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INTERNATIONAL JOURNAL ON ALGAE

AIMS & SCOPE

The algae are heterogeneous assemblage of phytosynthetic organisms, one of the most vast and diverse groups of ancient photoautotrophic pro- and eukaryotic organisms (about 30 000 known species). They are micro- and macroscopic, unicellular, colonial, or multicellular, mobile and immobile, attached and free-living. Algae are widespread in water and soil habitats, at different geographic latitudes, and on all continents. They occur in waters with different degrees of salinity, trophicity, organic matter, and hydrogen ions, and at various temperatures. They include planktonic, periphytonic and benthic organisms. Algae are unique model organisms in evolutionary biology and also are used in various genetic, physiological, biochemical, cytological, and other investigations. Algae have practical significance as edible or poisonous plants, as indicator organisms in the monitoring of ecological systems, as agents of self-purification of polluted waters and in the purification of sewage, as the primary producers in the trophic chains of hydrobionts in marine and freshwater, and also as organisms for biotechnology.

The quarterly *International Journal on Algae* (*IJA)* publishes selected papers translated from the first Russian language phycological journal, *Algologia,* founded in 1991 in the former Soviet Union. The aim of *Algologia* is to present recent advances in algology. The journal covers both fundamental and applied aspects in algology, including papers based on the results of wide range of field and experimental studies, as well as reviews and surveys and procedure papers. The journal is intended for specialists in theoretical, experimental, and applied algology, hydrobiology, microbiology, all scientists using algae as a model organisms for research, and all those interested in general problems of biology.

The aim and scope of *IJA* is to inform the western scientific community, especially algologists, about original studies by scientists of the former Soviet Union and Eastern Europe in the following subjects: General Problems of Algology; Morphology, Anatomy, Cytology; Reproduction and Life Cycles of Algae; Genetics; Physiology, Biochemistry and Biophysics; Ecology, Cenology and Conservation of Algae and their Role in Nature; Flora and Geography; Fossil Algae; Systematics, Phylogeny and Problems of Evolution of Algae; New Taxa and Noteworthy Records; and Applied Algology.

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Biodiversity of Algae of Hot Springs from the Kuril Islands (Russia)*

T.V. NIKULINA

Institute of Biology and Soil Science, Russian Academy of Science, Far East Branch,
159, 100 Letiya Vladivostoka Prosp., Vladivostok 690022, Russia

ABSTRACT

The results of a study of algae taxonomic diversity from hot springs of Kunashir, Shiashkotan, and Yankicha Islands (Kuril Islands, Russia) are presented in the current paper. Algal flora includes 163 species (180 species and infraspecific taxa) of 4 divisions: *Cyanoprokaryota*, *Euglenophyta*, *Bacillariophyta*, and *Chlorophyta*.

KEYWORDS: algae, species diversity, hot springs, the Kuril Islands, Russia.

INTRODUCTION

Algae often withstand high temperatures inhabiting warm waters of natural and artificial origin – hot springs, geysers, volcanic lakes or water-cooling industrial reservoirs. Algae species diversity is of great interest because natural hot springs are found on all continents. Typical inhabitants of hot water are blue-green algae, diatoms, and some representatives of green algae. Thermal stability of thermophilic and mezothermic species is high; they develop successfully and abundantly in waters with temperatures of 30-84 °C.

Algae species diversity of the Kuril Islands' hydrotherms is still not sufficiently studied, despite the fact that the study of algae species composition of inland water bodies of the Kuril Islands has been ongoing for more than seventy years. Descriptions of algal flora in freshwater and saltish rivers and reservoirs of eight islands of the Kuril Archipelago (Shumshu, Atlasova, Onekotan, Shiashkotan, Simushir, Makanrushi, Iturup, and Kunashir) are present in the works of Japanese and Russian scientists: Okada, 1934a, b, 1939; Fukushima, 1955-1958; Hirano, 1960; Barinova, 1989; Medvedeva, 1992; Nikulina & Eremenko, 1999; Nikulina, 2000a, b, 2002, 2004, 2006, 2008a, b; Cherepanova & Grebennikova, 2001; Nikulina & Sayenko, 2001.

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The data on algal flora of the Kuril Islands' hot springs are not so numerous and several publications, have outlined the descriptions of only some representatives of the following divisions: *Cyanoprokaryota*, *Rhodophyta*, *Chrysophyta*, and *Bacillariophyta*. For the islands of Kunashir and Yankicha, 36 species and infraspecific taxa of blue-green, red, golden algae and diatoms were indicated. For the thermal springs on Kunashir, Tereshkova et al. (1973) provided information concerning cultivation features, the artificial nutrient media, suitable for four species of thermophilic blue-green algae (*Coccopedia* sp., *Synechococcus* sp., *Phormidium ambiguum*, and *Ph. foveolarum* (Mont.) Gomont). Sentsova (1991) described two new species from the hot acidic spring on Kunashir – *Galdieria partita* Sentzova and *G. maxima* Sentzova (*Rhodophyta*). Gromov et al. (1991) described a new acidophilic species of golden algae from the fumaroles of the Mendeleev volcano – *Ochromonas vulkania* Gromov, Nikitina et Mamkayeva. In the monographic summary of Nikitina (2005) the information is presented on the flora of blue-green algae from thermae of Goryachiy (Warm) beach and the Mendeleev volcano. In addition 15 taxa of 3 classes, 4 orders, and 7 families are listed: *Synechococcus elongatus*, *Gloeocapsa pallida* Geitl., *Pleurocapsa minor* Hansg., *Calothrix elenkinii* Kossinsk., *Pseudanabaena bipes* Böcher, *Isocystis salina* Iwanoff, *Oscillatoria angusta* (Bory) Gomont f. *woronichinii* (Woron.) Poljansky, *O. brevis* (Kütz.) Gomont, *O. tenuis* C. Agardh, *O. thermarum* Woron., *Phormidium foveolarum* (Mont.) Gomont, *Ph. valderiae* (Delponte) Geitller, *Lyngbia martensiana* Menegh., *Microcoleus delicatulus* W. et G.S. West, *M. sociatus* W. et G.S West*. In the article of Nikulina (2007, 2008a, b) the first data is listed on the discovery of euglenophytes, diatoms, and green algae in hot springs at Cape Stolbchatiy and at the seaside of Alekhin Bay of Kunashir Island.

Representatives of *Cyanoprokaryota* from underwater hydrothermal vents of Yankicha Island are known from the works of Belyakova (2000a, b, 2001). The annotated checklists of these organisms contain 14 taxa of blue-green algae, belonging to 2 classes, 2 orders, and 4 families: *Chroococcidiopsis thermalis*, *Leibleinia willei* (Setchell et Gardner) P.S. Silva, *Leptolyngbya angustissima* (W. West et G.S. West) Anagn. et Komárek, *L. battersii* (Gomont) Anagn. et Komárek, *L. foveolarum* (Mont. ex Gomont) Anagn. et Komárek, *L. fragilis* (Menegh. ex Gomont) Anagn. et Komárek, *L. golenkiniana* (Gomont) Anagn. et Komárek, *L. lurida* (Kütz. ex Gomont) Anagn. et Komárek, *Schizothrix* cf. *cyanea* (Nägeli) Geitl., *Phormidium acuminatum* (Gomont) Anagn. et Komárek, *Ph. ambiguum* Gomont, *Ph. corallinae* (Kütz.) Anagn. et Komárek, *Ph. konstantinosum* (C. Agardh ex Gomont) Umezaki et Watanabe, *Pseudophormidium purpureum* (Gomont) Anagn. et Komárek.

* The species names are given according to the literature sources without modern taxonomical updates.

The aim of our research is to study the species composition of algal flora in the Kuril hydrothermal vents, to identify a set of dominant species in algal communities, to perform the ecological and geographical analysis of revealed algal flora, and to make acomparative analysis with the algal flora of Kamchatka hot springs.

MATERIALS AND METHODS

This study provides information on the composition of algal periphyton (fouling of solid artificial and natural substrates) in three groups of hot springs: Kunashir Island and hydro-therms of Shiashkotan and Yankicha Islands. All examined hot springs represent shallow streams (max. depth 30-35 cm), flowing from the crater fumaroles or cracks in the ground.

Kunashir Island. In August 1999, we examined two streams in the area of the former settlement Alekhino, which run into the Alekhin Bay. We analyzed 10 algological samples. The water temperature at the time of sampling in the streams was 26-48.1 °C (Table 1). Soil and sand with occasionally occurred in small and medium-sized stones. Hydrotherms belong to the northern group of Alehin streams located on the Sea Okhotsk coast of the Golovnina volcano. The waters of this group of sources on the composition belong to the sulfate-chloride, calcium-sodium term with pH 4-5, *T* 50-55 °C (Markhinin & Stratula, 1977).

Four samples of algae were collected in the caldera of Golovnin volcano in January 2007 from a hot spring of solfataric field at the foot of the southern slope of the volcano's Central Eastern dome. We identified several solfatar groups with thermal vents, the temperature of which varied from 60 to 103 °C. The chemical composition of water varied greatly, even within the group: from subneutral and slightly alkaline (pH 6-8.5), bicarbonate-sulphate and sodium-calcium to acidic (pH 2-2.5) sulphate and sodium (Markhinin & Stratula, 1977).

Algae were collected in August 1999 and April 2007 (7 and 3 samples, respectively) from Stolbovsky thermal springs and from a stream flowing from one of them. The surveyed streams are located on the west coast of the island, 2 km south of Cape Stolbchatiy. In August 1999 the water temperature in the hot spring was 40 °C, in the creek downstream – 24 °C; the bottom was represented by small and medium-sized stones. Stolbovsky springs were subneutral (pH 6.7-7), they were nitrogen, chloride, sodium sulphate; the water temperature was about 82 °C (Zharkov, 2006a, b; Zharkov & Poberezhnaya, 2008).

Shiashkotan Island. In August 1999 we studied three samples of algae from the hydrothermal outlet, located on the coast, 15 m from the water's edge, in the bay between Cape Obvalniy and Cape Borovoy (on the part of the Okhotsk Sea). The water temperature at the time of sampling reached 71 °C (Table 1). Soil was represented by small and medium-sized stones.

The published data are available only for the Obvalniy Springs located on the Pacific side of Shiashkotan Island on the Makarovsky Isthmus. In terms of water composition sodium chloride was identified, with total mineralization of 13.3 g/L, and water temperature of 60 °C with pH 6.98 (Markhinin & Stratula, 1977).

Yankicha Island. In August 1999, seven samples of algae were collected from the hydrothermal vents or their derivatives – small shallow-water reservoirs and also from streams flowing into the Crater Bay. Water temperatures in these springs were 50-60 °C (Table 1). The soil in the reservoirs was represented by sand and by small, medium, or large stones on a sandy substrate in streams. These springs refer to the southeast solfataric field, the temperature of the water reached 101 °C, pH 2.8-3.7. The chemical composition of terms is similar to the sea; the hydrochemical type they belong to is sodium chloride, with a salinity of 25-27 g/L (Markhinin & Stratula, 1977).

Samples of algal periphyton were collected according to standard methods (Gollerbakh & Polyansky, 1951) and fixed with a 4% solution of formaldehyde. In order to determine the diatom representatives, we prepared permanent microscopic slides by tempering the diatom valves in hydrogen peroxide (Swift, 1967). Algae were identified using relevant monographs, reports, and identification keys (Gollerbakh et al., 1953; Palamar-Mordvintseva, 1982; Moshkova & Gollerbakh, 1986; Krammer & Lange-Bertalot, 1986, 1988, 1991a, b; Junger & Moshkova, 1993; Vetrova, 1993; Hartley et al., 1996; Rundina, 1998; Komárek & Anagnostidis, 1998, 2005; Lange-Bertalot & Genkal, 1999; Krammer, 2000, 2002). During the identification of algae, we used light microscopes «Axioskop 40» (Zeiss, Lens 40x/065 and 100x/1.25 oil) and «Alphaphot-2 YS-2» (Nikon, Lens 40x/0.65 and 100x/1.25 oil).

The occurrence frequency of species was determined in accordance with the six-point scale (Corde, 1956). To describe the structure of the algal communities we isolated frequent species complexes, which contained dominants – taxa with a frequency of occurrence of 6 ("mass quantity") and subdominants assessing the abundance of 4 and 5 ("often" or "very often"). All the algae with a frequency of occurrence from 1 ("individual") to 3 ("quite often") were classified as minor species. In the absence of algal communities with real dominance we attributed other taxa with a particularly high frequency of occurrence to dominants.

In drawing up the environmental and geographical characteristics of the algal flora we used published data on the ecology and distribution of algae: Khursevich, 1976; Levadnaya, 1986; Sladeček, 1986; Watanabe et al., 1986, 1988; Algae …, 1989; Van Dam et al., 1994; Bukhtiyarova, 1999; Barinova et al., 2006. In order to determine the salinity scale we used the halobic scale of Kolbe (1927), refined for the reservoirs of the USSR by Proshkina-Lavrenko (1953). The relation of algae to the active environmental reaction (pH) was established according to the classification of Hustedt (1937-1939), supplemented by Meriläinen (1967).

RESULTS AND DISCUSSION

Algal flora of seven surveyed hot springs and their watercourses on three of the Kuril islands – Kunashir, Shiashkotan, and the Yanki – were represented by 163 species (180 taxa of infr. rank, including the nomenclature species type), 4 divisions, 9 classes, 24 orders, 46 families, and 67 genera: *Cyanoprokaryota* – 12 (12), *Euglenophyta* – 1 (1), *Bacillariophyta* – 145 (162), and *Chlorophyta* – 5 (5). The total number of taxa included filamentous algae from *Chlorophyta*, found under sterile conditions and therefore not identified to species (*Oedogonium* sp. ster. and *Spirogyra* sp. ster.). For algal flora of the Kurile Islands' hot springs, we listed for the first time 174 taxa of intraspecific level – 51 species and infr. taxa of blue-green algae, euglenophytes, diatoms and green algae for the overall algal flora of Kuril inland waters (Table 2).

The core of the studied algal flora is represented by diatoms – 90% of total species composition of the Kuril hydrothermal vents. The class *Bacillariophyceae*, which includes 123 infr. taxa (68.3% of the total number of algae found) is the most diverse. Among the leading families (51.1% of general algal flora composition) there are: *Bacillariaceae* – 22 species, *Pinnulariaceae* – 17 (18 infr. taxa), *Fragilariaceae* – 12 (16), *Cymbellaceae* – 12, *Naviculaceae* – 11 (12), and *Gomphonemataceae* – 10 (12). In a systematic structure of flora the greatest number of taxa belong to genera *Pinnularia* – 13, *Nitzschia* – 12, and *Navicula* – 10 species and varieties. In the division *Cyanoprokaryota* highest species diversity belongs to the genus *Phormidium*, represented by 3 species. Green and *Euglenid* algae have a small number of representatives – 1 and 5 species, respectively.

In algal communities of the Kuril hot springs water temperature was 24 to 71 °C (according to published data – up to 103 °C) the number of dominants and sub-dominants included diatoms and blue-green algae: *Synedra ulna*, *Hannaea arcus* var. *linearis* f. *recta*, *Achnanthes lanceolata*, *Rhoicosphenia abbreviata*, *Gomphonema parvulum*, *Placoneis elginensis*, *Navicula slesvicensis*, *Pinnularia acidophila*, *P. acido-japonica*, *Nitzschia auraria*, *N. capitellata*, *N. nana*, *N. palea*, *N. constricta*, *Synechocystis aquatilis*, *Microcystis firma*, *Chroococcidiopsis thermalis*, and *Phormidium breve* (Tables 1, 2).

