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Ecological assessment of wetland ecosystems of northern Kazakhstan on the basis of hydrochemistry and algal biodiversity

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Abstract – We studied diversity of algae and cyanobacteria in the wetlands of protected natural lakes with salinity ranging from 0.19 up to 32.7 in the arid/semiarid regions of Northern Kazakhstan. In plankton and periphyton of 34 lakes, we found 254 species belonging to 113 genera of 8 algal divisions. The diversity in arid regions is represented by widespread species of diatoms, green algae, and cyanobacteria in similar proportions. Alkaliphiles, among the indicators of acidification, and betamesosaprobionts, among the indicators of saprobity, predominated. The indices of saprobity in lakes varied from 1.47 to 2.7, reflecting low-trophic and low anthropogenically disturbed wetlands. Oligohalobes-indifferents are most common. Highly diverse algal communities were found irrespective of various levels of mineralization. As a consequence of aridization, salinity increase suppressed algal diversity. The mineralization was the most important variable defining the diversity levels, irrespective of the type and location of wetland lakes in the arid regions.

Keywords: Algae, cyanobacteria, aridization, diversity, salinity, wetland, water quality, Kazakhstan

Introduction

In arid regions, aquatic environments experience a stressful impact of high concentrations of mineral and organic substances due to high evaporation rates (SUBYANI 2005). Algal habitats are characterized by a high amplitude salinity variation that in large lakes suppresses algal diversity (HAMMER 1986). For example lower bacterial diversity (RUSZNYÁK et al. 2008) and algal species richness (ÁCS et al. 2003) were found in the open water area of Lake Velencei (where the conductivity is about 2.5–3.5 mS cm^{-1} averagely) than in the bog-like area of the lake (where the conductivity is about 1.5–2.3 mS cm^{-1} on average). Many algal species are indicators of environmental conditions reflecting the influence of

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salinity on aquatic communities and the regional flora as a whole. A decrease of algal diversity is in turn related to reduced productivity of aquatic ecosystem and thereby of the trophic level of wetlands. It is well known that an increase of salinity to 20, suppress the diversity of lake biota (HAMMER 1986).

The arid regions of Central Asia and Middle East occupy a considerable part of Eurasia (KÖPPEN and GEIGER 1953). In Kazakhstan, the arid and semiarid dry grasslands to deserts are widespread in the upper reaches of the Ob' River Basin and the Turkestan Desert (BRAGINA and BRAGIN, 2002). The hydrographic network of this territory is developed slightly, closed and has no constant drainage (SKLIARENKO, 2006). During spring high water, channels are filled with water that reaches lakes and spreads wide over the steppe. The freshwater and the salt waterlakes have depths not exceeding 2.5–3 m and have the typical features of all reservoirs of arid territories, a cyclic hydrological mode where the periods of filling and drying repeat each 12–15 years. Large highly mineralized lakes Balkhash, Tengiz, Issyk Kul' and Karakul', as well as the Aralian and Caspian seas, are confined to this climatic area (HAMMER 1986).

Phytogeographically, this region is situated near the boundary of the Irano-Turanian province and the province north of it (TAKHTAJAN 1978). A large number of lakes in this area are protected on account of their importance for biodiversity conservation (BRAGINA and BRAGIN 2002).

We previously studied algal biodiversity in respect to ecological assessment of the wetlands (BARINOVA et al. 2002) and compared it with other arid regions (BARINOVA et al. 2009). Here we continue studying the diversity of algal communities and its relation to salinity.

Material and methods

This research was based upon 98 samples of phytoplankton and periphyton collected in the North Kazakhstan Region in October 1999 and May–June 2000. Altogether 34 lakes were sampled, as well as the mouth of Karasu River near Lake Tuntugur, Jailmo Well near Lake Kulykol, and Jarsor Brook near Lake Jarsor located in the northern Kazakhstan arid area (Fig. 1). The water level in the studied shallow lakes depends on the climate and on snow melt, and is related to the complete or partial drying of some lakes in dry years. The studied shallow lakes have a permanent depth of 0.5–2.0 m. They become overgrown by underwater and surface vegetation, and exhibit high hydrogen sulphide content in their water, which varies in seasons and in lake gulfs (BRAGINA and BRAGIN 2002). Water salinity in the lakes varies from fresh to salty, with sulfates and chlorides prevailing.

The samples were taken by scooping up for phytoplankton and by scratching for periphyton and were fixed in 3% formaldehyde (WHITTON et al. 1991). Algae were studied with Swift and Amplival dissecting microscopes under magnifications of 740–1850 and were photographed with the digital camera Inspector 1. The diatoms were prepared with the peroxide technique (SWIFT 1967) modified for glass slides (BARINOVA 1988, 1997).

In parallel with sampling for algae we measured electrical conductivity, total dissolved solids, and pH with HANNA HI 9813, and DPC2, concentration of N-NO_3 with HANNA HI 93728 and phosphates with HACH spectrophotometer, as well as salinity by the argentometric method (APHA 1998); pH measurements were made down to 0.15.

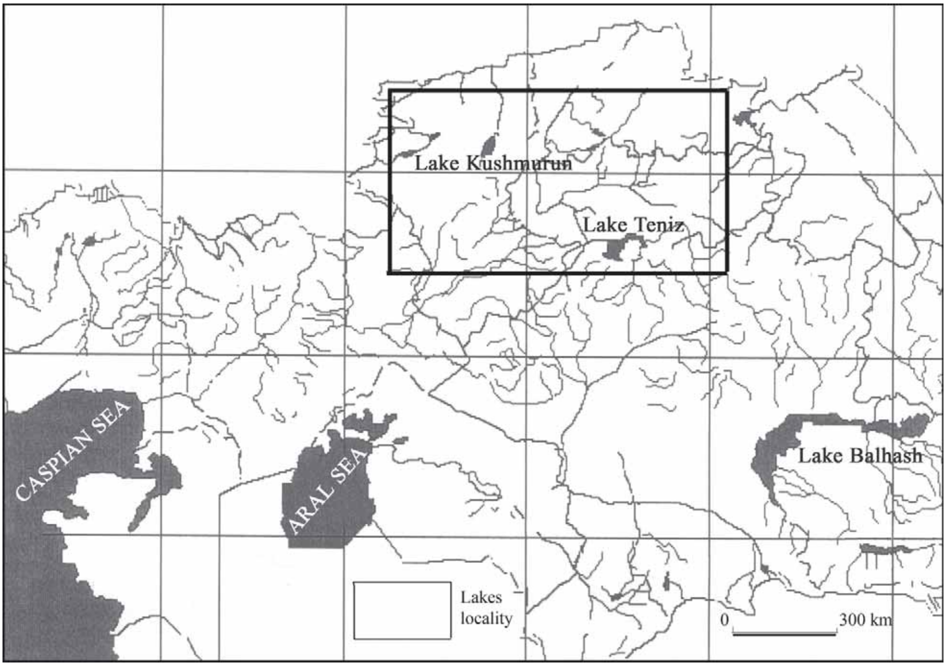

Fig. 1. Lakes and wetland region in the Northern Kazakhstan.

The assessment of $\beta+\gamma$ radioactive pollution of water samples was performed with detector-indicator of radioactivity QUARTEX RD 8901.

The algal abundances were assessed on the basis of a 6-score scale (KORDE 1956, BARINOVA et al. 2006).

The taxonomy follows the systems adopted in the »Süswasserflora von Mitteleuropa« (ETTL 1978; STARMACH 1985; ETTL and GARTNER 1988; KRAMMER and LANGE-BERTALOT 1991a, b, c, d; KOMÁREK and ANAGNOSTIDIS 1998) and MATTOX and STEWART (1984) system for green algae, with additions for individual taxa in GOLLERBACH et al. (1953), KISSELEV (1954), POPOVA (1966), VINOGRADOVA et al. (1980), PALAMAR-MORDVINTSEVA (1982), KRAMMER (1985, 2000), MOSHKOVA and GOLLERBACH (1986), LANGE-BERTALOT and KRAMMER (1987), MEFFERT (1987), KOMÁREK and ANAGNOSTIDIS (1989), POPOVSKY and PFIESTER (1990), BARBER and CARTER (1996), HEGEWALD (2000), RUMRICH et al. (2000).

The ecological and geographic characteristics of algae are obtained from the database compiled by the author for freshwater algae as a basis for statistical analysis of algal biodiversity distribution over ecological gradients (BARINOVA 2000, BARINOVA et al. 2000, 2006).

Our ecological analysis has revealed a grouping of freshwater algae in respect to pH, salinity and saprobity as well as the other habitat conditions. Each group was separately assessed with respect to its significance for bioindications. Species that respond predictably to environmental variables can be used as bioindicators reflecting the response of aquatic ecosystems to eutrophication, pH levels (acidifications), salinity and organic pollutants.

Distribution of species sensitive to pH and suitable as bioindicators for acidity is analyzed in accordance with the classification of HUSTEDT (1938–1939). This classification system is divided into pH-related groups, from alkalibiontes to acidobiontes.

The bioindication of salinity is based on the classification system by HUSTEDT (1957) with groups ranging from polyhalobes to oligohalobes-halophobes according to KOLBE's (1927) system of halobity.

There are several alternative approaches to assessment of saprobity (adaptation to excessive levels of nutrients), with that of PANTLE and BUCK (1955) modified by SLÁDEČEK (1973, 1986) being found most suitable for the present analysis. The indicators of saprobity are assigned to four groups according to their saprobity index values (S) ranging from polysaprobes (S=3.5–4.0) to xenosaprobes (S=0–0.5). The indices of saprobity are obtained as a function of saprobic species numbers and their relative abundances:

$$S = \Sigma sh / \Sigma h \qquad \text{(Eq. 1)}$$

where S indicates index of saprobity for algal community; s – species-specific saprobity level; h – abundance on the 6-scores scale (after KORDE 1956).

For phytogeographic analysis, species ranges were plotted and assigned to phytogeographic divisions of TAKHTAJAN (1978).

Statistical methods were used in comparative floristic approaches (NOVAKOVSKY 2004) for clarifying of algal flora similarity in the natural protected wetlands in the semi-arid climate of the Northern Kazakhstan. The percent disagreement was calculated by Ward's method in Statistica 6.0 Program.

Ecological classification of water quality was based on a combination of hydrochemical variables and the indices of saprobity (ROMANENKO et al. 1990, BARINOVA et al. 2006). The status of water objects was assessed as sum of all data integrated in the functional model of an aquatic ecosystem (BARINOVA et al. 2006). Gamma and beta radiation were studied as background variables.

