atliktų tyrimų duomenimis.

Tyrimų metu 9 ežeruose rastos 157 dumblių ir melsvabakterių rūšys. Didžiausia rūšių gausa pasižymėjo žaliadumbliai. Mažiausia fitoplanktono biomasė tyrimų laikotarpiu buvo Šakarvos ežere, tuo tarpu Asvejos ir Ūkojo ežeruose per trejus metus kito gana plačiose ribose ir viršijo 1 mg/l, tačiau tokios vertės dar yra būdingos mezotrofiniams vandens telkiniams. Chlorofilo *a* koncentracijos tyrimų laikotarpiu mažiausios buvo skaidriuose Šakarvų ir Platelių ežeruose. Trofiškumo indeksai (TSI), apskaičiuoti pagal chlorofilą *a* ir skaidrumą (pagal Sekio diską), tirtuose ežeruose kito nuo 31 iki 50,5.

Apibendrinant tyrimų rezultatus, visus tirtus ežerus pagal pagrindinių biogeninių elementų, chlorofilo *a*, fitoplanktono biomasės reikšmes ir trofiškumo indeksus vis dar galima priskirti mezotrofiniam vandens telkinių tipui.