With significant species richness, of studied algae in the hydrothermal vents, only 17 species and infraspecific taxa of diatoms were found in at least six springs – *Synedra ulna*, *Hannaea arcus* var. *linearis* f. *recta*, *Diatoma mesodon*, *D. vulgare*, *Gomphonema parvulum*, *Rhoicosphenia abbreviata*, *Encyonema silesiacum*, *Achnanthes lanceolata*, *Achnanthidium minutissima*, *Cocconeis placentula* var. *euglypta*, *Navicula avenacea*, *N. cryptocephala, N. cryptotenella, Pinnularia acidojaponica, Nitzschia linearis, N. nana,* and *N. palea* (Table 2).

TABLE 1. Hydrochemical parameters of the Kuril Islands' thermal springs

Water spring	*T*, °C*	Therm type	pH	Number of taxa	Dominants
Kunashir Island Stolbchatiy Cape, stream-1 (river-head)	40	Nitric, chloride-sulphate natrium	6.7-7.0	78	*Phormidium breve, Rhoicosphenia abbreviate*
Kunashir Island Stolbchatiy Cape, stream-1 (middle flow)	24	Nitric, chloride-sulphate natrium	6.7-7.0	58	*Ph. breve, Gomphonema parvulum, Synedra ulna, Achnanthes lanceolata, Nitzschia nana*
Kunashir Island Stolbchatiy Cape, stream-2	(82)	Nitric, chloride-sulphate natrium	6.7-7.0	59	*Nitzschia constricta N. capitellata*
Kunashir Island The Alekhin Bay, stream-1	48,1 (50-55)	Sulphate - chloride calcium-natrium	4-5	84	*Synechocystis aquatilis, Nitzschia capitellata, N. palea, Pinnularia acidophila, P. acido-japonica*
Kunashir Island The Alekhin Bay, stream-2	26	Sulphate - chloride calcium-natrium	4-5	48	*Navicula slesvicensis*
Kunashir Island The Caldera of Golovnin volcano, stream	(60-103)	Hydrocarbonate-sulphate, natrium-calcium, sulphate, natrium	2-8.5	26	*Placoneis elginensis*
Shiashkotan Island Stream	71 (60)	Chloride-natrium	6.98	44	*Hannaea arcus* var. *linearis* f. *recta*
Yankicha Island Stream, shallow water reservoir	50-60 (101)	Chloride natrium	2.8-3.7	75	*Microcystis firma, Chroococcidiopsis thermalis, Placoneis elginensis, Nitzschia aurariae*

* The temperature values according to the literature sources are given in brackets: Marikhin & Stratula, 1977; Zharkov, 2006; Poberezhnaya, 2008.

Kunashir Island. The fouling of the stones in the first spring, flowing along the coast of Alekhin Bay is represented by 84 taxa of blue-green algae and diatom species and varieties. The main part of fouling is represented by the blue-green alga *Synechocystis aquatilis* and diatoms *Nitzschia capitellata, N. palea, Pinnularia acidophila,* and *P. acidojaponica*. Species *Diatoma vulgare, Eunotia implicata, Gomphonema parvulum,* and *Nitzschia nana* have also high abundance ratings.

TABLE 2. The species composition of the Kuril Islands' thermal springs

Taxon	Kunashir Island			Shiashkotan	Yankicha	*T*, °C	Ecological-geographical features				
	Stolbchatiy Cape	The Alekhin Bay	Caldera of Golovnin volcano				Habitat	Halobity	pH	S	Distribution
CYANOPROKARYOTA											
Class C h r o o c o c c o p h y c e a e											
Order **Chroococcales**											
Family Synechococcaceae											
●*Synechococcus elongatus* (Nägeli) Nägeli	3-4	3	-	-	-	48.1	B-P	-	-	χ	k
Family Merismopediaceae											
**Synechocystis aquatilis* Sauv.	-	2-6	-	-	-	48.1	P	hl	-	o	k
Family Microcystaceae											
**Microcystis firma* (Kütz.) Schmidle	-	-	-	-	5-6	50-60	P	-	-	o	a-a
Family Chroococcaceae											
●*Gloeocapsopsis magma* (Bréb.) Komárek et Anagn.	1	-	-	-	-	40	B	-	-	-	k
Family Xenococcaceae											
●*Chroococcidiopsis thermalis* Goitl.	-	-	-	-	6	50-60	B	-	-	-	-
Class H o r m o g o n i o p h y c e a e											
Order **Oscillatoriales**											
Family Pseudonostocaceae											
●*Pseudanabaena biceps* Böcher	1	1-2	-	-	-	26	B	-	-	-	-
**P. minima* (G.S. An) Anagn.	2	-	-	-	-	-	B	-	-	-	-
Family Oscillatoriaceae											
●*Phormidium ambiguum* Gomont	1	-	-	-	-	24-40	B	i	i	-	k
**Ph. animale* (C. Agardh ex Gomont) Anagn. et Komarek	1	-	-	-	-	24-40	B-P	-	-	o	k
●*Ph. breve* (Kütz. ex Gomont) Anagn. et Komárek	5-6	-	-	-	-	24-40	B-P	-	-	β-ρ	k
Family Schizothrichaceae											
**Schizothrix pulvinata* Kütz. ex Gomont	2	-	-	-	-	-	E	-	-	-	a-a
Family Homoeothrichaceae											
Homoeothrix varians Geitl.	2-4	-	-	-	-	24-40	B	-	-	o	-
EUGLENOPHYTA											
Class E u g l e n o p h y c e a e											
Order **Euglenales**											
Family Euglenaceae											

Continuation of Table 2

**Euglena viridis* Ehrenb.	1	-	-	-	-	-	B-P	i	-	ρ-α	b
BACILLARIOPHYTA										
Class C o s c i n o d i s c o p h y c e a e										
Order **Thalassiosirales**										
Family Thalassiosiraceae										
**Thalassiosira nordenskiöldii* Cleve	-	-	-	-	1-2	50-60	P	hl	-	-	b
Family Stephanodiscaceae										
Cyclotella meneghiniana Kütz.	1	-	-	-	-	40	B-P	hl	alf	α-β	k
Order **Melosirales**										
Family Melosiraceae										
**Melosira dickei* (Thw.) Kütz.	1	2-3	-	-	-	40-48.1	B-P	i	i	-	-
**M. moniliformis* (O. Müll.) C. Agardh	-	-	-	3	1-2	50-71	B-P	hl	-	-	k
M. nummuloides C. Agardh	-	-	-	-	1-2	50-60	-	mh	-	-	-
M. varians C. Agardh	1-4	1	-	-	1	24-60	B-P	i	alb	β	k
Order **Aulacoseirales**										
Family Aulacoseiraceae										
Aulacoseira distans (Ehrenb.) Simonsen var. *distans*	-	1	-	-	-	48.1	B-P	i	acf	χ-o	b
**A. distans* var. *lirata* (Ehrenb.) Bethge	-	-	-	-	1	50-60	B-P	-	-	-	-
A. granulata (Ehrenb.) Simonsen	1	1-2	-	-	1	40-60	P	i	alf	β	k
A. italica (Kütz.) Simonsen	1	-	-	-	-	24	P	i	alf	o-β	k
Order **Triceratiales**										
Family Triceratiaceae										
Odontella aurita (Lyng.) Agardh	-	-	-	-	1	50-60	B-P	mh	alf	-	-
Family Plagiogrammaceae										
**Dimeregramma fulvum* (Greg.) Ralfs in Pritchard	-	-	-	-	1	50-60	B	-	-	-	-
Class F r a g i l a r i o p h y c e a e										
Order **Fragilariales**										
Family Fragilariaceae										
Asterionella formosa Hass.	-	1	1	1	1-2	48.1-60	P	i	alf	o-β	k
Ctenophora pulchella (Ralfs) Williams et Round	1	1-2	-	-	1	24-60	B-E	mh	alf	β-α	b
Fragilaria capucina Desmazières	1-2	1	-	-	-	24-48.1	B-P	i	alf	o-β	k
F. crotonensis Kitton	1-2	1	-	1	-	40-48.1	P	i	alf	o-β	b
**F. nitzschioides* Grun.	-	-	-	-	1	50-60	B	i	i	-	k
F. vaucheriae (Kütz.) J.B. Petersen	1-2	1	-	1	1-2	48.1-71	E	i	alf	β	k
Fragilariforma virescens (Ralfs) Williams et Round	1	-	-	-	-	40	B	hb	i	χ	a-a
Hannaea arcus (Ehrenb.) Patrick var. *arcus*	-	1	1	-	1	48.1-60	B	i	alf	χ	a-a

Continuation of Table 2

Hannaea arcus var. *amphioxys* (Rabenh.) Patrick	1	-	-	-	-	40	B	i	alf	χ-o	a-a
H. arcus var. *linearis* (Holmboe) R. Ross	-	1	1	-	1	48.1-60	B	i	alf	χ	a-a
H. arcus var. *linearis* f. *recta* (Cleve) Foget	1-3	1	-	5	1-2	24-71	B	i	alf	χ	a-a
Staurosira construens (Ehrenb.) Grun. f. *subsalina* (Hust.) Bukhtiyarova	-	-	1	-	-	-	B	i	alf	β	k
S. construens f. *venter* (Ehrenb.) Bukhtiyarova	1	-	-	-	-	40	B	i	alf	o	k
Synedra inaequalis H. Kobayasi	-	1	-	-	-	48.1	B	-	-	-	-
S. ulna (Nitzsch) Ehrenb.	1-6	1-3	1	1	1	24-60	B	i	alf	β-α	k
Tabularia tabulata (C. Agardh) Snoeijs	-	1	-	-	1-2	48.1-60	B-E	hl	-	-	k
Family Diatomaceae											
Diatoma anceps (Ehrenb.) Kirchner	1	1	-	-	1	40-60	B	hb	alf	o-χ	a-a
D. hiemale (Lyng.) Heib.	1	1-2	-	1	-	24-71	B	hb	i	χ	a-a
D. mesodon (Ehrenb.) Kütz.	1-2	1	-	2	1	24-71	B	hb	alf	χ	a-a
D. moniliforme Kütz.	-	-	-	-	1	50-60	B-P	hl	-	β-α	k
D. vulgare Bory	1	1-5	2-3	2	1-4	24-71	B-P	i	alb	β	b
Meridion circulare (Grev.) C. Agardh var. *circulare*	1	1	-	1	-	24-71	B	hb	alf	χ-o	k
M. circulare var. *constrictum* (Ralfs) Van Heurck	1-2	1	-	1	-	24-71	B	hb	alf	χ-o	k
Order **Tabellariales**											
Family Tabellariaceae											
Tabellaria fenestrata (Lyng.) Kütz.	-	-	-	1	-	71	B-P	hb	acf	β	b
T. flocculosa (Roth) Kütz.	1	1	1	1	1	24-71	B-P	hb	acf	o-χ	a-a
Order **Licmophorales**											
Family Licmophoraceae											
**Licmophora communis* (Heib.) Grun.	-	-	-	-	1	50-60	B	-	-	-	-
Order **Striatellales**											
Family Striatellaceae											
Grammatophora angulosa Ehrenb.	-	-	-	1	-	71	B	-	-	-	-
Class B a c i l l a r i o p h y c e a e											
Order **Eunotiales**											
Family Eunotiaceae											
Eunotia arcus Ehrenb.	-	1	-	-	-	48.1	B	hb	acf	o	k
E. bilunaris (Ehrenb.) Mills var. *bilunaris*	2	1-2	-	-	1	24-60	B	i	acf	β	k
**E. bilunaris* var. *linearis* (Okuno) Lange-Bert. et Nörpel	-	-	-	-	1	50-60	B	-	-	o	-
E. denticulata (Bréb.) Rabenh.	-	1	-	-	-	26	B	-	acf	-	-

Continuation of Table 2

Eunotia exigua (Bréb.) Rabenh.	1	1-2	2	-	-	24-48.1	B	i	acf	χ	k
E. implicata Nörpel, Lange-Bert. et Alles	1	1-4	-	-	-	24-48.1	B	-	-	-	-
E. muscicola Krasske	1	-	-	-	-	24-40	B	-	acf	-	-
E. pectinalis (O. Müller) Rabenh.	1	1	-	-	-	24-48.1	B	hb	acf	χ	k
E. praerupta Ehrenb.	1	1	1	1	-	48.1-71	B	hb	acf	χ	k
E. tenella (Grun.) Hust.	-	-	-	-	1	50-60	B	hb	acf	χ-o	k
Order **Mastogloiales**											
Family Mastogloiaceae											
Aneumastus tusculus (Ehrenb.) Mann et Stickle	-	-	-	-	1	50-60	B-P	i	alf	o-χ	k
**Mastogloia smithii* Thw. ex W. Smith	1-2	1	-	-	1	26-60	B	mh	alf	β	k
Order **Cymbellales**											
Family Rhoicospheniaceae											
Rhoicosphenia abbreviata (C. Agardh) Lange-Bert.	2-6	1-2	-	1	1	24-60	B	hl	alf	β	k
Family Cymbellaceae											
Brebissonia boeckii (Ehrenb.) O'Meara	-	-	-	-	1	50-60	B	mh	-	-	b
Cymbella affinis Kütz.	1	1	1	1	1-2	24-71	B	i	alf	o-β	b
C. cistula (Ehrenb.) Kirchner	1	-	-	-	-	40	B	i	alf	β	b
C. lanceolata (Ehrenb.) Van Heurck	1	-	-	-	-	40	B	i	alf	β	-
C. naviculiformis Auerswald	1	-	-	-	-	24-40	B	i	i	o	k
**C. pusilla* Grun.	1	-	-	-	-	40	B	i	alf	-	k
**C. subleptoceros* (Ehrenb.) Kütz.	-	-	-	1	-	71	B	-	-	-	-
C. tumida (Bréb.) Van Heurck	1	1	-	-	1	24-60	B	i	alf	o	b
Encyonema hebridicum Grun. ex Cleve	4	-	-	-	-	-	B	i	i	o	a-a
E. minutum (Hilse ex Rabenh.) Mann	1	1	1	1-2	1	24-71	B	i	i	o	k
E. silesiacum (Bleisch in Rabenh.) D. G. Mann	1-3	1	-	1-2	1	24-71	B	i	alf	α	k
**Placoneis elginensis* (Greg.) E.J. Cox	1	-	1-4	-	2-6	40-60	B	i	i	o-β	k
Family Gomphonemataceae											
Gomphoneis olivaceum (Hornem.) Dawson ex Ross et Sims	1-2	1	-	1	1	26-71	B	i	alf	β	b
G. quadripunctatum (Østrup) Dawson ex Ross et Sims	1-3	1	-	-	-	24-40	B	i	i	-	b
Gomphonema acuminatum Ehrenb. var. *acuminatum*	1	1	-	-	-	24-48.1	B	i	alf	β	b
G. acuminatum var. *coronatum* (Ehrenb.) W. Smith	1	-	-	-	-	24-40	B	i	alf	β	b