Results

Influence of ecological conditions on biodiversity of algae in the arid region wetlands of Kazakhstan

Because of the remoteness of Kazakhstan's protected areas, algal diversity there has remained virtually unstudied. The lakes that we studied can be considered as typical for this region. Their salinity (as the saltiness or dissolved salt content of a body of water) varies from 0.19 to 32.7 NaCl g L^{-1} (Tab. 1) increasing during the summer dry period and contains not only chlorides but also sulphates as regional norm. The acidity varies from slightly acid to alkaline, whereas the concentration of nitrates and phosphates attests to a sufficient trophic base for algal development (Tab. 1). At the same time, the saprobity indices of PANTLE and BUCK (1955) modified by SLÁDEČEK (1973) varied from 1.65 in the Gr. Karakamys Lake and 1.47 in the Karasu River mouth to 2.7 in the lakes Tahtakul and Aksuat, which indicates a lack of appreciable anthropogenic impact.

Tab. 1. Environmental conditions, species number and index of saprobity in the lakes of the Kazakhstan arid regions in 1999–2000; classes of salinity and groups of salinity indicators according to HUSTEDT (1957): mh, mesohalobes; hl, oligohalobes – halophilous; i, oligohalobes – indifferent; saprobity index S according to SLÁDEČEK (1973), and equation (1).

No of Lake	Lake	Conductivity, mSm/cm	NaCl g L^{-1}	Class of Salinity	pH	$P–PO_4^{3-}$, mg L^{-1}	$N-NO_3^{-}$, mg L^{-1}	No. of algal species	Saprobity Index S	Group of salinity indicators	Group of similarity on the tree
1	Aike	11.73	6.79	III	7.01	0.16	3.4	19	1.98	hl	1
2	Aksuat	1.16–6.95	0.69–3.94	IV	6.16–6.56	0.01–0.02	1.0–1.4	1	2.70	–	2
3	Alpash	8.72	4.92	IV	7.05	0.01	1.0	13	1.74	i	2
4	Annovskoe	0.7–0.79	0.43–0.45	IV	6.87–7.11	0.01	1.2–2.0	22	1.71–1.81	hl	2
5	Balykty	4.33	2.43	IV	7.84	0.02	1.1	26	2.21	i	1
6	Batpakkol	0.37	0.21	IV	7.29	0.26	2.3	2	2.0	hl	2
7	Biesoygan	0.851	0.52	IV	6.76	0.39	2.1	7	2.55	i	2
8	Bozshakol	0.62–0.91	0.38–0.55	IV	6.43–7.37	0.20–2.25	1.7–8.5	63	1.95–2.13	hl	3
9	Chushkaly	16.4	9.35	III	6.94	0.28	1.7	18	1.97	hl+mh	1
10	Gr. Kak	57.3	32.7	II	6.36	0.05	2.2	6	2.11	hl	2
11	Gr. Karakamys	0.81–2.88	0.46–1.7	IV	6.59–6.66	0.01–0.68	0.8–1.2	28	1.65–1.8	i+hl	2
12	Gr. Sankebay	14.29	8.17	III	7.40	0.09	1.6	3	2.49	hl	2
13	Jaltyr	11.47	6.52	III	6.77	1.0	1.0	6	1.86	i	2
14	Jaman	0.37–0.41	0.22–0.23	IV	6.54–7.53	0.03–0.08	1.2–1.6	57	1.78–2.10	i+hl	3
15	Jarken	0.86	0.49	IV	6.74	0.03	0.9	22	2.00	i+hl	2
16	Jarkol	5.45–5.67	3.1–3.42	IV	7.26–7.38	0.17–1.08	2.3–4.1	8	1.7–1.96	i	2
17	Jilandy	1.48	0.85	IV	7.15	0.68	1.2	4	2.05	i+hl	2
18	Kamyshovoe	0.37–0.43	0.21–0.26	IV	6.29–7.14	0.02–0.11	1.2–1.9	79	1.86–1.9	i+hl	3

Tab. 1. – continued

No of Lake	Lake	Conductivity, mSm/cm	NaCl g L^{-1}	Class of Salinity	pH	$P–PO_4^{3-}$, mg L^{-1}	$N-NO_3^{-}$, mg L^{-1}	No. of algal species	Saprobity Index S	Group of salinity indicators	Group of similarity on the tree
19	Karasu River, near Lake Tuntugur	0.398	0.24	IV	6.86	0.23	1.4	2	1.47	hl	2
20	Koybagor	1.1–1.16	0.66–0.69	IV	6.83–7.35	0.07–0.27	1.3–2.0	112	1.95–2.04	i+hl	3
21	Kulagul	0.87–1.16	0.50–0.69	IV	7.48–7.57	0.17–0.98	0.0–0.6	18	2.38–2.44	i	1
22	Kulykol	10.4–10.9	5.94–6.43	III	6.73–7.18	0.03–0.3	1.1–2.1	20	1.85–2.3	i	1
23	Kulykol, Well Jailma	1.01	0.58	IV	7.28	0.06	1.0	3	2.35	i+hl	2
24	Kushmurun	30.1	18.0	III	6.77	0.1	3.5	8	2.08	i+hl	2
25	Majbalyk	1.95–3.23	1.11–1.78	IV	6.92–7.4	0.0–0.02	1.4–2.2	4	2.04	i	2
26	Sankebay	14.68	8.8	III	8.15	0.54	5.4	5	1.93	i	2
27	Sarykol	1.14–1.17	0.67–0.69	IV	6.97–6.98	0.0–0.06	0.9–1.5	37	1.71–2.15	i	1
28	Shoshkaly	6.14–6.56	3.49–3.92	IV	6.33–7.15	0.03–0.32	1.1–1.3	31	1.87–2.53	i+hl	1
29	Stream Jarsor	0.63–0.79	0.38–0.44	IV	6.78–6.86	0.01	1.0	19	1.76–1.99	i+mh	2
30	Sultan	3.04	1.73	IV	6.73	0.0	0.9	5	2.15	i	2
31	Suly	0.328	0.19	IV	7.13	1.77	1.4	7	1.84	i	2
32	Tahtakul	0.99–2.3	0.56–1.38	IV	6.35–6.79	0.03–0.48	1.1–1.8	7	1.8–2.7	i	2
33	Teniz	2.52–6.99	1.43–3.98	IV	6.66–6.69	0.0–0.04	1.0–1.5	61	1.87–1.96	i+hl	3
34	Tyuntugur	1.03–1.16	0.63–0.7	IV	6.66–7.53	0.01–0.26	1.5–2.0	58	1.88–2.12	i+hl	3

Our taxonomic analysis revealed 254 species from eight taxonomical divisions, among which diatoms slightly prevail over green and blue-green species (Tab. 2, Fig. 2a). For 13 species we indicate only generic assignments because certain critical features, such as sexual forms in *Spirogyra*, are lacking in our material.

Tab. 2. Ecology and geographical distribution of algae and cyanobacteria in Kazakhstan lakes. Ecological types: Habitat: B – benthic; P – planktonic; P-B – planktonic-benthic; T – temperature; temp – temperate; eterm – eurytermic; warm – warm-water; cool – cool-water; Reo – reophility and oxygenation; st – standing water; str – stream; D – saprobity categories of WATANABE (1986); es – eurysaprob; sx – saproxen; sp – saprophil; S – saprobity categories of SLÁDEČEK (1986); o – oligosaprob; o-α – oligo-alfa-mesosaprob; o-β – oligo-beta-mesosaprob; β – beta-mesosaprob; β-α – beta-alfa-mesosaprob; α – alfa-mesosaprob; α-β – alfa-beta-mesosaprob; x – xenosaprob; α-ρ – alfa-meso-polysaprob; ρ – polysaprob; Hal – halobity; mh – mesohalobe; i – oligohalobious-indifferent; hl – oligohalobious-halophilous; hb – oligohalobious-halophobous; ph – polyhalobe; pH – acidophility; ind – indifferent; alf – alkaliphil; acf – acidophil; alb – alkalibiont; Geo – chorological types; mt – Mediterranean; k – cosmopolite; b – Boreal; Pt – Paleotropical; Nt – Neotropical; Ha – Holarctic. »–« no data. Numbers of lakes as in Table 1.

No	Taxon	No of Lake	Habitat	T	Reo	D	S	Hal	pH	Geo
Cyanoprokaryota										
1	*Anabaena constricta* (Szaf.) Geitl.	21	P–B	–	–	–	p	–	–	Ha
2	*Anabaena contorta* Bachm.	1	P	–	st-str	–	–	–	–	k
3	*Anabaena flos-aquae* (Lyngb.) Bréb. f. flos-aquae	18	P	–	st	–	β	i	–	k
4	*Anabaena flos-aquae* f. *jacutica* (Nyg.) Elenk.	8	P	–	–	–	–	i	–	b
5	*Anabaena minima* Tschernov	33	–	–	–	–	–	–	–	b
6	*Anabaena* sp.	18, 28, 33	–	–	–	–	–	–	–	–
7	*Anabaena spiroides* Kleb.	34	P	–	st-str	–	o	i	–	k
8	*Anabaena variabilis* Kütz.	9	P-B	–	st	–	–	mh	–	k
9	*Aphanizomenon flos-aquae* (L.) Ralfs	6, 8, 20	P	–	–	–	β	hl	–	k
10	*Aphanothece clathrata* W. et G. S. West	1, 4, 8, 14, 20, 24, 27	P	–	–	–	β	hl	–	k
11	*Aphanothece stagnina* (Spreng.) A. Br.	8, 20, 21	P-B	–	–	–	o	hl	ind	k
12	*Chroococcus limneticus* Lemm.	20	P	–	–	–	o	–	–	k
13	*Chroococcus minor* (Kütz.) Näg.	33	B	–	–	–	o-β	–	–	k
14	*Chroococcus minutus* (Kütz.) Näg.	20	P	–	–	–	–	–	–	k
15	*Chroococcus turgidus* (Kütz.) Näg.	1, 3, 5, 8, 21, 33, 35	P-B	–	–	–	o	hl	alf	k
16	*Chroococcus vacuolatus* Skuja	33	P-B	–	–	–	–	–	–	b, mt