Continuation of Table 2

Gomphonema angustatum (Kütz.) Rabenh.	2-3	1-2	1	2	1	26-71	B	i	alf	o	b
G. angustum Agardh	-	-	-	1	-	71	B	i	alf	o	b
G. clavatum Ehrenb.	-	1	-	-	1	48.1-60	B	i	i	o	k
G. intricatum Kütz. var. *vibrio* (Ehrenb.) Cleve	1	-	-	-	-	40	B	i	-	-	b
G. parvulum (Kütz.) Kütz. var. *parvulum*	2-6	1-4	1	2	1-2	24-71	B	i	alf	β	b
G. parvulum var. *lagenula* (Kütz.) Freng.	3	1	-	-	-	48.1	B	i	alf	-	k
G. truncatum Ehrenb.	-	1	-	1	1	48.1-71	B	i	alf	β	b
Reimeria sinuata (Greg.) Kociolek et Stoermer	1-2	1	-	1	-	24-71	B	i	alf	β	b
Order **Achnanthales**											
Family <u>Achnanthaceae</u>											
Achnanthes coarctata (Bréb.) Grun.	-	-	-	1-2	-	71	B	i	i	o	a-a
A. exigua Grun. var. *Exigua*	1-2	-	-	-	-	40	B	i	alf	β	k
**A. exigua* var. *capitata* Hust.	1-3	-	-	-	-	24-40	B	-	-	-	-
A. lanceolata Bréb. ex Kütz. var. *lanceolata*	1-6	1-2	-	1	1	24-71	B	i	alf	χ-β	k
A. lanceolata var. *elliptica* Cleve	1-2	1	-	-	-	24-48.1	B	i	alf	-	a-a
A. lanceolata var. *haynaldii* (Schaarschmidt) Cleve	1-3	-	-	-	-	24-40	B	i	alf	χ-β	k
Family <u>Achnanthidiaceae</u>											
Achnanthidium minutissima (Kütz.) Czarnecki	1-4	1	1	1	1	24-71	B	i	i	o-β	b
**Eucocconeis flexella* Kütz.	-	1	-	-	-	26	B	mh	i	o	a-a
Family <u>Cocconeidaceae</u>											
Cocconeis disculus (Schum.) Cleve	-	1	-	1-3	1	26-71	B	i	-	-	-
**C. pediculus* Ehrenb.	-	-	1	-	-	-	B	hl	alf	β	k
C. pinnata Greg.	-	-	-	-	1-2	50-60	-	-	-	-	-
C. placentula Ehrenb. var. *placentula*	-	1	-	1	-	48.1-71	B	i	alf	β	b
C. placentula var. *euglypta* (Ehrenb.) Grun.	1-3	1	1	1-2	1	24-71	B	i	alf	-	b
C. placentula var. *lineata* (Ehrenb.) Van Heurck	-	-	1	-	1	50-60	B	i	alf	-	b
**C. scutellum* Ehrenb.	-	1	-	-	1-2	26-60	B	hl	-	-	-
Order **Naviculales**											
Family <u>Diadesmidaceae</u>											
**Luticola mutica* (Kütz.) Mann	-	1	-	-	-	48.1	B	i	i	o-β	a-a
Family <u>Amphipleuraceae</u>											
Frustulia rhomboids (Ehrenb.) De Toni var. *rhomboids*	1	1	-	-	-	24-48.1	B	hb	acf	o-χ	a-a

Continuation of Table 2

**Frustulia rhomboides* var. *amphipleuroides* Grun.	1	-	-	-	-	-	B	hb	acf	-	a-a
F. vulgaris Thw.	1-3	1	-	-	-	24-48.1	B	hb	alf	o	b
Family Neidiaceae											
Neidium ampliatum (Ehrenb.) Krammer	1	1	-	-	-	24-48.1	B	hb	i	o	k
Family Sellaphoraceae											
**Fallacia pygmaea* (Kütz.) Stickle	-	1	-	-	-	26	B	mh	alf	α	b
Family Pinnulariaceae											
**Caloneis bacillum* (Grun.) Cleve	-	1	-	1	-	26	B-P	i	alf	o	k
**C. molaris* (Grun.) Krammer	1-4	-	-	-	-	24-40	B	i	i	-	a-a
C. silicula (Ehrenb.) Cleve var. *silicula*	1	1	-	-	-	40-48.1	B	i	alb	o	k
**C. silicula* var. *truncatula* Grun.	-	-	-	-	1	50-60	B-P	i	alf	-	k
**Pinnularia acidojaponica* Idei et Kobayasi	1	1-6	1-3	1	1	26-71	B	-	acf	-	-
**Pinnularia acidophila* Hofmann et Krammer	-	1-6	-	1	1	26-71	B	-	acf	-	-
P. borealis Ehrenb.	1	1	-	-	1	26-60	B	i	i	χ	a-a
P. brebissonii (Kütz.) Rabenh.	-	-	-	-	1	50-60	B	i	i	α-β	b
P. major (Kütz.) Rabenh.	1	-	-	-	-	-	B	i	acf	β	b
P. microstauron (Ehrenb.) Cleve	1-2	-	-	-	-	24-40	B	i	i	o	b
**P. neomajor* Krammer	1	-	-	-	-	-	B	-	acf	o-χ	-
**P. obscura* Krasske	1	1-3	-	-	-	26-48.1	B	-	-	-	-
**P. rhombarea* Krammer	1	-	-	-	-	24-40	B	-	-	-	-
**P. stomatophora* (Grun.) Cleve	1	-	-	-	-	-	B	-	-	-	-
**P. subgibba* Krammer var. *undulata* Krammer	1	-	-	-	-	40	B	-	-	o	-
P. subrupestris Krammer	-	1	-	-	-	48.1	B	-	-	-	-
P. viridiformis Krammer	1	1	-	-	-	24-40	B	-	-	-	-
P. viridis (Nitzsch) Ehrenb.	-	1	-	-	-	48.1	B	i	i	β	b
Family Diploneidaceae											
Diploneis elliptica (Kütz.) Cleve	1-2	1	-	-	-	26-40	B	i	alf	o	k
D. ovalis (Hilse) Cleve	1	1	-	-	-	26-40	B	hl	alf	β	b
Family Naviculaceae											
Navicula avenacea (Bréb. et Godey) Bréb.	1-3	1	1	1	1	24-71	B	i	acf	β	-
N. capitata Ehrenb. var. *capitata*	1	1	-	-	1	26-60	B	hl	alf	β-α	k
N. capitata var. *hungarica* (Grun.) R. Ross	1	1	-	1	-	26-71	B	hl	alf	β	b
N. cryptocephala Kütz.	1-2	1-2	1	1	1	24-71	B-P	hl	alf	α	k

Continuation of Table 2

Navicula cryptotenella Lange-Bert.	2-4	1-2	-	1	1	24-71	B	i	alf	β	k
**N. digitoradiata* (Greg.) Ralfs	-	-	-	-	1	50-60	B	hl	alf	-	k
N. directa (W. Smith) Ralfs	-	-	-	-	1	50-60	B-P	mh	-	-	-
N. integra (W. Smith) Ralfs	1-2	1	-	-	-	24-48.1	B	mh	i	χ-o	a-a
Navicula menisculus Schum.	1	-	-	-	-	24	B	hl	alf	β-α	k
N. placentula (Ehrenb.) Grun.	-	1	-	-	-	26	B	i	alf	β	k
N. radiosa Kütz.	1	-	-	-	1	24-60	B	i	i	o-β	k
N. slesvicensis Grun.	1	1	-	-	-	26-48.1	B	hl	i	β	k
Family Pleurosigmataceae											
Gyrosigma acuminatum (Kütz.) Rabenh.	1	-	-	-	-	40	B	i	alb	β	b
Order **Thalassiophysales**											
Family Catenulaceae											
Amphora normanii Rabenh.	1-2	1	-	-	1	24-60	B	hb	alf	β-α	b
A. ovalis (Kütz.) Kütz.	1	1	-	-	1	40-60	B	i	alb	o-β	k
A. pediculus (Kütz.) Grun.	1-2	-	-	1	-	24-71	B	i	alb	β	k
**A. veneta* Kütz. f. *capitata* E.Y. Haworth	5	1	-	-	-	26	B	i	alb	β	b
Order **Bacillariales**											
Family Bacillariaceae											
Bacillaria paradoxa Gmel.	-	-	-	-	1	50-60	P	mh	alb	β	k
**Denticula kuetzingii* Grun.	1	1	-	-	1	40-60	B	i	alf	β	b
Hantzschia amphioxys (Ehrenb.) Grun.	1	1	-	-	1	24-60	B	i	alf	α	k
**H. distinctepunctata* (Hust.) Hust.	-	2	-	-	-	26	B	i	-	-	k
**H. marina* (Donkin) Cleve in Cleve et Grun.	-	1	-	-	-	48.1	B	hl	-	-	-
**Nitzschia aurariae* Cholnoky	-	-	-	-	2-6	50-60	B	i	-	-	k
**N. brevissima* Grun.	1	-	-	-	-	48.1	B	hl	i	o-β	k
N. capitellata Hust	2-6	1-6	-	-	-	26-48.1	B	i	alb	o	k
**N. constricta* (Kütz.) Ralfs	1-6	1	-	-	-	40-48.1	B	mh	alf	β	k
N. dissipata (Kütz.) Grun.	1	1	-	-	1	24-60	B	i	alf	o-β	b
N. fonticola Grun.	1-2	1-2	-	1	1	24-71	B	i	alf	o	b
N. frustulum (Kütz.) Grun.	1-3	-	-	-	-	24-40	B	hl	alb	o	k
N. linearis W. Smith	1-2	1	1	-	1	24-60	B	i	i	o	b
N. nana Grun.	2-6	1-4	1	1	1	24-71	B	mh	-	-	b
N. palea (Kütz.) W. Smith	3-5	1-6	1	2	1	24-71	B	i	i	α	k
N. paleacea (Grun.) Grun.	2	1	1	1	-	24-71	P	i	alf	o-β	k
**N. pellucida* Grun.	-	-	-	-	1	50-60	B	hl	-	-	k
**N. recta* Hantsch	1	-	-	-	-	-	B	i	alf	α-β	b
**N. thermaloides* Hust.	-	-	1	-	4	50-60	-	hl	-	-	-

End of Table 2

Nitzschia vermicularis (Kütz.) Hantzsch	-	-	-	-	1	50-60	B	i	alf	β	k
Tryblionella levidensis W. Smith	-	1	-	-	-	48.1	B	hl	alf	α	b
**T. marginulata* (Grun. in Clever et Grun.) D.G. Mann	1	-	-	-	-	-	-	hl	-	-	-
Order **Rhopalodiales**											
Family Rhopalodiaceae											
Epithemia adnata (Kütz.) Bréb. var. *porcellus* (Kütz.) R. Ross	1	-	-	-	-	40	B	i	alb	β	k
**Rhopalodia acuminata* Krammer	1-2	1	-	-	-	40-48.1	B	hl	-	-	-
Rh. rupestris (W. Smith) Krammer	-	1	-	-	-	48.1	B	-	-	o	a-a
Order **Surirellales**											
Family Surirellaceae											
Surirella angusta Kütz.	1	1	-	-	1	24-60	B	i	alf	β	k
S. brebissonii Krammer et Lange-Bert.	-	1	-	-	1	48.1-60	B	i	i	β	k
**S. minuta* Bréb.	1	-	-	-	-	40	B	i	alf	-	b
CHLOROPHYTA											
Class C h l o r o p h y c e a e											
Order **Oedogoniales**											
Family Oedogoniaceae											
Oedogonium sp. ster.	-	-	-	-	1	50-60	B	-	-	-	-
Class U l v o p h y c e a e											
Order **Ulotrichales**											
Family Ulothrichaceae											
Ulothrix zonata (Weber et Mohr) Kütz.	1	-	-	-	-	24	B	i	i	o	k
Family Chaetophoraceae											
**Stigeoclonium nanum* (Dillw.) Kütz.	2	-	-	-	-	24	B	-	-	-	-
Class Z y g n e m a t o p h y c e a e											
Order **Zygnematales**											
Family Spirogyraceae											
Spirogyra sp. ster.	1-3	-	-	-	-	24-40	B	-	-	-	-
Order **Desmidiales**											
Family Desmidiaceae											
**Cosmoastrum punctulatum* (Bréb.) Pal.-Mordv.	1	-	-	-	-	24	P	i	acf	o	k

Note: The occurrence frequency of listed organisms on the six-point scale: 1 – singly, 2 – rarely, 3 – rather often, 4 – often, 5 – very often, 6 – large numbers (Corde, 1956). Habitat: P – plankton, BP – benthic-planktonic, B – benthic, E – epiphytic, BE – benthic-epiphytic. Halobity: mh – mesohalobes, hl – halophiles, hb – halophobes, i – indifferent. Relation to pH: alf – alcaphilic, alb – alcalibionts, acf – aciodophiles, i – indifferent. Saprobity: χ – xenosaprobionts, o-χ –oligo-xenosaprobionts, χ-o – xeno-oligosaprobiont, χ-β – xeno-betamesosaprobionts, o–oligosaprobiont, o-β – oligo-betamesosaprobiont, β – beta-mesosaprobiont, β-α – beta-alphamesosaprobiont, α-β – alpha-betamesosaprobiont, β-ρ – beta-polymesosaprobiont, α – alpha-mesosaprobiont, ρ-α – poly-alphamesosaprobiont, «-» – no data, "*" – species is first indicated for the algal flora of the Kuril Islands; «●» – species previously reported from hot springs of the Kuril Islands; species not marked species («●») for the first time indicated for the hot springs of the Kuril Islands. *T*, °C ─ temperatures registered by us.

Algal flora of the second hot spring of Alekhin Bay basin has a similar floristic composition; however, the total number of taxa does not exceed 48. Occurrence of these species is characterized as sporadic and rare. Only one species, *Navicula slesvicensis*, has a frequency of occurrence "often" – the highest possible for these algal communities (Table 2). Algal flora from the hot spring of the Golovnin volcano's caldera has extremely poor composition and is presented by 26 infr. taxa of diatoms. The occurrence frequency of algae ranges "individual" – "often", and only the species *Placoneis elginensis* has the abundance "often" (Table 2).

Hot spring and a stream flowing from it, belonging to the Stolbovskiy group of hot springs (Stolbchatiy Cape), were surveyed in August 1999. They have a similar structure of algal communities and have 78 and 58 infr. taxa, respectively. Fouling of the stones in the thermal spring was represented by *Phormidium breve* (blue-green) and *Rhoicosphenia abbreviata* (diatoms), as well as species with lower abundance – *Nitzschia palea*, *N. nana*, *Achnanthes lanceolata*, *Synedra ulna*, and *Homoeothrix varians* (Table 2). The creek is dominated by *Phormidium breve*, *Synedra ulna*, *Gomphonema parvulum*, *Achnanthes lanceolata*, and *Nitzschia nana*, while *Melosira varians*, *Rhoicosphenia abbreviata, Achnanthidium minutissima, Navicula cryptotenella*, and *Nitzschia palea* share the role of subdominants.