Tab. 2. – continued

No	Taxon	No of Lake	Habitat	T	Reo	D	S	Hal	pH	Geo
17	*Chroococcus varius* A. Br.	4, 8	B	–	–	–	o-β	–	–	k
18	*Coelomoron pusillum* (Van Goor) Komárek	1, 4, 8, 14, 21, 33	P	temp	st	–	α	–	–	k
19	*Coelosphaerium kuetzingianum* Näg.	15	P	–	–	–	–	i	–	k
20	*Coelosphaerium minutissimum* Lemm.	21	P	–	–	–	–	hl	–	k
21	*Gloeotrichia pisum* (Ag.) Thur.	4, 18	B	–	–	–	–	hl	ind	k
22	*Gomphosphaeria aponina* Kütz.	28, 33	P	–	–	–	–	hl	alf	k
23	*Lyngbya aestuarii* (Mert.) Leibm.	28	P-B	–	–	–	–	–	–	k
24	*Lyngbya contorta* Lemm.	1	–	–	–	–	–	hl	–	Ha
25	*Lyngbya* sp.	15, 18	–	–	–	–	–	–	–	–
26	*Merismopedia minima* Beck	18, 20, 28, 33, 34	B	–	–	–	–	–	–	Ha
27	*Merismopedia smithii* De Toni	14, 18, 20	P	cool	–	–	–	–	–	Ha
28	*Merismopedia tenuissima* Lemm.	1, 8, 9, 14, 20, 33	P-B	–	–	–	β	hl	–	k
29	*Microcystis aeruginosa* (Kütz.) Kütz.	7, 8	P	–	–	–	β	hl	–	k
30	*Microcystis pulverea* f. *delicatissima* (W. et G. S. West) Elenk.	1	P	–	–	–	–	i	–	k
31	*Nostoc kihlmanii* Lemm.	30	P	cool	st	–	–	i	ind	Ha
32	*Oscillatoria brevis* Kütz. ex Gom.	10	P-B	–	st	–	α	–	–	k
33	*Oscillatoria limosa* (Roth) Ag.	11	P-B	–	st-str	–	α	hl	–	k
34	*Oscillatoria princeps* Vauch. ex Gom.	10, 22	P-B	–	st-str	–	α	–	–	k
35	*Phormidium ambiguum* Gom.	11	B	–	st-str	–	–	i	ind	k
36	*Phormidium autumnale* (Ag.) Gom.	20, 30, 33	B	–	st-str	–	β	–	–	k
37	*Phormidium paulsenianum* B.-Peters.	28	B	–	–	–	–	ph	–	Ha
38	*Phormidium retzii* Ag. ex Gom.	10	B	–	st-str	–	o	–	–	k
39	*Rhabdogloea scenedesmoides* (Nyg.) Komárek et Anagn.	8	P	cool	st	–	–	–	–	Ha
40	*Spirulina major* Kütz. ex Gom.	10	P	–	st	–	–	–	–	k
41	*Synechocystis sallensis* Skuja	20	P-B	cool	st	–	o	–	acf	Ha, Nt
42	*Tolypothrix* sp.	21	–	–	–	–	–	–	–	–
43	*Woronichinia compacta* (Lemm.) Komárek et Hindák	1, 18, 21, 27	P	cool	st	–	–	–	–	Ha, Pt

Tab. 2. – continued

No	Taxon	No of Lake	Habitat	T	Reo	D	S	Hal	pH	Geo
Bacillariophyta										
44	*Achnanthes brevipes* Ag.	11, 13, 28	B	–	–	–	–	hl	alf	k
45	*Achnanthes gibberula* var. *interrupta* Poretzky et Anisimova	20	B	–	–	–	–	hl	–	k
46	*Achnanthes lanceolata* (Bréb. in Kütz.) Grun. in Cl. et Grun.	5, 8, 22, 29, 34	P-B	warm	st-str	sx	o	i	alf	k
47	*Achnanthes minutissima* Kütz.	3, 11, 18, 20, 27–29, 33	B	eterm	st-str	es	o	i	alf	k
48	*Amphipleura pellucida* (Kütz.) Kütz.	5, 33	B	–	st	–	o-α	i	alf	k
49	Amphora coffeaeformis (Ag.) Kütz.	3, 22, 33	B	–	st-str	–	–	mh	–	k
50	*Amphora commutata* Grun. in V. H.	3	B	–	–	–	–	hl	–	k
51	*Amphora holsatica* Hust. in Pasch.	11	P	–	st-str	–	–	hl	–	k
52	*Amphora ovalis* (Kütz.) Kütz.	3, 8, 11, 14, 18, 20, 33, 34	B	temp	st-str	sx	α-β	i	alf	k
53	*Amphora pediculus* (Kütz.) Grun. ex A. Schmidt	5, 8, 16, 20, 21, 33, 34	B	temp	–	es	α-β	i	alf	k
154	*Amphora veneta* Kütz.	4, 8, 10, 14, 28	B	–	–	es	α-p	i	alf	k
55	*Asterionella formosa* Hass.	4, 8, 18	P	–	–	sx		i	alf	k
56	*Aulacoseira granulata* (Ehrb.) Sim.	8, 33, 34	P-B	cool	st-str	es	β	i	alf	k
57	*Aulacoseira italica* (Ehrb.) Sim.	34	P-B	cool	st-str	es	β	i	alf	k
58	*Caloneis amphisbaena* (Bory) Cl.	5, 8, 12, 20, 28–30, 34	B	–	–	–	–	hl	alf	k
59	*Caloneis silicula* (Ehrb.) Cl.	5, 8, 11, 18, 20, 32	B	–	st	sp	β	i	alf	k
60	*Caloneis westii* (W. Sm.) Hendey	5, 33	B	–	–	–	–	mh	–	k
61	*Campylodiscus noricus* Ehrb.	26, 33	B	–	–	–	o	i	alf	k
62	*Chaetoceros* sp.	9, 33	P	–	–	–	–	–	–	–
63	*Cocconeis placentula* Ehrb.	9, 11, 15, 18–20, 33	P-B	temp	st-str	es	o	i	alf	k
64	*Craticula cuspidata* (Kütz.) D. G. Mann	5, 20, 33	B	temp	st	–	–	i	alf	k
65	*Cyclostephanos dubius* (Fricke in A. Schmidt) Round	20	–	–	–	–	β-α	hl	alf	k
66	*Cymatopleura librile* (Ehrb.) Pant.	5, 7, 89, 14, 18, 20, 25, 27, 28, 34	P-B	–	–	–	–	–	–	k

Tab. 2. – continued

No	Taxon	No of Lake	Habitat	T	Reo	D	S	Hal	pH	Geo
67	*Cymbella cornuta* (Ehrb.) R. Ross	8, 14, 18, 27, 31, 34	B	–	–	–	–	i	alf	k
68	*Cymbella neocistula* Krammer	14	B	–	st-str	sx	β	i	alf	k
69	*Cymbella tumida* (Bréb.) V. H.	8, 18, 20	B	temp	–	sx	o	i	alf	k
70	*Cymbella turgidula* Grun.	5, 14, 18, 20, 33	B	–	st-str	es	–	–	ind	k
71	*Diatoma vulgare* Bory var. *vulgare*	18, 20, 22, 27, 33, 34	P-B	–	st-str	–	x	i	ind	k
72	*Diatoma vulgare* var. *ehrenbergii* (Kütz.) Grun.	34	B	–	–	–	–	i	alf	k
73	*Diploneis elliptica* (Kütz.) Cl.	23	B	eterm	–	sx	o	i	alf	k
74	*Diploneis ovalis* (Hilse) Cl.	24	B	–	–	sp		i	alb	b
75	*Encyonema silesiacum* (Bleisch. in Rabenh.) D. G. Mann in Round et al.	8, 18, 27, 34	B	–	st-str	sx	o-β	i	ind	k
76	*Epithemia adnata* (Kütz.) Bréb.	5, 8, 14, 18, 20, 31, 34	B	temp	–	sx	β	i	alf	k
77	*Epithemia sorex* Kütz.	14, 18, 20, 33	B	temp	st	sx	β	i	alf	k
78	*Epithemia turgida* (Ehrb.) Kütz.	4, 8, 11, 14, 15, 18, 20, 29, 31, 34	B	temp	–	–	–	i	alf	k
79	*Eunotia exigua* (Bréb. ex Kütz.) Rabenh.	11	B	–	–	es	o	hb	acf	k
80	*Eunotia minor* (Kütz.) Grun. in V. H.	18	–	–	–	es	β-α	–	ind	k
81	*Eunotia monodon* Ehrb.	15	B	–	–		o	hb	acf	k
82	*Eunotia pectinalis* (O. Müll.) Rabenh.	18, 27	B	–	–	sx	–	hb	acf	k
83	*Eunotia praerupta* Ehrb. var. *praerupta*	18	B	cool	st-str	sx	–	hb	acf	k
84	*Eunotia praerupta* var. *bidens* (Ehrb.) Grun. in Cl. et Grun.	18	B	cool	–	–	–	hb	acf	k
85	*Eunotia sibirica* Cl. in Cl. et Grun.	11, 31	B	–	–	–	–	i	–	b
86	*Fallacia pygmaea* (Kütz.) Stikle et Mann	5, 24	B	–	–	es	α	mh	alf	k
87	*Fragilaria crotonensis* Kitton	3, 8	P	–	st	es	–	hl	alf	k
88	*Fragilaria* sp.	15, 24	–	–	–	–	–	–	–	–
89	*Fragilaria ulna* (Nitzsch) L.-B.	4, 5, 8, 11, 13, 14, 18–21, 26, 27, 29, 33, 34	P-B	temp	st-str	es	β	i	ind	k
90	*Fragilaria vaucheriae* (Kütz.) B. Peters.	8, 14, 16, 17, 18, 20, 21, 27, 28, 33, 34	P	–	–	–	–	i	alf	Ha

Tab. 2. – continued

No	Taxon	No of Lake	Habitat	T	Reo	D	S	Hal	pH	Geo
91	*Fragilariforma constricta* (Ehrb.) Williams et Round	14	B	–	–	–	–	i	acf	Ha
92	*Fragilariforma virescens* (Ralfs) Williams et Round	14, 18	P-B	–	st	es	x	i	ind	k
93	*Fragilariopsis separanda* (Hust.) Hasle	24	–	–	–	–	–	hl	–	Ha
94	*Frustulia* sp.	24	–	–	–	–	–	–	–	–
95	*Geissleria schoenfeldii* (Hust.) L.-B. et Metzetlin in L.-B.	20	B	–	–	–	–	i	alf	b
96	*Gomphonema acuminatum* Ehrb. var. *acuminatum*	11, 20	P-B	–	st	es	β	i	alf	k
97	*Gomphonema acuminatum* var. *coronatum* (Ehrb.) W. Sm.	14, 18, 20	P-B	–	st	–	β	i	ind	k
98	*Gomphonema augur* Ehrb.	14, 18	B	–	–	es	–	i	ind	k
99	*Gomphonema clavatum* Ehrb.	8, 18, 33	B	–	–	es	–	i	–	k
100	*Gomphonema parvulum* (Kütz.) Kütz.	8, 11, 33	B	temp	str	es	β	i	ind	k
101	*Gomphonema truncatum* Ehrb.	8, 14, 18, 20	P-B	–	–	es	β-α	–	–	k
102	*Gyrosigma acuminatum* (Kütz.) Rabenh.	5, 8, 18, 22, 26, 34	B	cool	–	–	β	i	alf	k
103	*Gyrosigma spenceri* (W. Sm.) Cl. var. *spenceri*	9, 16, 22, 33	B	–	–	es	o	mh	alf	k
104	*Gyrosigma spenceri* var. *nodiferum* Grun.	3, 9, 13, 14, 28	B	–	–	–	–	i	ind	b
105	*Hippodonta hungarica* (Grun.) L.-B., Metzeltin et Witkowski	14, 16, 18, 20, 21, 34	B	–	st-str	es	β	i	alf	k
106	*Luticola mutica* (Kütz.) Mann	33, 34	B	–	–	sp	o-β	–	–	k
107	*Mastogloia* sp.	11, 20, 33		–	–	–	–	–	–	–
108	*Melosira varians* Ag.	34	P-B	temp	st-str	es	β	hl	alf	k
109	*Navicula exigua* Grun.	5, 7–9, 14, 16, 20, 22, 25–28, 33, 34	B	–	–	es		i	alf	k
110	*Navicula gregaria* Donk.	8	B	–	–	es	β	mh	alf	k
111	*Navicula peregrina* (Ehrb.) Kütz.	34	B	–	–	es	o	mh	alf	k
112	*Navicula rhynchocephala* Kütz.	8, 14, 18, 28	B	–	–	–	α	hl	alf	k
113	*Navicula* sp.	3, 20	–	–	–	–	–	–	–	–
114	*Navicula viridula* (Kütz.) Ehrb.	5, 8, 14, 18, 20, 28, 33, 34	B	–	–	es	α	hl	alf	k
115	*Neidium dubium* (Ehrb.) Cl.	10, 20	B	–	–		β	i	alf	k
116	*Neidium iridis* (Ehrb.) Cl.	8, 18, 20	B	–	st	es	o	hb	ind	k
117	*Nitzschia acicularis* (Kütz.) W. Sm.	2, 5, 9, 14, 15, 18, 20–22, 24, 27, 28, 33, 34	P-B	temp	–	es	α	i	alf	k

Tab. 2. – continued

No	Taxon	No of Lake	Habitat	T	Reo	D	S	Hal	pH	Geo
118	*Nitzschia clausii* Hantzsch	11, 29	B	–		es	o-α	mh	acf	k
119	*Nitzschia dissipata* (Kütz.) Grun.	11, 18, 20, 22, 25, 34	B	–	st-str	sx	β	i	alf	k
120	*Nitzschia filiformis* (W. Sm.) V. H.	8, 9, 14, 28, 34	B	–	–	es	α-β	hl	–	k
121	*Nitzschia linearis* (C. Ag.) W. Sm.	3, 8, 20, 28, 31, 34	B	temp	–	es	β	i	alf	k
122	*Nitzschia macilenta* Greg.	14, 18, 20, 34	–	–	–	–	–	hl	–	–
123	*Nitzschia palea* (Kütz.) W. Sm.	5, 7, 8, 12–15, 18, 20, 21, 27, 28, 33, 34	P-B	temp	–	sp	β-α	i	ind	k
124	*Nitzschia reversa* W. Sm.	5	–	–	–	–	–	hl	–	k
125	*Nitzschia sigmoidea* (Nitzsch) W. Sm.	20	P-B	–	–	–	β	i	alf	k
126	*Nitzschia* sp.	22, 24	–	–	–	–	–	–	–	–
127	*Nitzschia vermicularis* (Kütz.) Hantzsch in Rabenh.	3, 5, 11, 12	B	–	–	–	β	i	alf	k
128	*Pinnularia gibba* Ehrb. var. *gibba*	18, 20, 33	B	–	–	es	–	i	ind	b
129	*Pinnularia gibba* var. *subundulata* A. Mayer	20, 34	B	–	–	–	–	i	–	b
130	*Pinnularia microstauron* (Ehrb.) Cl. var. *microstauron*	20, 29	B	temp	–	sp	o	i	ind	k
131	*Pinnularia microstauron* var. *brebissonii* (Kütz.) Mayer	8	B	–	st-str	es	β	i	ind	k
132	*Pinnularia viridis* (Nitzsch) Ehrb.	3, 14, 20, 22, 29, 31, 32, 34	P-B	temp	–	es	β	i	ind	k
133	*Pinnularia* sp.	18	B	–	–	–	–	–	–	–
134	*Rhoicosphenia abbreviata* (C. Ag.) L.-B.	4, 8, 9, 14, 15, 17, 27, 28, 33, 34	P-B	–	–	es	β	i	alf	k
135	*Rhopalodia gibba* (Ehrb.) Müll.	14, 18, 20, 29	B	temp	–	es	o	i	alb	k
136	*Rhopalodia musculus* (Kütz.) O. Müll.	29	P-B	–	–		x	mh	alb	k
137	*Sellaphora pupula* (Kütz.) Mereschkowsky	18, 34	B	eterm	st	sp	α	hl	ind	k
138	*Stauroneis anceps* Ehrb. var. *anceps*	6, 8, 9, 11, 16, 18, 20, 22, 28, 33	P-B	–	–	sx	β	i	ind	k
139	*Stauroneis anceps* var. *gracilis* Rabenh.	8	B	–	–	sx	–	i	ind	k
140	*Stauroneis phoenicenteron* (Nitzsch) Ehrb. f. *phoenicenteron*	18, 20	B	temp	–	s	β	i	ind	k

Tab. 2. – continued

No	Taxon	No of Lake	Habitat	T	Reo	D	S	Hal	pH	Geo
141	*Stauroneis phoenicenteron* f. *gracilis* (Ehrb.) Hust.	20	–	–	–	–	–	–	ind	–
142	*Stauroneis* sp.	20	B	–	–	–	–	–	–	–
143	*Stephanodiscus hantzschii* Grun.	1, 7–9, 18, 20, 33, 34,	P-B	temp	st	es	α	i	alf	k
144	*Stephanodiscus* sp.	5	–	–	–	–		–	–	–
145	*Surirella brebissonii* Kram. et L.-B.	20, 27, 33	B	–	st-str		β-α	i	alf	k
146	*Surirella linearis* W. Sm.	14	P-B	–	–	es	β	i	ind	Ha
147	*Surirella ovalis* Bréb.	16, 26, 29, 33	P-B	–	–	es	o	mh	alf	k
148	*Surirella ovata* var. *pinnata* (W. Sm.) Rabenh.	20, 27, 33, 34	B	–	–	es	β	i	alf	k
149	*Surirella tenera* Greg.	34	P-B	–	st	es	β	i	alf	k
150	*Tryblionella gracilis* W. Sm.	5, 17, 20, 23, 29	B	–	–	–	–	–	–	k
151	*Tryblionella hungarica* (Grun.) D. G. Mann	–	P-B	–	–	sp	α	mh	alf	k
Chlorophyta										
152	*Actinastrum hantzschii* Lagerh.	8, 14, 21, 34	P-B	–	st-str	–	β	i	–	k
153	*Ankistrodesmus falcatus* (Corda) Ralfs	20	P-B	–	st-str		β	hb	–	k
154	*Ankistrodesmus fusiformis* Corda sensu Korsch.	14, 20	P-B	–	st-str	–	–	i	–	k
155	*Binuclearia lauterbornii* (Schmidle) Pr.-Lavr.	1, 23	P	–	–	–	–	–	–	Ha
156	*Chaetophora pisiformis* (Roth) Ag.	18, 32	B	–	st-str	–	–	–	–	k
157	*Chlamydomonas* sp.	20		–		–	–	–	–	–
158	*Cladophora fracta* (Müll. ex Vahl.) Kütz.	4, 5, 9, 13, 14, 22, 27, 28, 33, 34	P-B	–	st-str	–	β	–	–	k
159	*Cladophora glomerata* (L.) Kütz.	11	P-B	–	st-str	–	β	i	alf	k
160	*Closterium acerosum* (Schrank) Ehrb.	28	P-B	–	st-str	–	α	i	ind	k
161	*Closterium dianae* Ehrb.	5, 18, 20, 33, 34	P-B	–	st-str	–	o	–	–	k
162	*Closterium ehrenbergii* Menegh.	15	P-B	–	st-str	–	β	hb	ind	k
163	*Closterium gracile* Bréb. in Chevalier	8, 22	P-B	–	st-str	–	–	hb	acf	k
164	*Closterium* sp.	8		–	–	–	–	–	–	–
165	*Coelastrum microporum* Näg. in A. Br.	8, 33	P-B	–	st-str	–	β	i	ind	k

Tab. 2. – continued

No	Taxon	No of Lake	Habitat	T	Reo	D	S	Hal	pH	Geo
166	*Coelastrum sphaericum* Näg.	8, 14, 20	P-B	–	st-str	–	–	i	–	k
167	*Coenochloris pyrenoidosa* Korsch.	11, 14, 18	P	–	–	–	–	hl	–	Ha
168	*Coenococcus polycoccus* (Korsch.) Hind.	4, 11, 15, 18, 20, 33, 34	P	–	st	–	–	–	–	k
169	*Coenocystis planktonica* Korsch.	12	P	–	st	–	β	i	–	k
170	*Coenocystis subcylindrica* Korsch.	15, 27	P	–	–	–	–	i	–	b
171	*Cosmarium punctulatum* Bréb.	4, 18, 27	P-B	–	–	–	–	hb	acf	k
172	*Cosmarium* sp.	4, 14, 18, 27, 34		–	–	–	–	–	–	–
173	*Crucigenia tetrapedia* (Kirchn.) W. et G. S. West	4, 8, 20, 27, 33, 34	P-B	–	st-str	–	β	i	ind	k
174	*Crucigeniella apiculata* (Lemm.) Komárek	34	P-B	–	st-str	–	–	–	–	k
175	*Desmodesmus brasiliensis* (Bohlin) Hegew.	8, 20, 33	P-B	–	st-str	–	β	–	–	k
176	*Desmodesmus denticulatus* (Lagerh.) An, Friedl et Hegew.	20	P-B	–	st-str	–	β	i	–	k
177	*Desmodesmus opoliensis* (P. Richt.) Hegew.	20	P-B	–	st-str	–	–	–	–	k
178	*Desmodesmus spinosus* (K. Biswas) Hegew.	18	P-B	–	st-str	–	o-β	–	–	Ha, Nt
179	*Dictyosphaerium pulchellum* Wood	4, 8, 14, 20, 21	P-B	–	st-str	–	–	i	ind	k
180	*Elakatothrix acuta* Pasch.	20	P	–	–	–	–	i	–	k
181	*Elakatothrix gelatinosa* Wille	20	P	–	st-str	–	o	i	–	k
182	*Eremosphera gigas* (W. Archer) Fott et Kalina	8, 15, 34	P	–	–	–	–	i	acf	k
183	*Franceia tenuispina* Korsch.	18	P	–		–	–	–	–	Ha
184	*Lagerheimia ciliata* (Lagerh.) Chod.	20	P-B	–	st-str	–	–	–	–	k
185	*Lagerheimia genevensis* Chod.	1, 20	P	–		–	–	i	–	k
186	*Micrasterias* sp.	18		–		–	–	–	–	–
187	*Monoraphidium arcuatum* (Korsch.) Hind.	1, 20, 28, 34	P-B	–	st-str	–	–	–	–	k
188	*Monoraphidium contortum* (Thur.) Kom.-Legn.	1, 8, 9, 14, 15, 18, 20, 21, 27, 28, 33	P-B	–	st-str	–	–	–	–	k
189	*Monoraphidium griffithii* (Berk.) Kom.-Legn. in Fott	7, 8, 9, 14, 18, 20, 21, 28, 33, 34	P-B	–	st-str	–	–	–	–	k