Hydrotherms at Cape Stolbchatiy surveyed in April 2007 were characterized by a significant taxonomic composition (59 species and infr. taxa) and the dominance of diatoms *Nitzschia constricta* and *N. capitellata* in conjunction with the subdomainant from diatoms and blue-green: *Amphora veneta* f. *capitata*, *Caloneis molaris*, *Encyonema hebridicum*, *Navicula cryptotenella*, *Nitzschia nana*, and *Synechococcus elongatus*. Only in this source, at a temperature of 24 °C, we found individual cells of *Euglenophyta* representative *Euglena viridis*.

<u>Shiashkotan Island.</u> In this hot spring we found 44 taxa of diatoms. Benthic, alkaliphilic, and indifferent to salinity species of *Hannaea arcus* var. *linearis* f. *recta* prevailed in the algal community, its abundance is defined as "very often". All other species are of secondary importance, their frequency of occurrence is assessed as "individual" – "quite often" (Table 2).

<u>Yankicha Island</u>. In the rock fouling of thermal spring, its stream and its shallow lotic reservoirs we recorded algal communities with identical species composition, comprising 74 taxa of blue-green algae and diatoms, and one sterile conferva from *Oedogonium* genus of green algae. Communities are dominated by diatoms and blue-green algae: *Microcystis firma*, *Chroococcidiopsis thermalis*, *Navicula elginensis,* and *Nitzschia aurariae*. A significant proportion of species belongs to *Diatoma vulgare* and *Nitzschia thermaloides*. The maximum abundance value for these species is "often" (Table 2).

Algae growing in fouling of solid substrates of the seven hydrotherms of Kunashir, Shiashkotan, and Yankicha Islands have different compositions of the dominant species. Only *Nitzschia capitellata* and *Placoneis elginensis* species are found in algal communities of two different hot springs. *Nitzschia capitellata* is found in the streams, located at the Cape Stolbchatiy on the coast of the Alekhin Bay of Kunashir Island. *Placoneis elginensis* is found in the springs of Kunashir Island (caldera of Golovnin volcano) and Yankicha Island (Tables 1, 2).

Studies show that in the hot springs of Caucasus, Kamchatka, Buryatia, Kyrgyzstan, and Hungary, the temperature range of high algae diversity is quite wide – from 25 to 50 °C. With temperature over 60 °C the number of species drops sufficiently (Nikitina, 2005). In the studied hydrotherms the smallest number of taxa (26 species and infr. taxa) was observed in the hot springs of Golovnin caldera with water temperature reaching 103 °C, while the highest number of taxa (84) – in one of the hot springs with temperature 48.1 °C flowing into the Alekhin Bay. With a significant increase in water temperature, species composition of algal communities is depleted; however, the few remaining species develop actively and even become widespread under such conditions.

The vegetation of thermal springs mainly consists of cold-water algae adapted to high temperatures. Among the true thermophiles or characteristic representatives of the Kuril Islands' hot springs, we can distinguish such species as *Synechocystis aquatilis*, *Chroococcidiopsis thermalis*, *Pinnularia acidojaponica*, *P. acidophila*, and *Nitzschia thermaloides*.

The Kuril Islands geographically located near the Kamchatka peninsula, which also has a large number of hot springs. Algal flora of the peninsula's hot springs has been studied for a long time (Gutwinski, 1891; Elenkin, 1914; Petersen, 1946; Lupikina et al., 2001; Nikitina, 2001, 2005; Kuzyakina et al., 2005; Yoshitake et al., 2008). According to these studies, the algal communities of Kamchatka's hydrothermal vents with a water temperature range of 14-78 °C and pH range 1-10 is dominated by species that are marked as secondary for the hot springs of the Kuriles (*Achnantes exigua*, *Amphora veneta*, *Caloneis bacillum*, *Neidium ampliatum*, *Nitzschia amphibia*, *N. frustulum*). *Pinnularia marchica* Ilka Schönfelder, *Mastigocladus laminosus* Cohn) were not found there. Nevertheless, when comparing the species composition of algal floras form Kamchatka and the Kuril Islands, we revealed a significant number of common species of *Cyanoprokaryota* and *Bacillariophyta*: *Phormidium breve*, *Melosira varians*, *Hannaea arcus* var. *linearis* f. *recta*, *Diatoma mesodon*, *Eunotia bilunaris*, *Rhoicosphenia abbreviata*, *Encyonema silesiacum*, *Gomphonema parvulum*, *Achnanthes lanceolata*, *Cocconeis placentula*, *Frustulia rhomboides*, *Navicula cryptocephala*, *Nitzshia frustulum*, *N. nana*, and *N. palea.* These species are typical for cold-water streams, rivers, and lakes in the Kuril Islands (Nikulina, 2002, 2004, 2008).

The analysis of the diatom flora from hot springs of the three Kuril Islands showed that the information on their habitat range is available for 177 taxa, or 98.3% of the total number of species, varieties and forms, found in the investigated area. Most of the algae found belong to the benthic and benthic-planktonic species, i.e., 78.9 and 11.7%, respectively (Table 3).

TABLE 3. Distribution of algae from thermal springs according to their ecological groups

Ecological group	Island			The number of taxa in algal flora	% Ratio
	Kunashir	Shiashkotan	Yankicha		
Habitat					
Benthic	124	34	57	142	78.9
Planktonic	6	3	5	10	5.5
Bentic-planktonic	13	6	11	21	11.7
Epiphytic	2	1	1	2	1.1
Bentic-epiphytic	2	-	2	2	1.1
No data	2	-	2	3	1.7
Total	149	44	78	180	100
Halobity					
Mesohalobes	7	1	8	12	6.7
Halophiles	18	3	12	23	12.8
Indifferent	84	29	43	93	51.7
Halophobic	15	7	5	17	9.4
No data	25	4	10	35	19.4
Total	149	44	78	180	100
Relation to pH					
Alcallibionts	10	2	4	11	6.1
Alcalliphiles	64	26	36	71	39.4
Indifferent	26	5	11	29	16.1
Acidophiles	17	6	6	19	10.6
No data	32	5	21	50	27.8
Total	149	44	78	180	100
Geographical distribution range					
Cosmopolite	28	6	16	74	41.1
Boreal	20	5	8	44	24.5
Arcto-Alpine	39	16	20	22	12.2
No data	62	17	34	40	22.2
Total	149	44	78	180	100

For 145 species and infraspecific taxa there is available data on their relation to salinity (80.6% of the total). The most numerous group is algae, indifferent to salinity changes; their share is 51.7%. Halophiles have 12.8% of the total number of taxa (Table 3). Data on the relation to pH is known for 72.2% of species and infraspecific taxa from the total number of taxa noted herein. Alcalliphilic species dominate among them (39.4%).

TABLE 4. Percentage ratio of saprobity indicator species in algal flora of the Kuril Islands' springs

Saprobiological group	Saprobity level of indicator species	Kunashir	Shiashkitan	Yankicha	The number of taxa for algal flora	Overall number of taxa in the saprobiotic group	% Ratio
Xenosaprobionts (*S* = 0-0.50)	χ	11	4	5	11	22	12.2
	χ-o	5	2	1	6		
	o-χ	4	1	3	5		
Oligosaprobionts (*S* = 0.51-1.50)	χ-β	2	1	1	2	45	25.0
	o	26	6	8	30		
	o-β	12	5	7	13		
Betamesosaprobionts (*S* = 1.51-2.50)	β-o	-	-	-	-	44	24.4
	o-α	-	-	-	-		
	β	35	13	17	38		
	β-α	5	1	5	6		
Alphamesosaprobionts (*S* = 2.51-3.50)	α-β	2	-	1	3	10	5.6
	β-ρ	1	-	-	1		
	α	6	3	4	6		
	α-ρ	-	-	-	-		
Polysaprobionts (*S* = 3.51-4.50)	ρ-α	1	-	-	1	1	0.6
	ρ	-	-	-	-		
No data		39	8	26	58	58	32.2
Total		149	44	78	180	180	100

Geographic distribution is known for 140 taxa, representing 77.8% of the total number of algae. Proportion of widespread and cosmopolitan species – 41.1%, Boreal – 24.5%, Arcto-Alpine – 12.2% (Table 3).

One hundred and twenty-two (122) taxa are the water saprobity indicators, it is 67.8% of the total number of taxa in the algal flora of the investigated area. oligosaprobionts and betamezosaprobionts are the most fully represented – 25 and 24.4% respectively. The overall share of the remaining saprobity groups is 18.4% (Table 4).

CONCLUSIONS

Algal flora of the surveyed hot springs and their watercourses on the Kuril Islands is represented by 180 taxa of 4 divisions: *Cyanoprokaryota*, *Euglenophyta*, *Bacillariophyta*, and *Chlorophyta*. The core of algal flora is represented by diatoms (90% of the total number of species in examined hydrotherms).

For the algal flora of the Kuril Islands' hot springs, we listed for the first time 174 species and infraspecific taxa, and 51 for waters of the Kuril archipelago.

The communities of the Kuril Islands' hydrotherms are dominated by diatoms and blue-green algae. Algal flora of hot springs mainly consists of cold-water algae adapted to high temperatures. When the water temperature in the reservoirs is 60 °C and higher, the species richness of algal communities significantly drops. In the Kuril hydrotherms we found such species as *Synechocystis aquatilis*, *Chroococcidiopsis thermalis*, *Pinnularia acidojaponica*, *P. acidophila*, and *Nitzschia thermaloides*, which are true thermophiles or typical hot spring inhabitants.

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Algal Flora of Lakes and Rivers in the Republic of Karelia (Russia)*

T.A. CHEKRYZHEVA[1] & S.F. KOMULAINEN[2]

[1]*Northern Water Problems Institute, Karelian Research Centre of RAS,*
50, Nevsky St., Petrozavodsk 185003, Republic of Karelia, Russia

[2]*Institute of Biology, Karelian Research Centre of RAS,*
11, Pushkinskaya St., Petrozavodsk 185910, Republic of Karelia, Russia

ABSTRACT

Algal flora of ponds and streams of the Republic of Karelia is studied in the current paper. We give taxonomic peculiarities and ecogeographical structure of phytoplankton and periphyton – the most important components of different types of aquatic ecosystems of Karelia. Identified dominant species and indicator species can be regarded as illustrative in assessing the level of salinity, acidification, organic pollution and eutrophication.

KEYWORDS: phytoplankton, periphyton, taxonomic composition, indicator species, lakes, rivers, Republic of Karelia.

INTRODUCTION

The researches of algal flora in Karelian waters are of great interest in light of the natural and anthropogenic factors dynamics. Despite the early studies (Komulainen et al., 2006a, b), the algal flora inventory is still relevant from Karelian waters. Algological studies in high latitudinal waters are especially relevant. The analysis of the algal flora structure will hopefully solve the problem of biogeography, the history of biota formation and its dynamics. Data on the spatial heterogeneity of algal census will help in planning the future monitoring system, protection measures and rational use of natural resources under the effect of interacting natural and anthropogenic factors.

The purpose of this work is a comparative analysis of taxonomic structure and ecogeographical distribution of different types of algae in aquatic ecosystems of the Republic of Karelia.

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Characteristics of the surveyed water bodies

The Republic of Karelia is situated in the north of European part of Russia. Its area covers about 178,000 km^2. Karelia lies within the Arctic-Atlantic climate of temperate zone. The climate is temperate-continental with some features of maritime (Romanov, 1956). It has a well-developed hydrographical network, belonging to the basins of the White Sea (57%) and Baltic Sea (43%) (Surface ..., 1972). There are 61,100 lakes in its territory with total area of about 18,000 km^2. The total lake area is about 12%, being one of the highest in the world. Lakes with the area less than 1 km^2 predominate (95%). On the territory of the Republic of Karelia, there are 26,700 watercourses with a total length of about 83,000 km. However, predominant watercourses are less than 10 km long (95%). Only about 30 rivers have length of more than 100 km. The density of the hydrographical network comprises 0.53 km/km^{-2}.

The geological and climatic features of the Republic of Karelia determine specific "Karelian" type of surface water (Catalogue ..., 2001), which is characterized by wide variability of pH and color of water. The low level of mineralization along with high content of natural colored organic compounds of humic nature are the main features of the hydrochemistry of Karelian water bodies. An atmospheric component of the local runoff plays the main role in the formation of hydrochemical regime of rivers (Catalogue ..., 2001).

MATERIALS AND METHODS

The materials for this study are the research results of 1971-2006 in 273 water bodies of Karelia, belonging to the basins of the White (37 lakes, 34 rivers) and the Baltic (153 lakes, 49 rivers) seas.

Samples of phytoplankton and periphyton were collected and processed using standard (Kuzmin, 1975, 1984) and modified technique (Komulainen et al., 1989; Komulainen, 2003). We used published literature data for the ecogeographical analysis in order to characterize the geographic distribution of algae and their relation to salinity and to active environmental reaction (Kolbe, 1927; Hustedt, 1939; Proshkina-Lavrenko, 1953; Foged, 1964; Merilainen, 1967; Sladeček, 1973; Bibliographic ..., 1974; Unified ..., 1977; Levadna, 1986; Barinova et al., 2006).

Summary checklist of algae is composed basing on the system adopted in the series: Key of Freshwater Algae of the USSR (1951-1986) and the reference-book: Algae …, 1989.

Algal species identification was performed using the Identification key of freshwater algae of the USSR (1951-1986), the reference-book of Elenkin (1938), manuals: Diatoms of the USSR (fossil and modern) (1974), as well as individual publications

(Hustedt, 1930, 1939; Kosinskaya, 1960; Getsen, 1973; Komarenko & Vasilieva, 1975, 1978; Starmach, 1985; Krammer & Lange Bertalot, 1986, 1988; Eloranta & Kwandrans, 2007).

RESULTS AND DISCUSSION

The algal flora of the surveyed lakes and rivers, we identified 1092 taxa belonging to 221 genera and 96 families, 41 order, 10 classes and 10 divisions (Tables 1, 2). The distribution by orders, by the number of taxa and the percentage was as follows: *Bacillariophyta* – 482 (44%), *Chlorophyta* – 294 (27%), *Cyanophyta* – 146 (13.5%), *Chrysophyta* — 92 (8.5%), *Euglenophyta* – 33 (3%), *Xanthophyta* – 14 (1.5%), *Cryptophyta* – 12 (1%), *Dinophyta* – 11 (1%), *Rhodophyta* – 7 (0.5%). *Raphidophyta* are represented by only one species – *Gonyostomum semen* (Ehrenb.) Dies. Full list of algae, identified by some authors in the studied reservoirs of Karelia, is given in the monograph of Komulainen et al. (2006a, b).

TABLE 1. The taxonomic structure of algal flora in Karelian lakes and rivers

Division	Number					The share from overall algal flora composition,%
	Class	Order	Family	Genus	Taxon	
Cyanophyta	4	9	23	38	146	13.5
Chrysophyta	1	3	8	19	92	8.5
Bacillariophyta	2	8	18	49	482	44
Xanthophyta	3	3	6	9	14	1.5
Cryptophyta	1	1	1	4	12	1
Dinophyta	1	2	3	5	11	1
Euglenophyta	1	1	1	5	33	3
Chlorophyta	5	11	31	85	294	27
Raphidophyta	1	1	1	1	1	0
Rhodophyta	1	2	4	6	7	0.5
Total	20	41	96	221	1092	100

The base of the list (90%) is represented by diatoms, green, blue-green and golden algae. This matter is also characteristic for other reservoirs in the northwestern and northeastern boreal and subarctic areas of Russia and Fennoscandia (Shirshov, 1933; Levadnaya, 1974, Trifonova, 1976, 1990; Getsen, 1978, 1985, Johansson, 1982; Kuzmin, 1985; Trifonova & Petrova, 1994; Eloranta, 2007).