Tab. 2. – continued

No	Taxon	No of Lake	Habitat	T	Reo	D	S	Hal	pH	Geo
190	*Monoraphidium komarkovae* Nyg.	22	P	–	st-str	–	–	–	–	k
191	*Monoraphidium minutum* (Näg.) Kom.-Legn.	1	P-B	–	st-str	–	–	–	–	k
192	*Mougeotia* sp.	11, 18, 20, 28, 33		–		–	–	–	–	–
193	*Nephrochlamys rotunda* Korsch.	20	P-B	–	st-str	–	–	–	–	Ha
194	*Oedogonium* sp.	3, 11, 14, 15, 20, 29–32		–	–	–	–	–	–	–
195	*Oocystis lacustris* Chod.	4	P-B	–	st-str	–	β	hl	–	k
196	*Oocystis submarina* Lagerh.	1, 8, 27, 33	P-B	–	st	–	–	i	–	k
197	*Palmodictyon lobatum* Korsch.	15	B	–	st-str	–	–	–	–	k
198	*Pediastrum boryanum* (Turp.) Menegh.	1, 14, 18, 20, 27, 33, 34	P-B	–	st-str	–	β	i	ind	k
199	*Pediastrum duplex* Meyen	4, 14, 27	P-B	–	st-str	–	β	i	ind	k
200	*Pediastrum kawraiskyi* Schmidle	4, 8	P-B	–	st-str	–	–	–	–	Ha
201	*Pediastrum tetras* (Ehrb.) Ralfs	14, 20, 34	P-B	–	st-str	–	β	i	ind	k
202	*Penium* sp.	18		–	–	–	–	–	–	–
203	*Raphidocelis sigmoidea* Hind.	20	P	–	st-str	–	–	–	–	b, mt
204	*Raphidocelis subcapitata* (Korsch.) Nyg.	8, 33	P-B	–	st-str	–	–	–	–	Ha, Nt
205	*Scenedesmus acuminatus* (Lagerh.) Chod.	18, 20, 27	P-B	–	st-str	–	β	i	ind	k
206	*Scenedesmus acutiformis* var. *costatus* (Hub.-Pest.) Pankow	18	P-B	–	–	–	–	–	–	k
207	*Scenedesmus acutus* Meyen	14, 18, 20, 28	P-B	–	st-str	–	o-β	i	–	k
208	*Scenedesmus apiculatus* (W. et G. S. West) Chod. var. *apiculatus*	18, 28	P	–	st-str	–	–	–	–	Ha, Pt
209	*Scenedesmus apiculatus* var. *indicus* (Hortob.) Tzarenko	20	P-B	–	st-str	–	–	–	–	Ha, Nt
210	*Scenedesmus arcuatus* (Lemm.) Lemm.	14, 20	P-B	–	st-str	–	β	i	–	k
211	*Scenedesmus bijugatus* (Turp.) Kütz.	27	P	–		–	–	i	ind	k
212	*Scenedesmus disciformis* (Chod.) Fott. et Kom.	20	P-B	–	st-str	–	–	–	–	k
213	*Scenedesmus ellipticus* Corda	18, 27, 34	P-B	–	st-str	–	o-β	–	–	k
214	*Scenedesmus gutwinskii* Chod.	20	P	–		–	–	–	–	Ha
215	*Scenedesmus incrassatulus* Bohl.	20	P-B	–	st-str	–	–	–	–	k

Tab. 2. – continued

No	Taxon	No of Lake	Habitat	T	Reo	D	S	Hal	pH	Geo
216	*Scenedesmus obliquus* (Turp.) Kütz.	1, 8, 11, 20, 33	P-B	–	st	–	–	i	–	k
217	*Scenedesmus obtusus* Meyen	30	P-B	–	st-str	–	–	–	–	Ha
218	*Scenedesmus quadricauda* (Turp.) Bréb.	5, 14, 18, 20, 27, 33, 34	P	–	–	–	–	i	ind	k
219	*Schroederia setigera* (Schrod.) Lemm.	8	P	–	st-str	–	–	i	–	Ha, Nt
220	*Selenastrum gracile* Reinsch	14, 20	P-B	–	st-str	–	β	–	–	k
221	*Spirogyra* sp.	4, 15, 18, 27–30, 33	–	–	–	–	–	–	–	–
222	*Spirogyra weberi* Kütz.	29	–	–	–	–	–	–	–	k
223	*Staurastrum gracile* Ralfs	18, 27	P	–	st	–	–	i	–	k
224	*Staurastrum sebaldii* Reinsch.	4	P-B	–	–	–	–	–	acf	k
225	*Staurastrum* sp.	18	–	–	–	–	–	–	–	–
226	*Staurodesmus* sp.	14	–	–	–	–	–	–	–	–
227	*Stigeoclonium tenue* (Ag.) Kütz. emend. Cox et Bold	20	B	–	st-str	–	α	–	–	k
228	*Tetrachlorella alternans* (G. M. Smith) Korsch.	14	P-B	–		–	–	–	–	Ha
229	*Tetraedron caudatum* (Corda) Hansg.	34	P-B	–	st-str	–	β	i	ind	k
230	*Tetraedron incus* (Teil.) G. M. Smith	18, 20	P-B	–	st-str	–	–	i	–	k
231	*Tetraedron minimum* (A. Br.) Hansg.	1, 18, 20, 27, 34	P-B	–	st-str	–	β	i	–	k
232	*Tetrastrum elegans* Playf.	8, 20, 33	P	–	st-str	–	–	i	–	k
233	*Tetrastrum triacanthum* Korsch.	20	P	–	st-str	–	–	–	–	Ha
234	*Ulothrix tenerrima* Kütz.	29	B	–	–	–	–	i	–	k
235	*Ulothrix zonata* (Weber et Mohr) Kütz.	13, 22, 27, 34	P-B	–	st-str	–	o	i	ind	k
236	*Ulothrix* sp.	27	B	–	–	–	–	–	–	–
237	*Volvox aureus* Ehrb.	20	P	–	st	–	β	i	–	k
238	*Zygnema* sp.	18	B	–	–	–	–	–	–	–
Chrysophyta										
239	*Dinobryon sertularia* Ehrb.	11	P	–	–	–	–	i	–	k
Cryptophyta										
240	*Cryptomonas* sp.	1, 9, 16, 18, 20–22, 27, 32	P	–	–	–	–	–	–	–
Dinophyta										
241	*Glenodinium quadridens* (Stenis) Schiller.	20	P	–	–	–	–	–	–	k

Tab. 2. – continued

No	Taxon	No of Lake	Habitat	T	Reo	D	S	Hal	pH	Geo
Euglenophyta										
242	*Astasia inflata* Klebs	19	P	–	st	–	–	–	–	Ha, Nt
243	*Euglena acus* Ehrb. var. *acus*	20, 25, 34	P	eterm	st	–	β	i	ind	k
244	*Euglena oxyuris* Schmarda	14, 17	P		st-str	–	α	mh	ind	k
245	*Euglena viridis* Ehrb.	7	P-B	eterm	st-str	–	p	mh	ind	k
246	*Euglena* sp.	3, 4, 15	–	–		–	–	–	–	–
247	*Phacus caudatus* Hübn.	14, 20, 33	P-B	eterm	st-str	–	β	i	alf	k
248	*Phacus longicauda* (Ehrb.) Duj.	20	P-B	–	st	–	α	i	ind	k
249	*Phacus orbicularis* Hübn.	20	P-B	–	st-str	–	β	i	ind	k
250	*Trachelomonas hispida* (Perty) Stein emend. Delf.	4, 8, 18, 20, 27–29	P-B	eterm	st-str	–	β	i	–	k
251	*Trachelomonas volvocina* Ehrb.	8, 14, 18, 20, 27, 29, 34	P-B	eterm	st-str	–	β	i	ind	k
Xanthophyta										
252	*Ophiocytium majus* Missing	15, 33	P	–	st	–	–	–	acf	k
253	*Tribonema viride* Pascher	11, 15, 29, 33	P-B	–	–	–	–	i	–	k
254	*Tribonema* sp.	22	B	–	–	–	–	–	–	–

The lacustrine algoflora mainly consists of geographically widespread species (85% cosmopolitan, 9% of pan-Holarctic distribution, and 4.5% of Boreal distribution (Tab. 2).

In the lakes of arid regions, algae occur over the water column and on hard substrates, with some preference for the latter (Fig. 2b). The most abundant periphyton species are cyanoprokaryotic *Anabaena flos-aquae* f. *flos-aquae* (Kamyshovoe Lake), *Coelosphaerium minutissimum* (Kulagul Lake), *Phormidium retzii* (Lake Great Kak), diatoms *Amphora pediculus* (Great Kak Lake), and green algae *Binuclearia lauterbornii* (Aike Lake) and *Spirogyra weberi* (Jarsor Stream)

With respect to pH, the indicator species (HUSTEDT 1938–1939) are segregated into four groups among which the alkaliphiles prevail (Fig. 2c). Such distribution is characteristic of slightly alkalic conditions (Tab. 1). The most common alkaliphiles are *Chroococcus turgidus*, (Cyanoprokaryota) and *Achnanthes minutissima*, *Amphora ovalis*, *A. pediculus*, *Caloneis amphisbaena*, *Epithemia turgida*, *Fragilaria vaucheriae*, *Navicula exigua*, *Nitzschia acicularis*, *N. palea*, *Rhoicosphenia abbreviata* (Bacillariophyta). The diversity of pH indicators reflects the great amplitude of this variable.