TABLE 2. Percentage ratio of algal flora components in lakes and rivers of the Republic of Karelia

Division	Order		Family		Genus		Taxa	
	Lakes	Rivers	Lakes	Rivers	Lakes	Rivers	Lakes	Rivers
Cyanophyta	6	6	20	20	30	28	90	80
Chrysophyta	3	1	7	2	18	2	86	4
Bacillariophyta	7	6	18	17	45	42	333	320
Xanthophyta	3	1	5	1	8	1	12	1
Dinophyta	2	1	3	1	5	2	11	2
Euglenophyta	1	1	1	1	5	1	23	1
Chlorophyta	8	7	24	18	65	36	224	107
Total	30	23	78	60	176	112	779	515

The four divisions included 80 (83%) families: green (32%), blue-green algae (24%), diatoms (19%) and golden (8%) algae. It represents 1014 taxa, or 93% of their total number.

The leading groups according to their taxonomic diversity were 22 families (Table 3), combining 815 taxa, or 74.6% of their total number. The dominant taxa by number of families belong to the orders: *Naviculaceae* (*Bacillariophyta*) – 131, *Desmidiaceae* (*Chlorophyta*) – 104, *Fragilariaceae* (*Bacillariophyta*) – 55, *Eunotiaceae* (*Bacillariophyta*) – 50 taxa. Analysis of the genus spectrum (Table 4) revealed a group of most taxonomically significant genera. It includes 26 genera, or 12% of the total number of all genera.

Diatoms in aquatic ecosystems of Karelia lead in their species diversity of groups which is typical situation for all types of waters in the Arctic and Subarctic (Hilliard, 1959; Prescott, 1959; Sheath & Munuwar, 1975). Their diversity in the Karelian lakes and rivers is defined by such representatives as *Pennatophyceae* (434 taxa) and *Centrophyceae* (47 taxa). Of all diatoms (482 taxa), the most significant were two orders – *Raphales* (359 taxa) and *Araphales* (75 taxa). The richest taxa of pennate algae were genera *Navicula* Bory (54 taxa), *Eunotia* Ehrenb. (50), *Pinnularia* Ehrenb. (39), *Cymbella* Agardh (31), *Nitzschia* Hassall (31), *Achnanthes* Bory (28), *Gomphonema* Agardh (28), *Fragilaria* Lyngb. (25), and the richest taxa of the centric – *Aulacoseira* Simonsen (17) and *Cyclotella* Kütz. (14 taxa).

The most abundant in algal flora of all types of water bodies and the most common were the representatives of the *Raphales* order: *Tabellaria fenestrata* (Lyngb.) Kütz. var. *fenestrata*, *T. fenestrata* var. *intermedia* Grunow, *T. flocculosa* (Roth) Kütz., *Synedra ulna* (Nitzsch) Ehrenb. var. *ulna*. In lakes, the widespread pennate diatoms are *Asterionella formosa* Hassall var. *formosa* and *Fragilaria crotonensis* Kitton.

TABLE 3. The correlation of major families and the number of algae taxa in the flora of Karelian water bodies

The rate of the family	Family	Number of taxa	Percentage of total algal flora
1	*Naviculaceae*	131	12.0
2	*Desmidiaceae*	104	10.0
3	*Fragilariaceae*	55	5.0
4	*Eunotiaceae*	50	4.6
5	*Cymbellaceae*	42	3.8
6	*Achnanthaceae*	38	3.5
7	*Synuraceae*	36	3.3
8	*Scenedesmaceae*	35	3.2
9	*Nitzschiaceae*	34	3.1
10	*Euglenaceae*	33	3.0
11-12	*Gomphonemataceae*	29	2.7
11-12	*Dinobryonaceae*	29	2.7
13	*Ankistrodesmaceae*	26	2.4
14-15	*Oscillatoriaceae*	25	2.2
14-15	*Anabaenaceae*	25	2.2
16	*Surirellaceae*	22	2.2
17-18	*Closteriaceae*	21	1.8
17-18	*Stephanodiscaceae*	21	1.8
19	*Aulacoseiraceae*	17	1.5
20-21	*Rivulariaceae*	15	1.3
20-21	*Chrysococcaceae*	15	1.3
22	*Cryptomonadaceae*	12	1.0

In the algal flora of the river periphyton, there were significantly less species of centric diatoms belonging to the genera *Stephanodiscus* Ehrenb., *Cyclotella* Kütz., *Melosira* Agardh and *Aulacoseira* Simonsen than in the plankton of lakes. The most common species from *Aulacoseira* genus were *A. islandica* (O. Müll.) Simonsen f. *islandica*, *A. italica* subsp. *subarctica* O. Müll., *A. distans* (Ehrenb.) Kütz. f. *distans*, *A. ambigua* (Grunow) O. Müll. and *A. granulata* (Ehrenb.) Rolfs f. *granulata*. In lakes, species of these genera are quite widespread as well.

As for species diversity, green algae (294 taxa) are second only to diatoms. Species richness of this group is determined mainly by the representatives of *Desmidiales*, from genera *Cosmarium* Corda (40), *Closterium* Nitzsch (21), *Staurastrum* Meyen (17 taxa).

In the lake plankton *Desmidiales* are widespread, whereas in the diversity of periphyton algal census they occur sporadically and do not play significant role in the formation of their structure. *Chlorococcales* representatives are widely distributed in lakes and in the periphyton of Onega Lake inflows. Their species diversity is formed mainly by species of the genera *Scenedesmus* Meyen (23) and *Ankistrodesmus* Corda (18 taxa). Volvox algae are represented by few species of the genera *Chlamydomonas* Ehrenb., *Pandorina* Bory, *Eudorina* Ehrenb., *Volvox* (L.) Ehrenb., *Phacotus* Perty and are a obligatory element of the lake plankton.

The *Cyanophyta*, occupying the third place according to their species richness (146 taxa), has the most diverse species belonging to the genera *Anabaena* Bory (24) and *Oscillatoria* Vaucher (19 taxa). Several species of planktonic *Cyanophyta* from the genera *Aphanizomenon* Morren, *Anabaena* Bory, *Microcystis* Kütz., *Oscillatoria* Vaucher, *Gloeotrichia* J.C. Agardh cause "blooms" in the water reservoirs of the temperate zone. They are typical for the late summer algal flora of the Karelian lakes and they might be the agents of water blooms during intensive summer vegetation.

Species diversity of golden algae in the lakes of Karelia is formed by species of the genera *Dinobryon* Ehrenb. (24), *Mallomonas* Perty (21 taxa), and also several forms of nannoplankton genera *Kephyrion* Pascher (9), *Chrysococcus* Klebs (6), which are characterized by year-round development of phytoplankton in the Arctic and Subarctic (Matvienko, 1954; Getsen, 1973, 1985; Ermolaev & Safonova, 1974; Vasilyeva & Remigaylo, 1982).

Euglenoid algae is obligatory component of the phytoplankton. Their diversity in Karelian lakes is formed mainly by representatives of the genera *Trachelomonas* Ehrenb. (17 taxa), *Euglena* Ehrenb. (9) and *Phacus* Duj. (5).

The share of other orders *Xanthophyta*, *Cryptophyta*, *Dinophyta*, *Rhodophyta* in the formation of algal flora of the Karelian waters is negligible.

Phytoplankton of each reservoir is peculiar by its taxonomic composition. The comparison of the floristic checklists of phytoplankton communities, using indices of biocenotic similarity (Sørensen coefficient) showed that the average number of common species in the lakes does not exceed 30%, indicating a relatively low similarity degree of algal flora in the Karelian lakes. The eurytopic species are more likely to be common species for all water bodies with a wide adaptation range.

The most similar species composition is found in the lakes belonging to the same trophic type. The calculated values of Sørensen coefficient of species composition similarity reached 0.7 in similar lakes. At the same time, with higher trophic levels in lakes the species number ratio of centric diatom species to pennate diatom increases, as seen from the calculated Nygard indexes (*Centrales*/*Pennales* ratio), which were, 0.25; 042 and 0.72 for oligotrophic, mesotrophic and eutrophic lakes, respectively. The evaluation of the algal flora similarity in different types of lakes, using Thunmark index (number of species ratio *Chlorococcales*/*Desmidiales* from green algae) also showed the increase in these values, depending on the lake trophic level. Thus, for oligotrophic, mesotrophic and eutrophic lakes, the indexes were, 2.52; 3.20 and 8.34, respectively.

TABLE 4. The correlation of major genera in the algal flora of Karelian water bodies

The rate of the genera	Genus	Number of taxa	Percentage of total flora
1	*Navicula*	53	4.9
2	*Eunotia*	50	4.6
3	*Cosmarium*	40	3.7
4	*Pinnularia*	39	3.6
5-6	*Cymbella*	31	2.8
5-6	*Nitzschia*	31	2.8
7-8	*Achnanthes*	28	2.6
7-8	*Gomphonema*	28	2.6
9	*Fragilaria*	25	2.3
10-11	*Anabaena*	24	2.2
10-11	*Dinobryon*	24	2.2
12-13	*Scenedesmus*	23	2.2
12-13	*Synedra*	23	2.1
14-15	*Mallomonas*	21	1.9
14-15	*Closterium*	21	1.9
16	*Oscillatoria*	19	1.7
17	*Ankistrodesmus*	18	1.6
18-20	*Trachelomonas*	17	1.6
18-20	*Staurastrum*	17	1.6
18-20	*Aulacoseira*	17	1.6
21	*Surirella*	16	1.5
22	*Cyclotella*	14	1.3
23	*Staupodesmus*	12	1.1
24	*Euastrum*	11	1
25-16	*Oocystis*	10	0.8
25-26	*Diatoma*	10	0.8

Zonal features of algal flora. Climatic and zonal features are peculiar to the algal flora of Karelian lakes and are manifested at different levels of taxonomic structure. The main feature is the dominance of diatoms, green, blue-green and golden algae in the plankton of lakes. The specific "geographical" features of the Karelian lakes' algal flora are manifested in the *Cyanophyta*/*Chlorophyta* ratio, which is 1:2. This situation is common for many algal floras of the boreal lakes and rivers. All the studied lakes are located in similar climatic and zonal conditions, and, despite the slightly different ratio *Cyanophyta/ Chlorophyta* in different lakes, the "latitudinal" trends of this parameter for all the lakes are not identified. The distribution of the families also reflects the characteristics of algal flora in the northern Karelian lakes. The highest species diversity is found within the families *Naviculaceae*, *Desmidiaceae*, *Fragilariaceae* and *Eunotiaceae*, which is also peculiar for other reservoirs of the European North. The genera with the highest phytocenotic importance in the algal flora of Karelian lakes, and other reservoirs of the region, are pennate diatoms belonging to the genera *Navicula* Bory, *Eunotia* Ehrenb., *Nitzschia* Hassall, *Achnanthes* Bory, *Gomphonema* Agardh. A characteristic feature of boreal floras is the high number of monospecific families and genera. In the studied flora of Karelian water bodies, the monospecific families accounted for 28% and the monospecific genera – 46%.

Ecological and geographic features of species. Algal flora species diversity of the surveyed water bodies is mainly determined by a variety of hydrological, hydrochemical and environmental conditions. The data on the species ecology and their geographical distribution are given in Table 5.

The algal flora of Karelian water bodies is characterized by the predominance of cosmopolitan forms (73%), with significant proportion of boreal (16%) and north-alpine (11%) species, indicating that it is quite psychrophilic. As for the type of nature habitats, most of the species refer to the plankton forms (53%). The inhabitants of the benthos (18%) and fouling layers (14%), are represented mainly by diatoms, and are less abundant.

Despite the fact that the Karelian lakes and rivers have a very low concentration of dissolved salts, we were able to establish a relationship to salinity according to Kolbe classification (Proshkina-Lavrenko, 1953) for 609 (56%) of algal species. In addition to oligohalobes, among which the species indifferent to salinity dominate (67%), there are halophilic species (9%) that can exist under high salinity conditions, and halophobe (14%) species. We also identified some mesohalobe forms (6 taxa) from among the diatoms.

Most water bodies of Karelia are characterized by the predominance of aquatic species indifferent to acidity (66%) with a significant proportion of alkalophilic (24%) and acidophilic (10%) forms.

The quality or degree of organic water pollution in surveyed reservoirs was estimated using 479 identified saprobic indicator types (44% of the total list). Most of them are referred to as oligo-, oligo-β-, β-mesosaprobic forms (404 species out of 84%).

The assessment of water quality using indicator organisms according to Pantle-Buccu method under the modification of Sladeček (Bibliographic ..., 1974; Makrushin, 1974) and in accordance with environmental health classification (Sladeček, 1973; Oksiyuk

& Zhukinsky, 1983) revealed the β-mesosaprobic nature of waters in the surveyed lakes and rivers, which allowed to assign them to ecologically clean or slightly polluted.

TABLE 5. Ecological-geographical characteristics of algae in the Karelian water bodies

Ecological-geographical elements	Number of species	%
Habitat		
Plankton	568	53
Benthos	190	18
Fouling species	147	14
Littoral	133	13
Epiplankton	18	2
Total	1056	100
Geographical distribution		
Cosmopolitan	637	73
Boreal	140	16
North-Alpine	94	11
Total	871	100
Halobity		
Oligohalobes	44	7
Halophobes	87	14
Indifferent	406	67
Halophiles	52	9
Mesohalobes	20	3
Total	609	100
Relation to pH		
Acidophiles	69	10
Indifferent	467	66
Alkaliphilic	168	24
Total	704	100
Saprobility		
Xenosaprobes (χ)	7	1.5
Xeno-oligosaprobes (χ-o)	17	3.5
Oligosaprobes (o)	111	23
Oligo-β-mesosaprobes (o-β)	101	21
β-mesosaprobes (β)	192	40
β-α-mesosaprobes (β-α)	26	5.5
α-mesosaprobes (α)	18	4
ρ-α–poly-α-saprobes (ρ-α)	5	1
Polisaprobes (ρ)	2	0.5
Total	479	100

The calculated saprobity indexes were within the range 1-2.5. There was a slight saprobity increase in reservoirs that receive wastewater from catchments, human settlements and industrial sites.

Indicator species of environmental conditions. A characteristic feature of the hydrochemical regime of Karelian lakes, clean water bodies being subject to human impact, is the wide range of pH variability (from 4.2 to 7.5), variability of ion amount (5 to 200 mg/L) and the colour of water (from 5° to 300° of Pt-Co scale) (Catalogue ..., 2001).

Long-term studies of the phytoplankton floristic composition, ecological features and indicator properties of individual algae species in different types of Karelian lakes have revealed organisms that can be used as indicators of salinity level, acidification, organic pollution and eutrophication, and also agents of water bloom (Table 6).

Despite the fact that Karelian lakes have very low concentration of dissolved salts, there are also some halophilic species (*Nitzschia sigma* (Kütz.) W. Sm., *Navicula radiosa* Kütz., *N. cryptocephala* Kütz., *Cocconeis pediculus* Ehrenb., *Synedra capitata* Ehrenb., *Rhopalodia gibba* (Ehrenb.) O. Müll.) along with dominating indifferent oligohalobe species.