Salinity indicators (HUSTEDT 1957) are assigned to five ecological groups (Fig. 2d), with oligohalobes-indifferents as a dominant group, although the oligohalobes-halophiles and mesohalobes are also common, as well as a single species of polyhalobes (Tab. 2). Among the oligohalobes-indifferents the most common are *Amphora ovalis*, *Epithemia turgida*, *Fragilaria ulna*, *F. vaucheriae*, *Nitzschia acicularis*, *N. palea*, *Rhoicosphenia abbreviata* (Bacillariophyta), *Crucigenia tetrapedia*, *Pediastrum boryanum* (Chlorophyta), *Trachelomonas hispida, T. volvocina* (Euglenophyta). Remarkably, the blue-greens are

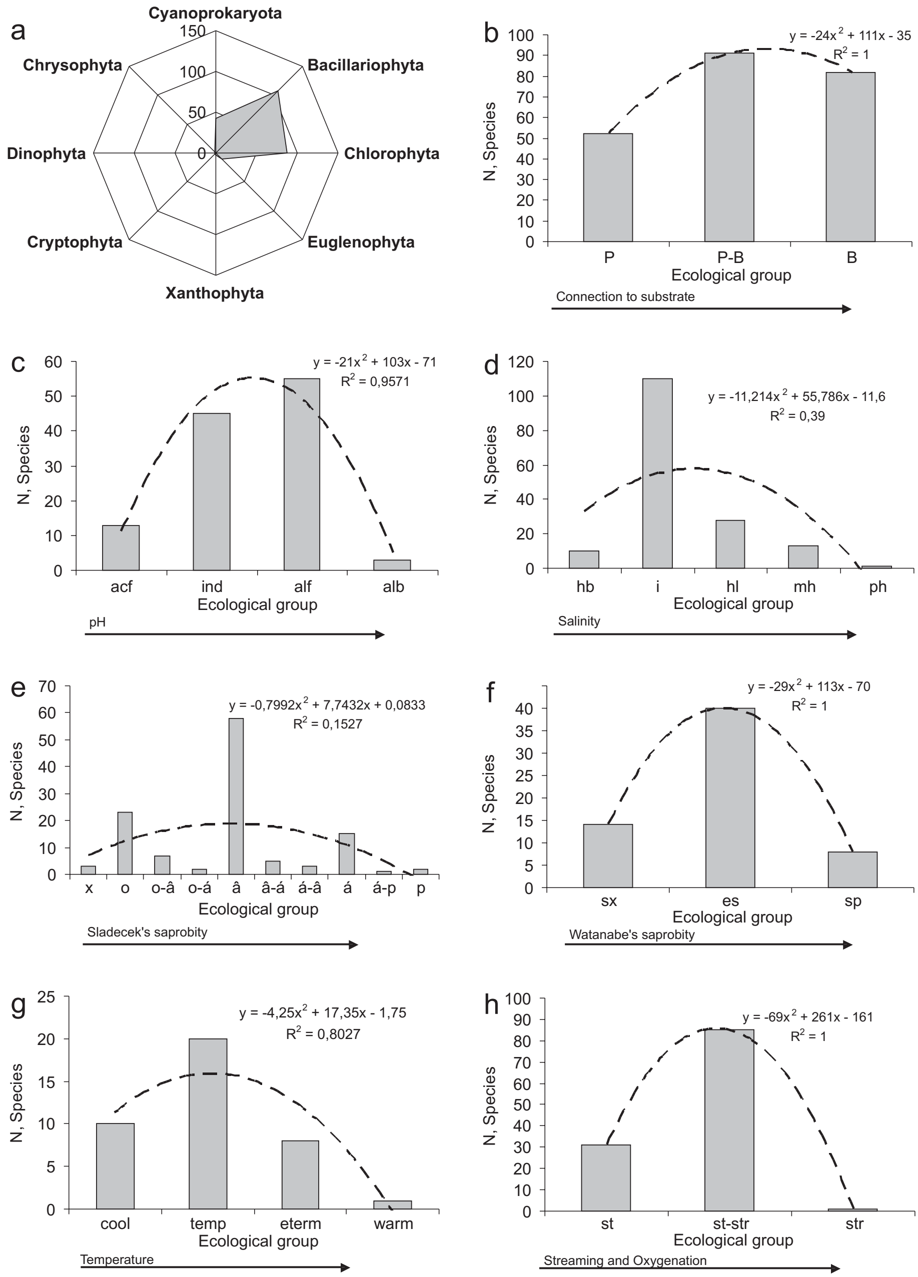

Fig. 2. Algal species diversity and ecology in the wetland lakes of Kazakhstan: a – distribution of species richness per taxonomic divisions; b – distribution of species per habitat ecological groups; c – distribution of species per groups of pH indicators; d – distribution of species per groups of salinity indicators; e – distribution of species per groups of saprobity indicators (after SLÁDEČEK 1973); f – distribution of species per groups of saprobity indicators (after WATANABE 1986); g – distribution of species per groups of temperature indicators; h – distribution of species per groups of streaming and oxygenation indicators.

mostly halophilic, but include also the only palyhalobic species *Phormidium paulsenianum*. All the halophobes are diatoms, among them several species of *Eunotia*.

Algal indicators of organic pollution are assigned to nine ecological groups (Figs. 2e, f; Tab. 2), representing the entire spectrum of indication systems (SLÁDEČEK 1973, 1986; WATANABE et al. 1986). Beta-mesosaprobionts prevail with *Phormidium autumnale*, *Microcystis aeruginosa* (Cyanoprokaryota), *Fragilaria vaucheriae*, *Surirella ovata*, *Pinnularia*

Tab. 3. Chemical variables (with standard deviation) and water quality classification based on concentrations of nitrate- nitrogen and phosphorus in the wetland lakes during 1–20 October 1999.

Lake	$N\text{-}NO_3$ (mg L^{-1})	$P\text{-}PO_4^{3-}$ (mg L^{-1})	Rank of water quality	
			$N\text{-}NO_3$	$P\text{-}PO_4^{3-}$
Aike	3.4±0.14	0.16±0.01	5a	4a
Kulykol	1.5±0.1	0.06±0.00	3b	3b
Kulykol (N2)	1.1±0.0	0.05±0.00	3b	3a
Kulykol, kordon Jailma	2.1±0.1	0.30±0.01	3b	4b
Kulykol, well Jailma	1.0±0.0	0.06±0.00	3a	3b
Stream Jarsor	1.0±0.0	0.01±0.00	3a	2a
Jarsor	8.6±0.3	4.06±0.12	5b	5b
Batpakkol	2.3±0.1	0.26±0.01	4b	4b
Kulagul	0.0±0.0	0.98±0.03	1	5b
Sankebay	5.4±0.2	0.54±0.20	5b	5a
Jarkol, Naurzum Natural Reserves*	4.1±0.2	1.08±0.03	5b	5b
Kushmurun, south part	3.5±0.1	0.10±0.00	5a	3b
Kojbagor, coast	2.0±0.1	0.13±0.00	4a	4a
Kojbagor	1.9±0.1	0.27±0.01	4a	4b
Tuntugur	1.9±0.1	0.12±0.00	4a	4b
Tuntugur, coast	2.0±0.1	0.26±0.01	4a	4b
River Karasu, near L. Tuntugur	1.4±0.1	0.23±0.01	3b	4b
Bozshakol	2.7±0.1	0.20±0.01	5a	4a
Bozshakol, north-east part	8.5±0.3	2.25±0.07	5b	5b
Biesoygan	2.1±0.1	0.39±0.01	4b	5a
Sarykol	1.5±0.1	0.06±0.00	3b	3b
Taly	1.7±0.1	0.15±0.00	4a	4a
Kamyshovoe	1.9±0.1	0.11±0.00	4a	4a
Jaman	1.6±0.1	0.08±0.00	4a	3b
Shoshkaly	1.3±0.1	0.32±0.01	3b	5a
Annovskoe	2.0±0.1	0.01±0.00	4a	2a
Maybalyk	1.4±0.1	0.02±0.00	3b	2b
Tahtakul	1.8±0.1	0.48±0.01	4a	5a
Sarybalyk	1.8±0.1	0.03±0.00	4a	2b
Aksuat	1.0±0.0	0.01±0.00	3b	2a
Gr. Karakamys	1.2±0.0	0.01±0.00	3b	2a

Note: the assessment of $\beta+\gamma$ radioactive pollution of water samples with detector-indicator of radioactivity QUARTEX RD 8901 shows that its level does not exceed 20 mkR/h. * – Naurzum Biosphere Reserve.

viridis (Bacillariophyta), *Cladophora*, *Crucigenia tetrapedia* (Chlorophyta), *Trachelomonas volvocina* (Euglenophyta).

Indicators of temperature conditions reflect a wide range of temperature fluctuations. A group of temperate species prevails, but species of cold and warm waters are also present (Fig. 2g).

Among indicators of streaming and oxygenation, species of slightly turbulent waters – moderate oxygenation prevail, yet in figure 2h, the summit of the trend is displaced toward the indicators of streaming highly oxygenized waters.

Tab. 4. Saprobity indices, species richness and classification of water quality in the wetland lakes of Kazakhstan during October 1999.