Most water bodies of Karelia are characterized by the predominance of aquatic species indifferent to the acidity with a significant proportion of acidophilic forms preferring lakes with low pH values. Among acidity indicating species there were many species of golden algae (genera *Dinobryon*, *Mallomonas*, *Synura*) along with diatoms (*Frustulia rhomboides* (Ehrenb.) D.T., *Eunotia robusta* var. *diadema* (Ehrenb.) Rolfs., *E. praerupta* Ehrenb.). Anthropogenic eutrophication of some Karelian lakes in recent decades occurs due to enrichment of waters with nutrient elements (mainly phosphorus) and can be observed primarily as "blooming" of lake water as a result of abundant *Cyanophyta*: *Microcystis aeruginosa* Kütz. (Elenkin) f. *aeruginosa*, *Aphanizomenon flos-aquae* Ralfs f. *flos-aquae*, *Gloeotrichia echinulata* (J.E. Sm.) P.G. Richt., *Woronichinia naegeliana* (Unger) Elenkin f. *naegeliana*, *Aphanothece clathrata* W. et G.S. West f. *clathrata*, a number of species of genera *Anabaena* Bory (24) and *Oscillatoria* Vaucher, as well as raphidophyte alga *Gonyostomum semen* (Ehrenb.) Diesing.

The water quality or degree of organic water pollution in surveyed Karelian lakes is estimated using saprobity indicator species. Most of them belong to oligo-, oligo-β- and β-mesosaprobic forms. Xenosaprobes, or indicator species of pure waters are rather scarce. They are mainly represented by diatoms: *Achnanthes lanceolata* Bréb. in Kütz. var. *lanceolata*, *Ceratoneis arcus* (Ehrenb.) Kütz. var. *arcus*, *Cymbella helvetica* Kütz., *Eunotia lunaris* (Ehrenb.) Grun. in V.H., *Meridion circulare* (Grev.) Agardh. Species characterizing more severe pollution are also few in the phytoplankton (β-α- and α-saprobic conditions). They are the representatives of the *Cyanophyta* (*Oscillatoria sancta* (Kütz.) Gomont f. *sancta*, *O. splendida* Grev., *O. tenuis* Agardh), green (*Chlamydomonas incerta* Pascher, *Ch.*

reinhardii Dang., *Gonium pectorale* O. Müll.), *Euglenophytes* (*Euglena caudata* Hübner, *E. polymorpha* Dang.), diatoms (*Stephanodiscus hantzschii* Grun. in Cl. et Grunow f. *hantzschii*, *Nitzschia acicularis* (Kütz.) W. Sm.) algae.

TABLE 6. Indicator species of environmental conditions in the water bodies of the Republic of Karelia

Indicators of pure waters	Indicators of acidated waters
Ceratoneis arcus	*Frustulia rhomboides*
Meridion circulare	*Eunotia robusta* var. *diadema*
Aulacoseira distans var. *alpigena*	*E. praerupta*
Eunotia pectinalis	*E. praerupta* var. *bidens*
Navicula rotaeana	*E. pectinalis*
Cymbella helvetica	*E. pectinalis* var. *ventralis*
Achnantches lanceolata	*E. lunaris*
	E. arcus
	E. elegans
	E. bigibba
	E. faba
Indicators of organic pollution	**Indicators of hig mineralization**
Oscillatoria sancta	*Nitzschia sigma*
O. splendida	*Navicula radiosa*
O. tenuis	*N. cryptocephala*
Chlamydomonas incerta	*Cocconeis pediculus*
Ch. reinhardii	*Synedra capitata*
Gonium pectorale	*Rhopalodia gibba*
Euglena caudata	**Indicators of higher water trophy and agents of water bloom**
E. polymorpha	
Stephanodiscus hantzschia	*Aphanothece clathrata*
Nitzschia acicularis	*Microcystis aeruginosa*
Cryptomonas ovata	*Aphanizomenon flos-aquae*
C. obovata	*Anabena lemmermanii*
C. marssonii	*A. spiroides*
C. reflexa	*Gloeotrichia echinulata*
C. rostrata	*Volvox globator*
Chroomonas acuta	*Tribonema affine*
Ch. breviciliata	*Eudorina elegans*
Planctococcus sphaerocystiformis	*Ankistrodesmus arcuatus*
	Monoraphidium contortum
	Gonyostomum semen

At the same time, β-mesosaprobic species of *Cryptophytae* from the genera *Chroomonas* Hansg. and *Cryptomonas* Ehrenb. in polysaprobic zone, located usually near the pollution source, may have a significant number of their populations and can be good pollution indicators.

CONCLUSIONS

We studied the composition and distribution peculiarities of algal flora in various water bodies of the Republic of Karelia. We obtained the first results of algal flora inventory of water bodies of the Republic.

Systematic analysis of the flora showed that the lake algal flora of the Republic of Karelia combines features of boreal and central European type. Algae species diversity is determined by diatoms, blue-green, green and golden algae. They represent more than > 90% of floristic checklist.

Phytoplankton and phytoperiphyton of Karelian lakes and rivers is characterized by the predominance of cosmopolitan forms (73%), with significant proportion of boreal (16%) and north-Alpine (11%) species, indicating its psychrophilic character.

Ecological and geographical analysis of algal flora showed that the species indifferent to salinity and active environmental reaction dominate in the water bodies.

Most saprobic indicator species belong to oligo-β-oligo and β-mesosaprobic forms. The identified species can be regarded as illustrative in assessing the level of salinity, acidification, organic pollution and eutrophication. Analysis of water quality in surveyed lakes and rivers using indicator organisms revealed β-mesosaprobic nature of their waters, which allowed to assign them to the category of completely clean or slightly polluted.

Our research can not be considered definitive, because we studied the flora of less than 1% of the total number of reservoirs and water bodies of the Republic of Karelia.

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Freshwater Algae as Potential Source of Polyunsaturated Fatty Acids: Review*

R.A. BHOSALE[1] & B.B. CHAUGULE[2]
[1]*corresponding author*

[1] *Institute of Bioinformatics and Biotechnology (IBB), University of Pune,*
Pune-411 007, Maharashtra, India
e-mail: rahul.bibb1987@gmail.com
Present address:
VIB Department of Plant System Biology, University of Ghent,
Technologiepark 927, Ghent-9000, Belgium
[2] *Department of Botany, University of Pune Ganeshkhind,*
Pune-411 007, Maharashtra, India
e-mail: chaugule@unipune.ernet.in

ABSTRACT

Polyunsaturated fatty acids form an elite class of food constituents that exhibit large spectrum of crucial functions in biological systems. Investigations over the past two decades have revealed their roles and those of their eicosanoid metabolites, and have highlighted their homeostatic functions in mammals. A growing interest in the nutritional and pharmaceutical importance of polyunsaturated fatty acids (PUFAs) has created an increasing demand for purified PUFAs. As the traditional sources are inadequate for fulfilling this demand, alternative sources are being sought. Algae are a great source of highly valuable products and they are considered as potential alternative for the large scale production of PUFAs. Various investigations have been actively carried out for screening of potential microalgal strains and development of feasible culture techniques for the commercial production of these vital compounds. In this review, we provide the combined information from various reports on freshwater algae as source of important PUFAs. This review recommends the freshwater algae over marine algae as an uncontaminated source of PUFAs.

KEYWORDS: freshwater algae, microalgae, macroalgae, PUFAs, ω-3, ω-6, polyunsaturated fatty acids.

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INTRODUCTION

Fatty acids and oils are vital for the growth and survival of all organisms. Lipids are important structural components of membranes and, in many organisms, play a crucial role in energy storage. Natural sources of lipids include plants, animals and microorganisms (Sijtsma & Swaaf, 2004). Plant and animal oil are very well known for their application in nutrition. Plant oils are relatively cheaper and healthier than animal fats, due to their relatively high amounts of unsaturated fatty acids. But last some decades, the interest in some specific animal oils; the long-chain polyunsaturated fatty acids (PUFAs), as present in fish oils has increased considerably, due to their favourable effects on human health. But their are some limitations of using fish oil for PUFA production include the undesirable fishy flavour of such products, the oxidative instability of fish oil and the difficulties of producing concentrates of the individual fatty acid from raw material (Yongmanitchai & Ward, 1989). In addition, fish oil may be contaminated by pesticides and heavy metals due to environmental pollution. It also contains substantial amounts of undesirable fatty acids and cholesterol. Long chain PUFAs are also not produced by fish due to lack of respective enzymes so studies are turned to the primary producers of long chain PUFAs. As a result, alternative sources of high quality long chain PUFAs have been sought to meet the future demand (Bhosale et al., 2009).

In aquatic ecosystems, algae are the primary producers and serve as feed for grazing zooplankton, fish and other animals. Many studies have been undertaken on the occurrence of specific chemical compounds in algae, viz. amino acids, polysaccharides, fatty acids, sterols, volatile constituents and vitamins (Graham & Wilcox, 1999). Due to their high nutritional value, several studies concerning the fatty acid composition of the different classes of freshwater and marine algae have been undertaken. Again, on account of accumulation of heavy metals and pesticides by marine algae due to environmental pollution, studies are further concerted to the freshwater algae. The cold water inhabiting algae have a potential to serve as a source of long chain PUFAs. It is also possible to cultivate them on artificial substratum such as nylon nets as they reproduce asexually by monospores (Bhosale et al., 2009).

This review first summarizes classification of algae and fatty acids. It then discusses the significance and metabolism of PUFA. Further it discusses the other different sources of PUFA and how freshwater algae are potential source of PUFAs. Finally it concludes the strategies to improve the production of PUFAs using freshwater algal biomass to fulfil the demand of PUFAs.

Classification

Algae

In general, algae are organisms that include seaweeds and a number of single-celled and multicellular microscopic forms. Algae are omnipresent; they dwell in oceans, freshwater bodies, rocks, soils and trees. There may be over 50,000 algal species on the earth. Some algae are used as source of food but in recent decades, there has been renewed interest in the consumption of algae as sources of health food and high value chemicals and pharmaceuticals, and for an aquaculture, agriculture and wastewater management (Yap & Chen, 2001). Algae can be classified in main two broad categories that are marine algae and freshwater algae. The can be further divided into two types, such as microalgae and macroalgae. They are further classified on the basis of pigment which they have. The classifications of algae are represented in Figure **1**.

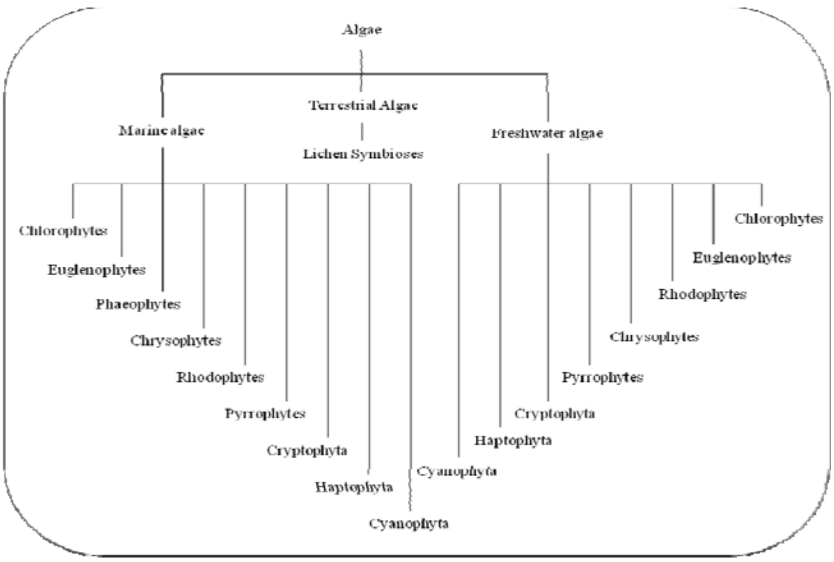


Figure **1**. Classification of algae

Fatty acids

The three main types of fatty acids encountered, in variable concentrations, in food are: (1) saturated fatty acids (SFA) (2) monounsaturated fatty acids (MUFA), and (3) polyunsaturated fatty acids (PUFA). PUFAs are classified mainly into four families designated ω-3, ω-6, ω-7, ω-9 (Figure **2**). The ω-3 and ω-6 families of fatty acids predominate in plants and animals (Yap & Chen, 2001). Saturated and monounsaturated types of fatty acids are synthesised endogenously both by animals and plants, while the third is produced only by plants and therefore needs to be supplied exogenously in animals (Patil & Gislerod, 2006). Among the fatty acids, PUFA have beneficial effects such as reducing coronary heart disease risk and blood cholesterol, thus reducing the risk of arterio-sclerosis, inflammation and several carcinomas (Ginzberg et al., 2000; Guil-Guerrero et al., 2001).

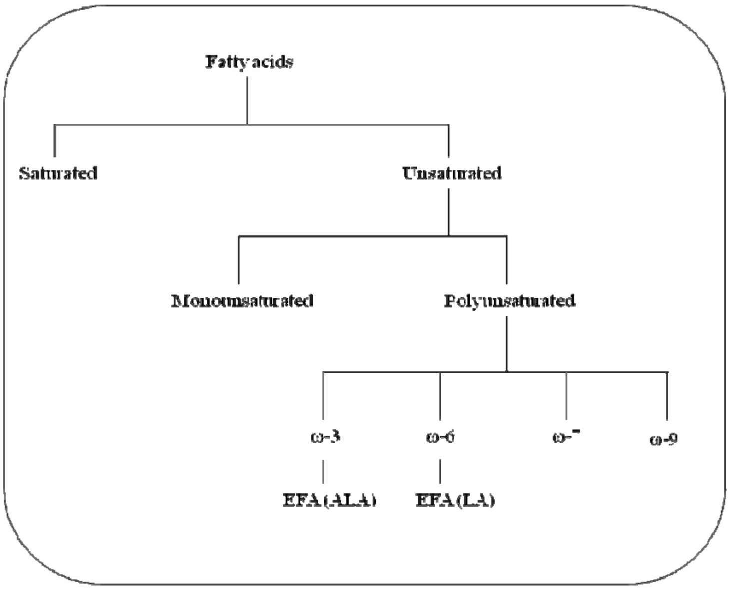


Figure **2**. Classification of fatty acids

Polyunsaturated fatty acids (PUFAs)

Long-chain PUFAs are composed of a long hydrocarbon chain (18 or more carbon atoms) and a terminal carboxylate group having two or more double carbon bonds. They are classified according to the position of the first double bond, as counted from the methyl terminus. A so-called ω-3 PUFA has its first double bound at position 3, as counted from the methyl terminus. Other PUFA groups are ω-6, where the first double bond is located six carbons from the methyl terminus, ω-7, where the first double bond is located seven carbons from the methyl terminus and ω-9, where the first double bond is located nine carbons from the methyl terminus. As a synonym of ω, the symbol 'n' is often used to classify PUFAs. Double bonds in PUFAs may also be counted from the carboxylate group and are then represented by the symbol Δ (Sijtsma & Swaaf, 2004).

Table 1 represents several ω-3 PUFAs and their uses. α-Linolenic acid (ALA,18:3 Δ9,12,15), eicosapentaenoic acid (EPA, 20:5 Δ5,8,11,14,17) and docosahexaenoic acid (DHA, 22:6 Δ4,7,10,13,16,19) are the most studied PUFAs within this group and their chemical structures are shown in Figure **3**. In Table 2 several ω-6 PUFAs and their uses are listed. Linoleic acid (LA, 18:2 Δ9,12), γ-Linolenic acid (GLA, 18:3ω-6) and arachidonic acid (AA, 20:4 Δ5,8,11,14) and their chemical structures are shown in Figure **4**.

PUFA Metabolism

It has long been accepted that LA and ALA are converted in the liver to their respective LCPUFA, namely, AA and DHA. However, the complexities of the synthetic pathway are still the subject of many investigations. Initially it was proposed that both animals and man converted the 18 carbon PUFA to LCPUFA through a simple series of desaturation (adding a double bond each time) and elongation (adding 2 carbons each time) steps in the endoplasmic reticulum. While this still holds true for LCPUFA with 20 carbons, such as AA and eicosapentaenoic acid (EPA, 20:5n-3), work from a number of laboratories has demonstrated that the final few steps in the synthesis of the terminal 22 carbon LCPUFA containing 5 and 6 double bonds, such as DHA, involves a complex process that occurs in the peroxisomes of the liver (Gibson & Makrides, 1998).

TABLE 1. List of some ω-3 PUFAs and their uses

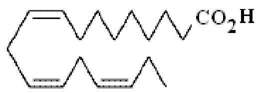
Fatty acids	Uses and functions
α-Linolenic acid (ALA,18:3 Δ9,12,15)	Lower risk of cardiovascular disease, neuroprotective effect, prevention and treatment of cachexia and anorexia, use in the treatment of breast cancer. In the form of free fatty acids, glycerides and phospholipids they used for health products, drug delivery, therapeutics, etc. Food flavours and aromas, fragrances. Agrochemicals, antifungal, antibacterials, plant growth regulators.
Eicosapentaenoic acid (EPA, 20:5 Δ5,8,11,14,17)	Cardiovascular health, autoimmune diseases, growth and development, positive effects on lung and kidney diseases, type II diabetes, obesity, ulcerative colitis, Crohn's disease, burns, anorexia nervosa, osteoporosis, osteoarthritis, attention deficit/hyperactivity disorder, and early stages of colorectal cancer.
Docosahexaenoic acid (DHA, 22:6 Δ4,7,10,13,16,19)	Attention-Deficit Hyperactivity Disorder (ADHD) reduces symptoms of depression positive effects on existing heart disease, infant development, reduce symptoms and inflammation associated with rheumatoid arthritis, reduce the pain of menstrual cramps, can reduce sensitivity of the fingers and toes to cold in Raynaud syndrome, and reduce fatigue and joint pain associated with lupus.

Abbreviations: SFA – saturated fatty acids, EFA – essential fatty acid, MUFA – monounsaturated fatty acids, PUFA – polyunsaturated fatty acids, LCPUFA – long chain polyunsaturated fatty acid, ω-3 – omega-3, ω-6 – omega-6, LA – linoleic acid, ALA – alpha linolenic acid, GLA – gamma linolenic acid, AA – arachidonic acid, EPA – eicosapentanoeic acid, DHA – docosahexaenoic acid.

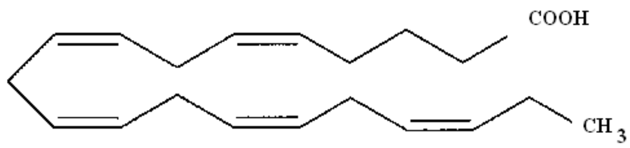
Metabolic pathways of ω-3 and ω-6 fatty acids

The ω-3 and ω-6 fatty acids share the same pools of enzymes and go through the same oxidation pathways while being metabolized (Figure **5**). Their biosynthesis is represented in Figure **6**. Once ingested, ALA and LA can be elongated and desaturated into LC PUFAs. LA is converted into gamma-linolenic acid (GLA, 18:3 n-6), an omega-6 fatty acid that is a positional isomer of ALA. GLA, in turn, can be converted to the long-chain omega-6 fatty acid, arachidonic acid (AA, 20:4 n-6). ALA can be converted, to a lesser extent, to the long-chain omega-3 fatty acids, eicosapentaenoic acid (EPA; 20:5 n-3) and docosahexaenoic acid (DHA; 22:6 n-3).

α-Linolenic acid (ALA, 18:3ω3)



Eicosapentaenoic acid (EPA, 20:5ω3)



Docosahexaenoic acid (DHA, 22:6ω3)

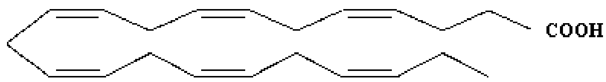


Figure **3**. Structures of ω-3 PUFAs

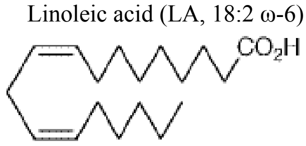
Significance of polyunsaturated fatty acids

Biological Role

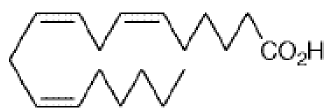
Polyunsaturated fatty acids are structural components of cell and organelle membranes. They are very important in regulation of membrane structure, fluidity, phase transitions and permeability and various membrane associated processes. PUFAs perform many vital functions in biological membranes and serves as a precursor of a variety of lipid regulators in cellular metabolism (Nettleton, 1995; Gill & Valivety, 1997). Also in plants they perform very crucial role. PUFAs are converted by a variety by a variety of enzymes to various oxygenated compounds, acting as anti-infectives, wound-response mediators, chemotactic agents, aroma, and flavour compound. In lower animals, PUFA derived metabolites, mediate cellular processes and ecological responses including metamorphosis, reproduction, chemotaxis and immune function (Gill & Valivety, 1997).

In higher animals, long chain PUFAs are precursors of a diverse series of oxygenated fatty acids termed ‘eicosanoids’ that are very crucial to the development and proper maintenance of homeostasis (Hwang, 2000). Among the most important properties of eicosanoids are cytoprotective effects, modulation of renal function, mediation allergic and inflammatory reactions, induction and inhibition of thrombotic processes and regulation of smooth muscle cell tone leading, for example, to vaso- and broncho-constriction or broncho-relaxation and to the postnatal closure of the ductus arteriosus Botalli (Sellmayer & Koletzko, 1999). Apart from being intercellular mediators, arachidonic acid and eicosanoids also have been identified as novel intracellular second messenger in inflammatory and mitogenic signaling (Kahn et al., 1995) The eicosanoids derived from EPA and AA in humans including prostaglandins, prostacyclins, thromboxanes and leukotrienes are produced through two main pathways; cyclo-oxygenase and lipooxygenase pathways, each is catalyzed by a distinct group of enzymes.

Linoleic acid (LA, 18:2 ω-6)



γ-Linolenic acid (GLA, 18:3ω-6)



Arachidonic acid (AA, 20:4ω-6)

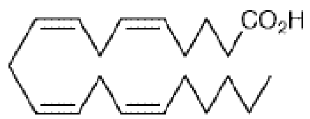


Figure **4**. Structures of ω-6 PUFAs

Linolenic and α-linolenic acid: essential fatty acids

Higher animals lack Δ12 and Δ15 desaturase so they are unable to produce fatty acids over C18 so indirectly they cannot form linoleic acid (LA, 18:2n-6 Δ9,12) and α-linolenic acid (ALA, 18:3n-3 Δ9,12,15). LA and ALA are hence considered to be essential fatty acid (EFA) and must be obtained from the diet, as they are the precursors of ω-3 and ω-6 families of PUFA.

Soybean, mustard, canola, flax and perilla are sources of *a*-linolenic acid, while sunflower, safflower, groundnut and sesame are rich in linoleic acid. Deficiency of LA in diets and unusual ratios of LA and ALA induce changes in the PUFA composition of neuronal and glial membranes which leads to changes in retina and brain functions (Fernstorm, 1999). LA paucity may also lead to skin lesions (Gurr, 1999).

TABLE 2. List of some ω-6 PUFAs and their uses

Fatty acids	Uses and functions
Linoleic acid (LA, 18:2 Δ9,12)	One of the two classes of essential fatty acids growth and development of infants help to maintain the health of cell membranes, improve nutrient use, and establish and control cellular metabolism provide the raw materials that help in the control of blood pressure, blood clotting, inflammation, body temperature, and other body functions helps in the absorption, and transport through the bloodstream, of the fat-soluble vitamins A, D, E, and K.
γ-Linolenic acid (GLA, 18:3)	Helps in prevention of diabetes, is beneficial in dry-eye conditions such as Sjögren's syndrome, protective against osteoporosis, menopausal symptoms, premenstrual syndrome, eczema, allergies, rheumatoid arthritis, attention deficit/hyperactivity disorder (ADHD), help to lessen cravings for alcohol and prevent liver damage, against breast cancer, to prevent the development of heart disease and ulcers.
Arachidonic acid (AA, 20:4 Δ5,8,11,14)	Precursor in the production of eicosanoids: the prostaglandins, thrombo-xanes, prostacyclin and the leukotrienes, aggregates platelets, and stimulates white blood cells, important structural components of the central nervous system, are considered essential for pre- and post-natal brain and retinal development, biosynthesis of anandamide- and neurotransmitter.

TABLE 3. Conventional sources of PUFAs (Gill & Valivety, 1997)

Fatty acid	Conventional sources	% composition
ω-3	Fatty fish: salmon and tuna, fish oil, Flaxseed, canola oil, and walnuts	-
ω-6	Meats from animals, corn, safflower, sunflower, and cottonseed oils	-
ALA	Plants: *Brassica*, Glycine, *Juglans*, *Linum* spp.	4-21
GLA	Plants: *Oenothera*, *Borage*, *Ornithogalum* spp.	1.3-7.6
AA	Fish: *Brevoortia*, *Clupea*, *Sardina* spp.	0.2-0.6
	Animal tissues	0.1-0.3
EPA	Fish: *Brevoortia*, *Engraulis*, *Sardina*, *Scomber* spp.	1.7-6.2
DHA	Fish: *Brevoortia*, *Engraulis*, *Sardina*, *Scomber* spp.	1.6-7.4

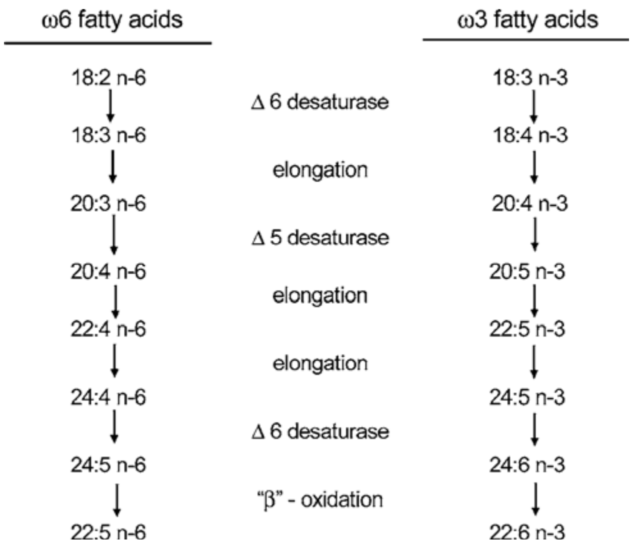


Figure **5**. Metabolic pathways of ω-3 and ω-6 fatty acids (Heird & Lapillone, 2005)

TABLE 4. Alternative sources of PUFAs (Gill & Valivety, 1997)

Fatty acid	Alternative sources	% composition
ω-3	Algae, fungi, mosses, bacteria	-
ω-6	Algae, fungi, mosses, bacteria	-
ALA	Algae: *Chlorella* spp.	0.9-1.7
GLA	Fungi: *Mucor*, *Mortierella*, *Aspergillus* spp.	3.6-4.5
	Algae: *Chlorella* and *Spirulina* spp.	0.6-1 .6
AA	Fungi: *Pythium*, *Mortierella* spp.	3.4-6.3
	Algae: *Porphyridium* spp.	1.6-3.6
	Mosses: *Rhytidiadelphus*, *Brachythecium*, *Eurhynchium* spp.	0.7-2.4
EPA	Fungi: *Mortierella*, *Pythium* spp.	2.9-6.4
	Algae: *Chlorella*, *Monodus*, *Porphyridium*, *Nannochlorops*, *Cryptoleura*, *Schizymenia*, *Navicula* spp.	1.8-4.8
	Mosses: *Brachythecium*, *Eurhynchium*, *Scleropodium* spp.	0.7-3.1
	Bacteria: *Rhodopseudomonas*, *Shewanella* spp.	0.6-1.7
DHA	Fungi: *Jhraustochytrium*, *Entomophthora* spp.	0.9-1.5
	Algae: *Gonyaulax*, *Gyrodinium*, *Cryptoconidium* spp.	2.7-4.1
	Bacteria**:** *Rhodopseudomonas* spp.	0.6-1.1

TABLE 5. PUFA content of marine microalgae and macroalgae

Species	Total PUFA %	LA (18:2n6)	ALA (18:3n3)	GLA (18:3n6)	AA (20:4n6)	EPA (20:5n3)	DHA (22:6n3)
Ulva rotundata[5]	57.2	2.6	15.9	0.1	0.3	0.7	-
Enteromorpha intestinalis[5]	56.9	9.6	16.8	0.6	1.2	2.0	-
Lambia antarctica[6]	60.8	22.3	23.7	-	5.2	5.0	0.9
Prasiola crispa[6]	45.7	6.3	26.1	-	2.4	8.4	-
Laminaria saccharina[5]	35.2	6.2	4.2	1.2	12.0	4.8	-
L. digitata[5]	44.4	7.5	9.5	0.7	4.9	8.2	-
L. solidungula[6]	5.7-8.8	9.8-11.3	-	8.1-12.5	17.6-25	-	
Desmarestia muelleri[6]	5.2-10.1	11.4-24.8	-	10.4-14.6	13.2-21.8	-	
D. antarctica[6]	3.6	8.0	-	14.6	25.4	-	
Fucus vesiculosus[5]	30.6	10.5	5.0	0.6	6.0	4.0	-
Undaria pinnatifida[5]	67.5	9.1	25.5	0.9	13.3	7.2	-
Halidrys siliquosa[5]	32.9	6.3	4.4	4.4	11.3	3.8	-
Porphyra umbilicalis[5]	68.8	3.0	0.3	0.4	16.5	42.2	-
Chondrus crispus[5]	35.7	2.1	1.4	0.4	17.9	12.8	1.1
Palmaria palmata[5]	49.1	1.7	2.1	0.2	2.3	41.2	-
Gracilaria verrucosa[5]	25.5	3.8	3.1	0.3	5.1	10.7	-
Ulva fenestrata[1]	50.8-60.1	9.8-10.1	16.8-16.9	0.9-1.3	0.8-1.9	1.4-1.5	1.6-3.4
Costaria costata[1]	28.1-40	8.9-9.0	1.8-4.0	1.2-2.2	9.5-13.0	3.3-6.6	-
Grateloupia turuturu[1]	49.3-54.1	1.4-1.9	-	0.4-0.8	19.5-23.9	22.6-30.4	-
Undaria pinnatifia[2]	73.7	7.41	11.2	1.71	13.3	-	-
Hizikia fusiforme[2]	57	3.56	0.41	0.42	5.30	0.09	-
Himanthalia elongata[4]	38.16	4.39	8.79	-	10.69	5.50	-
Phycodrys rubens[6]	42.4	0.5	-	-	35.3	4.8	0.3
Ptilota gunneri[6]	18.1	2.6	0.4	-	0.9	9.4	0.6
Delesseria lancifolia[6]	36.8	0.3	-	-	31.1	4.4	1.0
Georgiella confluens[6]	62.6	0.7	1.2	-	1.9	40.9	1.3
Myriogramme smithii[6]	63.0	1.7	-	-	13.0	48.3	-
Neuroglossum ligulatum[6]	46.8	1.7	-	-	7.7	35.3	1.5
Pantoneura plocamioides[6]	52.2	0.6	-	-	12.6	25.9	-
Devaleraea ramentacea[6]	43.3	3.4	4.1	-	0.6	24.2	1.6
Palmaria palmata[6]	68.9	0.5	-	-	-	67.3	0.7
P. decipiens[6]	53.7	0.4	0.2	-	-	49.8	0.5
Gymnogongrus turquetii[6]	60.0	3.6	-	-	-	44.3	0.5