Lake	No. of algal species	Index of saprobity (S)	Rank of water quality based on biological variables	Rank of water quality based on chemical variables	Water Ecosystem State Index (WESI)
Aike	20	1.98	3a	5a	0.5
Kulykol	2	2.3	3b	3b	1.0
Kulykol (N2)	2	1.85	3a	3b	0.8
Kulykol, kordon Jailma	3	2.3	3b	4b	0.7
Kulykol, well Jailma	3	2.35	3b	3b	1.0
Stream Jarsor	7	1.99	3a	3a	1.0
Jarsor	–	–	–	5b	–
Batpakkol	2	2.0	3a	4b	0.6
Kulagul	4	2.38	3b	5b	0.5
Sankebay	5	1.93	3a	5b	0.4
Jarkol. Naurzum Natural Reserves	2	1.7	3a	5b	0.4
Kushmurun, south part	9	2.08	3b	4a	0.8
Kojbagor, coast	29	2.03	3b	4b	0.7
Kojbagor	26	1.95	3a	4a	0.6
Tuntugur	6	1.93	3a	4b	0.6
Tuntugur, coast	26	1.88	3a	4a	0.6
Karasu River near L. Tuntugur	2	1.47	2b	4b	0.7
Bozshakol	23	1.99	3a	5a	0.5
Bozshakol, north-east part	31	1.95	3a	5b	0.4
Biesoygan	7	2.55	4a	5a	0.7
Sarykol	10	2.15	3b	3b	1.0
Taly	6	2.05	3b	4a	0.8
Kamyshovoe	22	1.9	3a	4a	0.6
Jaman	8	1.78	3a	4a	0.6
Shoshkaly	2	2.53	4a	5a	0.7
Annovskoe	5	1.71	3a	4a	0.6
Maybalyk	–	–	–	3b	–
Tahtakul	2	2.7	4a	5a	0.7
Sarybalyk	–	–	–	4a	–
Aksuat	–	–	–	3b	–
Karakamys	–	–	–	3b	–

Assessment of wetland lacustrine ecosystems according to the hydrochemical and hydrobiological variables

Hydrochemical data for autumn of 1999 (dry period) are represented in tables 1 and 3. The analysis of water conductivity and mineralization reveals a group of highly mineralized lakes – Jarsor, Sankebay and Kushmurun – with salinity level above 7. The other lakes are brackish or freshwater. Practically all the investigated lakes show the neutral or slightly alkalic reaction typical of natural water bodies with active self-purification processes. Sul-

Tab. 5. Chemical variables (with standard deviation) and water quality classification based on concentrations of nitrate nitrogen and phosphorus in the wetland lakes during May–June 2000.

Lake	$N\text{-}NO_3$ (mg L^{-1})	$P\text{-}PO_4^{3}$ (mg L^{-1})	Rank of water quality	
			$N\text{-}NO_3$	$P\text{-}PO_4^{3-}$
Alpash	1.0±0.0	0.01	3a	2a
Kulykol	1.2±0.0	0.03	3b	2b
Gr. Kak	2.2±0.1	0.05	4b	3a
Suly	1.4±0.1	1.77	3b	5b
Balykty	1.1±0.0	0.02	3b	2b
Stream Jarsor	1.0±0.0	0.01	3a	2a
Jarsor	2.9±0.1	0.32	5a	5a
Maybalyk	2.2±0.1	0.00	4b	1
Kulagul	0.6±0.0	0.17	3a	4a
Gr. Sankebay	1.6±0.1	0.09	4a	3b
Jarkol, Naurzum Natural Reserves*	2.3±0.1	0.17	4b	4a
Chushkaly, Naurzum Natural Reserves*	1.7±0.1	0.28	4a	4b
Tounsor (Teniz)	1.5±0.1	0.00	3b	1
Kojbagor	1.3±0.1	0.07	3b	3b
Tuntugur	1.5±0.1	0.01	3b	2a
Teniz	1.0±0.0	0.04	3a	3a
Sultan	0.9±0.0	0.00	3a	1
Bozshakol	1.7±0.1	0.00	4a	1
Jarken	0.9±0.0	0.03	3a	2b
Jaltyr	1.0±0.0	1.00	3a	5b
Sarykol	0.9±0.0	0.00	3a	1
Jilandy	1.2±0.0	0.68	3b	5b
Kamyshovoe	1.2±0.0	0.02	3b	2b
Jaman	1.2±0.0	0.03	3b	2b
Shoshkaly, western part	1.1±0.0	0.03	3b	2b
Annovskoe	1.2±0.0	0.00	3b	1
Gr. Karakamys	0.8±0.0	0.04	3a	3a
Tahtakul	1.1±0.0	0.03	3b	2b
Sarybalyk	1.5±0.1	0.00	3b	1
Aksuat	1.4±0.1	0.02	3b	2b
Karakamys	1.0±0.0	0.68	3a	5b

phide (H_2S plus the acid-soluble sulfides of metals) concentration 2.005 mg L^{-1} was found in the northeastern part of Bozshakol Lake only, which is evidence of periodic anoxia.

The saprobity index S varies from 1.47 to 2.70, which corresponds to 2b – 4a ranges of water quality (Tab. 4). The biotic component of lake ecosystems provides for a high level of self-purification.

Tab. 6. Saprobity index S, species richness and water quality classification in wetland lakes of Northern Kazakhstan in May–June 2000.

Lake	Maximum no. of algal species, (per sample)	Index of saprobity (S)	Rank of water quality based on the biological variables	Rank of water quality based on the chemical variables	Water Ecosystem State Index (WESI)
Alpash	14	1.74	3a	3a	1.0
Kulykol	8	2.04	3b	3b	1.0
Gr. Kak	9	2.11	3b	4b	0.7
Suly	7	1.84	3a	4b	0.6
Balykty	26	2.21	3b	3b	1.0
Stream Jarsor	10	1.76	3a	3a	1.0
Jarsor	–	–	–	5a	–
Maybalyk	4	2.04	3b	4b	0.7
Kulagul	13	2.44	4a	4a	1.0
Gr. Sankebay	2	2.49	4a	4a	1.0
Jarkol, Naurzum Natural Reserves	6	1.96	3a	4b	0.6
Chushkaly, Naurzum Natural Reserves	12	1.97	3b	4b	0.7
Tounsor (Teniz)	30	1.87	3a	3b	0.8
Kojbagor	64	2.04	3b	3b	1.0
Tuntugur	23	2.12	3b	3b	1.0
Teniz	25	1.96	3a	3a	1.0
Sultan	5	2.15	3b	3a	1.25
Bozshakol	30	2.13	3b	4a	0.8
Jarken	23	2.00	3b	3a	1.25
Jaltyr	6	1.86	3a	5b	0.4
Sarykol	23	1.71	3a	3a	1.0
Jilandy	6	2.05	3b	5b	0.5
Kamyshovoe	53	1.86	3b	3b	1.0
Jaman	40	2.10	3b	3b	1.0
Shoshkaly, western part	23	1.87	3b	3b	1.0
Annovskoe	10	1.81	3a	3b	0.8
Gr. Karakamys	6	1.65	3a	3a	1.0
Tahtakul	4	1.80	3a	3b	0.8
Sarybalyk	5	1.48	2b	3b	0.6
Aksuat	1	2.70	4a	3b	1.2
Karakamys	18	1.80	3a	5b	0.4

In spring, the lakes Kak, Jarsor, Sankebay and Sarybalyk were strongly mineralized, with salinity above 7 (Tabs. 5, 6). The other lakes remained freshwater or brackish. The pH reaction was neutral or slightly acidic in all the lakes, characteristic of natural waters with active self-purification processes.

The defined background radioactivity in the studied lakes during 1999–2000 was stable, with a level not exceeding 20 mkR h^{-1}, presenting the regional norm and unable to impact lake communities.

Discussion

The overall diversity is the highest in the lakes Bozshakol, Kamyshovoe, Kojbagor (63 – 112 species), and some other freshwater lakes (Tab. 1) of IV water salinity class.

Bio-indicational analysis of algal diversity shows that the dominant indicator species are alkaliphiles, oligohalobes-indifferents and beta-mesosaprobes conveying the integrity of major ecological variables.

Similarity analysis (Fig. 3) is based on the distribution matrix of 254 revealed species over 34 water bodies and calculated as the percent disagreement by WARD's method. The dendrogram shows that the algal taxonomic diversity is divided into three different clusters, with most of the Kazakhstan lakes separated at the 74% similarity level. The group designated at the 82% similarity level (cluster 2) comprises algal assemblages of lakes with great amplitude of salinity fluctuations (II to IV classes), with species numbers 1 – 28. The dominant indicators are oligohalobes-indifferent, halophiles and mesohalobes.

The second group discriminated at 82% similarity level comprises assemblages of moderately mineralized lakes of III–IV salinity classes, with the species numbers 18 – 37. The dominant indicators are oligohalobes-indifferent, halophiles and occasionally mesohalobes.

Cluster 3 of low similarity level comprises assemblages of slightly mineralized lakes of IV salinity class: Bozshakol, Tuntugur, Jaman, Teniz, Kamyshovoe, and Kojbagor, with species numbers 57 (Jaman) to 112 (Kojbagor), dominated by oligohalobes-indifferent and halophiles; mesohalobes are lacking in these lakes.

Therefore, the dendrogram clustered all the revealed diversity around three major variables: species richness of algal communities, salinity class, and the dominant salinity indicators. The most similar are the species-rich communities of slightly mineralized lakes, as well as the species-poor communities of highly mineralized lakes (ÁCS et al. 2003). These regularities indicate that, other conditions remaining the same, salinity is the main depressing factor of algal diversity irrespective of the type and distribution of the water body. In other words, the compositions of algal communities reflect in the first place the salinity level related to climatic aridity.

Because the species diversity in protected wetlands is mostly influenced by natural factors, floristic cores can reflect historical natural impact on algal biodiversity. Comparative floristics help summarize regional algal diversity in major floristic cores (Fig. 4). We used comparative floristic approaches also for revealing the major factors influencing the lacustrine flora enriching process. In the statistical program GRAPHS (NOVAKOVSKY 2004) which presented not only tables of calculation but also constructed visual graphs, we ana-

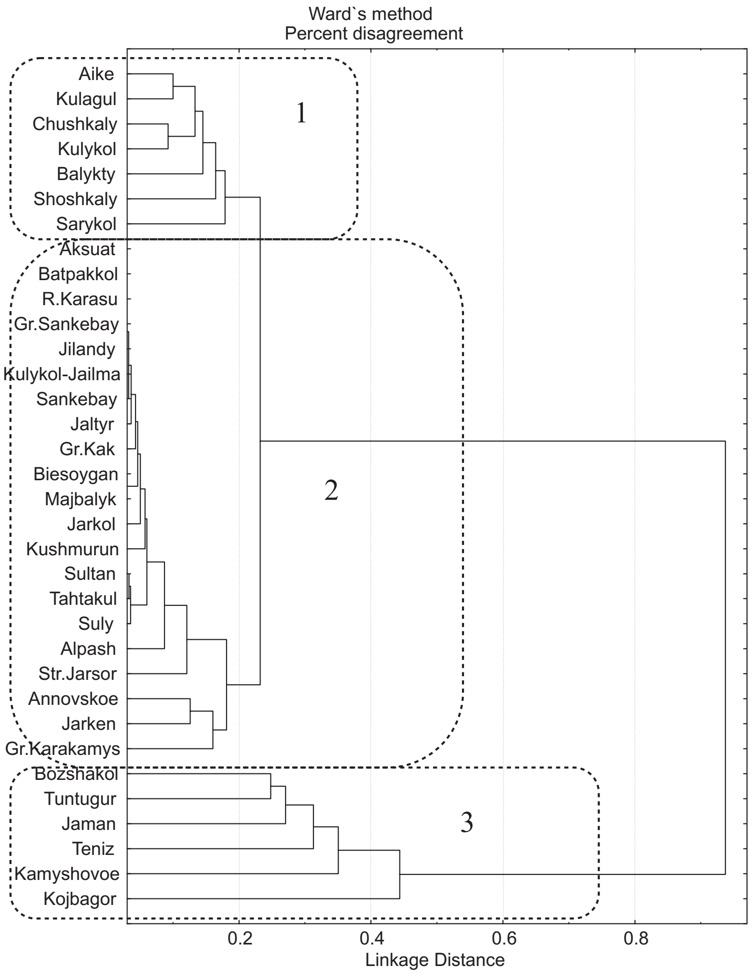

Fig. 3. Tree diagram for algal species diversity in the wetland lakes of Kazakhstan, WARD's method, percent disagreement.

lyzed presence-absence of 254 species in 34 lakes with SERENSEN-CHEKANOVSKY indices calculation. As a result, a dendrite of similarity (Fig. 4) shows five floristic cores, which are marked by dashed lines.

Most lakes with species rich communities and fresh water combined into central core (A). The lakes Bozshakol with 63 species and Kojbagor with 112 species placed in the center of core A. All lakes from core (A) are 3–4 salinity class with high species diversity, low to medium dissolved solids and seasonally fluctuating electrical conductivity, neutral to low acidic range of pH, low to middle nutrient concentration, and III–IV class of water pollution. This means that ecosystems in core (A) lakes are well developed.

Core (B) formed 9 freshwater lakes with middle species diversity, medium dissolved solids and nutrients concentration, clearer than in core (A), but with neutral to low alkalic water.

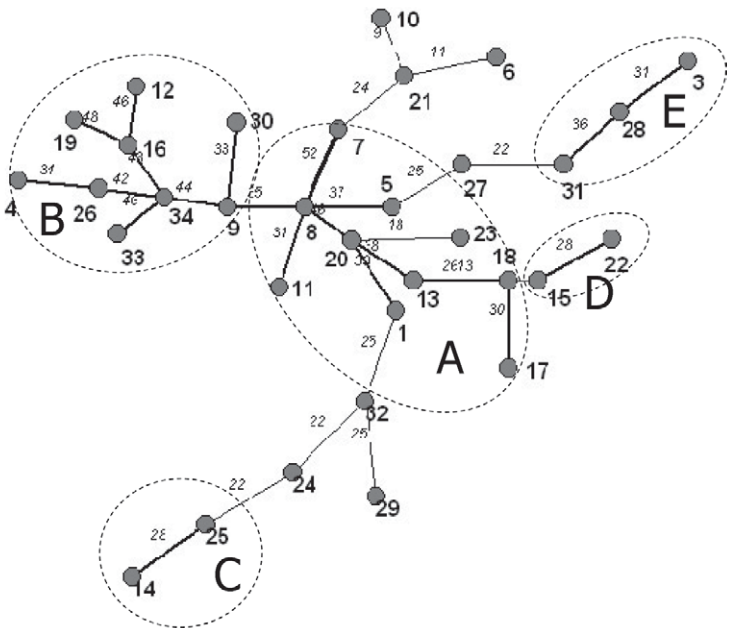

Fig. 4. Dendrite of similarity constructed on the base of SERENSEN-CHECKANOVSKY indices.

Core (C) included two lakes only that connected with core (A) and characterized as freshwater, low alkaline, low organic polluted with low to medium dissolved solids and nutrients concentration.

Core (D) also formed two lakes, which have conditions similar to those lakes of core (C) and also closely related with the diversity of core (A).

The last core (E) included three freshwater lakes, which have similar conditions with lakes from the major core (A).

A few lakes that are not included in the mentioned above cores have intermediate (as in Tahtakol or Kushmurun) or extreme environmental conditions such as in the Great Kak Lake: high salinity and electrical conductivity, low acidic water with low phosphates and medium nitrates concentration and as a result low species diversity.

Therefore, comparative floristic analysis pointed to salinity as the most important factor that has had a historical influence on algal diversity in the studied wetland lakes.

The assessment of the aquatic ecosystems state is based on a correlation of hydrochemical data and their ranges for nitrogen and phosphorus (the trophic elements) with those for saprobity indices (the biota's self-purification capacity). We calculated the index of the water ecosystem state, WESI (BARINOVA 2000, BARINOVA et al. 2006) relating the ranges of self-purification to those of trophic elements. WESI reflects the potentials of the aquatic ecosystem to regenerate after anthropogenic impacts. It also conveys the intensity of anthropogenic impacts if such occurred. In the case of WESI above or equal to 1.0, the ecosystem is assessed as balanced and buffered from anthropogenic impacts. At WESI below 1.0, the biotic components are under toxic influences. A smaller WESI reflects a greater toxicity. Sometimes the latter can be natural rather than anthropogenic.

Our analysis showed a normal (balanced) state for the ecosystems of the lakes Kulykol, the spring Jailma, the spring Jarsor and Sarykol Lake (Tab. 4) in dry autumn of 1999. Most of the samples reveal a slight natural toxic influence which may be come from sulphides. More significant toxic influence is recognized for the lakes Aike, Sankebay, Jarkol, and Bozshakol. However, the composition of their algal communities gives no evidence of heterotrophy.

Normal state (WESI above or equal 1.0) was found in the spring season of 2000 in the lakes Alpash, Kulykol, Balykty, Kulagul, Great Sankebay, Kojbagor, Tuntugur, Teniz, Sultan, Jarken, Sarykol, Kamyshovoe, Jaman, Shoshkaly, Karakamys, Aksuat, and the stream Jarsor. This group includes most of the lakes. At the same time, a slight toxic suppression of photosynthetic activity was revealed for the lakes Suly, Majbalyk, Jarkol, Chushkaly, Taunsor (Teniz), Bozshakol, Jaltyr, Jilandy, Annovskoe, Tahtakul, Sarybalyk, Karakamys. Therefore, the toxicity might have been temporary, during the dry period, unrelated to any constant anthropogenic impact. According to the functional model of aquatic ecosystems (BARINOVA 2000, BARINOVA et al. 2006), ecosystems of majority of lakes are at the regenerating stage and most influenced by evaporation in summer season.

Algal species and index saprobity S dynamic in communities during the 1999–2000 study period show that the maximal taxonomic diversity (number of species) for algal communities in 1999 was observed in the lakes Kojbagor (64), Bozshakol (30), Kamyshovoe (53) and Jaman (40). The saprobity index S varied from 1.48 to 2.70, which corresponds to 2b–4a ranks of water quality. Although sulfides were periodically revealed in Bozshakol Lake, algal species richness is rather high because this lake is fresh and provides the best environment not only for higher aquatic plant development, but also for algal diversity in plankton and submerged plants. The means of S for these lakes in the spring revealed a high self-purification capacity.

The most species-rich in the year 2000 were the lakes Balykty (26), Tounsor (Teniz) (30), Kojbagor (64), Tuntugur, Bozshakol (30), Kamyshovoe (53), Jaman (40), and other swith more than 20 species per each sample.

On the basis of nitrate concentration, most of the lakes in 1999 were assigned to 4b and 5a–b water quality ranges (Tab. 3), which indicates a reduced consumption of this element by the lacustrine biota. For phosphate concentrations, 19 samples fall in the same high ranges. Only in the Kulagul (Kulykol) Lake is there a high concentration of phosphates against the minimal nitrate concentration. In this lake the algal productivity is limited by nitrogen which explains the low consumption of phosphates. During the study period only in the northeastern part of Bozshakol Lake was a high concentration of sulfides (H_2S) found, which can be explained by anaerobic decomposition of dead matter produced by the lake ecosystem during the periods of water bloom or a decay of aquatic macrophytes. This biota toxic variable periodically formed a reduction zone in the bottom, but in the thin layer of water under the surface life is flourishes.

On account of their nitrate and phosphate concentrations, several lakes were assigned to 4b and 5a water quality classes in 2000 (Tab. 5), indicating under-consumption of these components by the biota. In lakes Maybalyk, Tounsor (Teniz), Sultan, Bozshakol, Sarykol, Annovskoe, and Sarybalyk, a relatively high concentration of nitrates was associated with a low concentration of phosphates; the nitrates were under-consumed, because the development of algal community was limited by phosphorus. Nitrogen was not a limiting factor in these lakes. As a whole, the biotic communities were actively developing, although occasionally restricted by the deficit of phosphorus in freshwater lakes and in a single brackish lake, Sarybalyk.

Conclusion

The calculated indices of the environmental quality of Kazakhstan's arid region wetlands ranged within the expected natural variations. Toxic influence is recognized in Jaltyr, Jilandy, and Karakamys. A slight natural influence was revealed for most of the lakes. The organic matter enriching the water after aquatic plant death regulates the production of sulfides as toxic substances for algae. Yet the algal communities provide no evidence of heterotrophy. The toxicity might have been temporary, unrelated to a constant anthropogenic impact. According to the functional model of aquatic ecosystems (BARINOVA et al. 2006), lakes Jaltyr, Jilandy, and Karakamys are assigned to the regeneration stage.

In comparison to 1999 and 2000, salinity (mineralization) in the studied lakes slightly decreased (by 0.01–0.02), with the exception of Sarybalyk and Aksuat, where it increased from 1.47 and 0.69 respectively in autumn 1999 to 8.88 and 3.94 respectively in spring 2000.

Salinity as a consequence of aridization suppressed algal diversity, and thereby decreased the productivity of the first trophic level, undermining the trophic base of wetlands as water fowl habitat.

Lake ecosystems are insignificantly disturbed, only few of them revealing an appreciable toxic effect. The saprobity indices calculated for each of the lakes attest to a high self-purification capacity. By comparing of the ecosystem state indices, WESI, for 1999 and 2000 we are led to the conclusion that self-purification activity increased from dry to wet seasons in Kulagul, Sankebay, Jarkol, Kojbagor, Tuntugur, Bozshakol, Annovskoe, and Tahtakul. A seasonally increase of salinity in lakes Aksuat, Sarybalyk, and Jarsor did not affect their general state.

Therefore, we concluded that salinity in the lakes is the most important factor that has also had a historical influence on the algal diversity of the arid region wetland lakes.

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