End of Table 5

Gigartina skottsbergii[6]	49.4	0.7	-	-	-	25.2	-
Audouinella purpurea[6]	70.4	0.6	-	-	-	60.3	-
Rhodymenia subantarctica[6]	20.4	0.9	1.1	-	-	10.8	-
Hymenocladopsis crustigena[6]	54.8	3.4	0.8	-	-	37.3	0.5
Laminaria ochroleuca[4]	46.94	6.79	5.15	-	14.20	8.62	-
Undaria pinnatifida[4]	69.11	6.23	11.97	-	15.87	9.43	-
Nereocystis luetkeana[3]	57.11	5.96	7.57	-	16.77	12.58	-
Porphyra perforata[3]	42.86	2.16	2.97	-	6.74	14.33	-
Fucus distichus[3]	42.01	11.03	4.94	-	11.72	6.43	-
Pterigophora sp.[3]	60.41	5.44	9.62	-	9.63	14.67	-
Ulva fenestrata[3]	54.59	3.67	24.07	-	1.11	3.39	-
Gloiopeltis furcata[3]	7.15	1.03	-	-	-	1.86	1.06
Callophylis sp.[3]	28.03	0.56	-	-	-	5.68	4.19
Choiopelsis fenax[3]	35.56	1.17	-	-	-	9.74	6.22
Soliera robusta[3]	18.42	7.78	-	-	-	0.95	0.68

1 – Hotimchenko, 2002; 2 – Dawczynski et al., 2007; 3 – Colombo et al., 2006; 4 – Sanchez-Machado et al., 2004; 5 – Fleurence et al., 1994; 6 – Graeve et al., 2002.

Significance of ω-3 PUFAs: EPA and DHA

The therapeutic significance of ω-3 polyunsaturated fatty acids (PUFAs) such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) has been clearly indicated by recent clinical and epidemiological studies (Simopoulos et al., 1991; Dervon et al., 1993). EPA performs many vital functions in biological membranes and serves as a precursor of a variety of lipid regulators in cellular metabolism (Nettleton, 1995; Gill & Valivety, 1997). These findings have led to considerable interest in developing commercial processes for EPA production (Belarbi et al., 2000; Molina Grima et al., 2003). DHA recently attracted much attention because of its various physiological functions in the human body. DHA is an essential component of cell membranes in some human tissues and, for instance, accounts for over 60% of the total fatty acids in the rod outer segment in the retina (Giusto et al., 2000). Furthermore, DHA is regarded to be essential for the proper visual and neurological development of infants, because of its role as a structural lipid component (Nettleton, 1993; Crawford et al., 1997; Das & Fams, 2003). As pre-term and young infants are unable to synthesize DHA at a rate fast enough to keep up with the demand from the rapidly growing brain (Crawford, 1987), they should obtain these compounds from their diet. In general, breast-feeding serves as a good source of PUFAs

TABLE 6. PUFA content of some freshwater microalgae and macroalgae

Division	Class and species	Total PUFA	LA (18:2n6)	ALA (18:3n3)	GLA (18:3n6)	AA (20:4n6)	EPA (20:5n3)	DHA (22:6n3)
		%						
Chlorophyta	**Chlorophyceae**							
	Chlamydomonas[3]	34.3-35.1	4.9-7.0	24.2-26.9	-	-	0.7-0.9	-
	Pseudokirchneriella subcapitata[4]	21.7	5.1	11.4	-	-	-	0.1
	Tetraselmis sp.[4]	18.6	2.5	6.4	-	0.6	4.8	0.2
	Scenedesmus obliquus[5]	7.8-39.25	0.08-0.81	4.53-27.08	0.07-1.90	0.08-0.92	0.07-1.66	-
	Chlorella[3]	42.6-47.0	9.2-12.1	28.1-28.9	1.4-1.8	-	-	-
	Pseudodictyosphaerium jurisii[6]	3.78	0.85	0.77	0.08	0.14	0.15	0.15
	Chlorella vulgaris[6]	2.33	0.40	0.13	0.07	0.09	0.02	0.10
	Scenedesmus obtusiusculus[6]	12.64	0.80	3.17	0.09	0.68	0.30	0.75
	Monoraphidium braunii[7]	6.86	1.17	0.56	0.12	0.78	0.02	0.02
	Parietochloris incisa[8]	66	17	2	1	43	1	-
	Trebouxiophyceae							
	Oocystis sp.[4]	16.8	6.4	8.1	-	0.5	1.1	–
	Choricystis minor[6]	5.44	0.90	1.80	0.04	0.14	0.04	0.22
Haptophyta	**Prymnesiophyceae**							
	Isochrysis galbana[4]	39.9	7.0	3.8	-	-	0.8	15.8
	Isochrysis sp. (PSI 1)[2]	41.8-57.0	1.7-2.4	4.1-6.1	2.0	-	0.5-1.1	6.0-9.0
	Isochrysis sp. (T.ISO)[2]	52.2-63.7	2.9-4.8	4.9-5.9	0.9-2.5	-	0.7-1.3	7.5-11.4
	Pavlova sp.[4]	39.8	2.1	1.8	-	0.4	18.0	13.2

Heterokontophyta	**Bacillariophyceae**							
	Nitzschia paleacea[2]	48.7-61.5	1.2-1.9	0.5-1.1	0.1-1.3	0.2-1.2	18.1-28.4	0.6-1.2
	N. closterium[2]	27.4-35.9	0.6-0.9	0.3-0.6	0.7-1.3	2.1-2.7	6.5-8.3	0.1-0.4
	Phaeodactylum tricornutum[4]	37.2	1.5	0.3	-	2.2	28.4	0.2
	Eustigmatophyceae							
	Nannochloropsis limnetica[6]	39.10	3.83	0.37	0.18	5.26	0.08	0.06
	N. oceanica[4]	37.8	9.7	0.5	-	3.7	23.4	–
Cryptophyta	**Cryptophyceae**							
	Rhodomonas baltica[4]	33.7	11.7	12.0	-	0.2	4.4	–
	Rhodomonas[3]	59.6-68.9	0.9-1.4	20.8-21.3	-	-	11.0-15.8	3.6-4.5
Cyanophyta	**Cyanophyceae**							
	Synechococcus[1]	23-61	1-43	1-10	3-16	-	-	-
Rhodophyta	**Florideophyceae**							
	Sirodotia spp.[7]	31.45-40.37	0.15-3.85	0.26-3.25	0.36-6.62	1.48-2.16	1.05-3.02	3.72-10.63
	Porphyridiophyceae							
	Porphyridium cruentum[4]	14.5	2.1	-	-	6.0	6.1	–

1 – Kenyon et al., 1972; 2 – Renaud et al., 1995; 3 – Ahlgren et al., 1992; 4 – Patil et al., 2007; 5 – Makulla, 2000; 6 – Krienitz & Wirth, 2006; 7 – Bhosale et al., 2009; 8 – Bigogno et al., 2002.

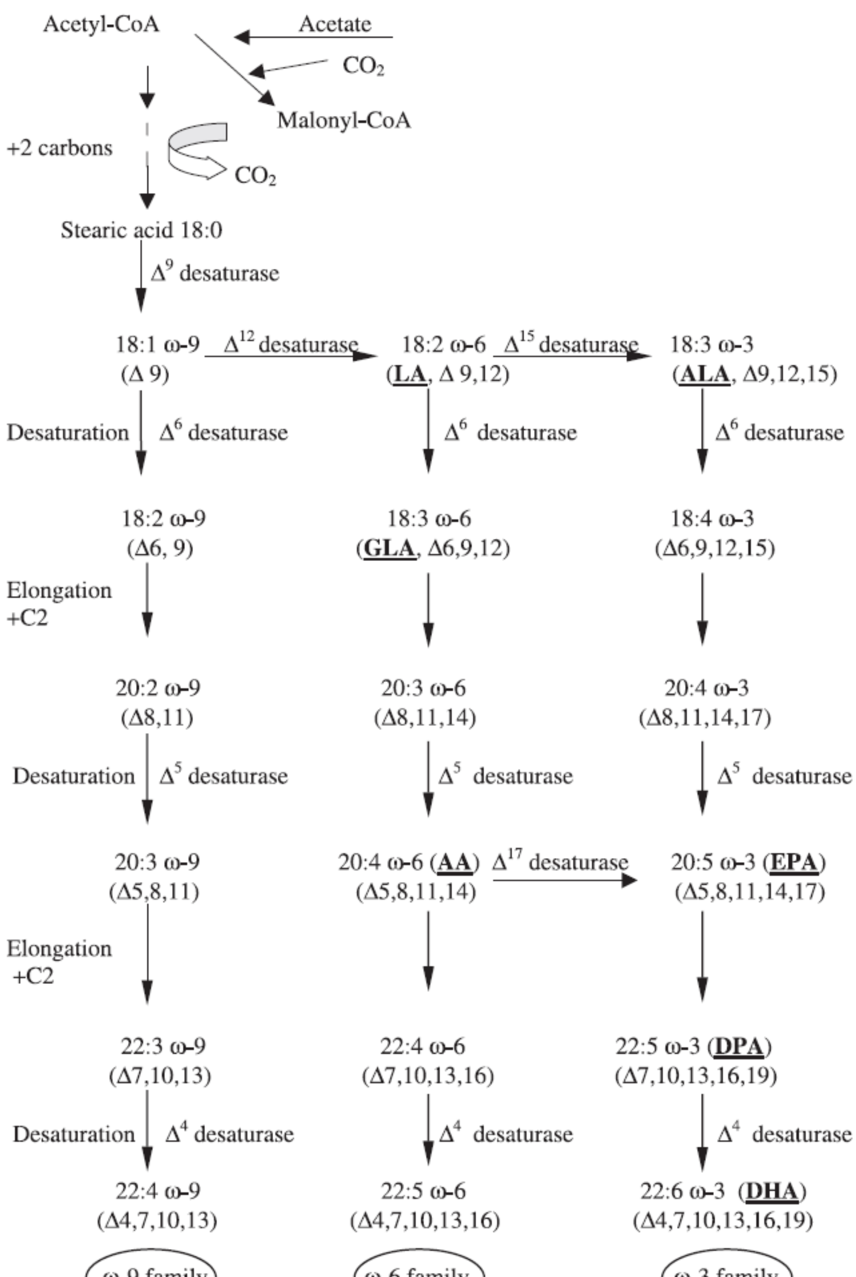


Figure **6**. Biosynthesis of polyunsaturated fatty acids (Wen & Chen, 2003)

(Huisman et al., 1996). However, although it was recommended that all infant formulas include DHA (FAO/WHA Expert Committee 1994), the application of DHA in some infant formulas only started recently. In addition, DHA reduces or inhibits risk factors involved in various diseases like cardiovascular diseases (Kromann & Green, 1980; Kang & Leaf, 1996; Nordøy et al., 2001) and has some positive effects on diseases such as hypertension, arthritis, arteriosclerosis and thrombosis (Horrocks & Yeo, 1999).

Significance of ω-6 PUFAs: AA and GLA

The position of the double bond in the fatty acids strongly affects the properties of its derivatives. For instance, eicosanoids derived from the ω-6 PUFA arachidonic acid (20:5 Δ5, 8,11,14) have strong inflammatory properties, whereas those produced from eicosapentaenoic acid are anti-inflammatory (Gill & Valivety, 1997). GLA is converted from its parent acid LA by Δ6 desaturase and provides a substrate for further desaturation and elongation reactions yielding the precursors of eicosanoids.

Sources of PUFA

Conventional sources

Main sources of LA, ALA and GLA are oils of selected plant seeds and AA, EPA, DHA are oils obtained from certain marine fish. Fishes such as salmon, sardine, mackerel, menhaden, anchovy and tuna are preferably used for fish oil production as their flesh usually contains a high proportion of fat tissues (up to 20-30% of fatty acids). The composition and content of fatty acids in fish oils are subject to seasonal and climatic variations, and also depends upon species of fish and geographical locations of catching sites (Yap & Chen, 2001). In addition, fish oil may be contaminated by pesticides and heavy metals due to environmental pollution. It also contains substantial amounts of undesirable fatty acids and cholesterol. However, safety issues concerning the contamination levels of various toxins that accumulate in fish and concentrate in fish oils have been raised repeatedly. As a result, alternative sources of high quality long chain PUFAs have been sought. Therefore alternative sources of PUFAs are now being exploited. Table 3 and 4 lists examples of conventional and alternative sources of PUFA respectively.

Alternative sources of PUFA

Fish do not synthesize long-chain n-3 fatty acids in significant quantity. They acquire these fatty acids through their diet by consuming marine zooplankton that has fed on phytoplankton. Phytoplankton such as bacteria, lower fungi, microalgae and some microalgae-like organisms are known as the primary producers in the marine food chain. They are the actual primary synthesizers of PUFAs. PUFAs accumulate in the food chain and are eventually incorporated into fish oils. These microorganisms, especially microalgae have been recognized as an alternative source of PUFAs because they contain the enzymatic systems for synthesizing the entire range of PUFAs. In addition, marine microalgae are considered as main producers as fish oil are considered as main source of PUFAs. Many studies have been undertaken on the occurrence of specific chemical compounds in algae, viz. amino acids, polysaccharides, fatty acids, sterols, volatile constituents and vitamins (Graham et al., 1999). Due to their high nutritional value, several studies concerning the fatty acid composition of the different classes of freshwater and marine algae have been undertaken. But marine algae accumulate heavy metals and pesticides due to water pollution so fresh water algae, especially red algae have been studied for their PUFA contain (Bhosale et al., 2009).

Algae as a source of PUFA

Algae have many advantages of using sources of PUFA. The diversity and abundance of different species of algae can expedite the selection of strains producing a large proportion of their lipids as a single predominant fatty acid form. Some algal strains such as seaweeds are available throughout the year. Microalgal strains can be cultured on large scale and can be used throughout the year for production of PUFAs as there is usually no seasonal and climatic dependence. Nowdays various fermentation technologies are developed so they can be applied for large scale cultivation of algae under very controlled manner. As temperature goes on decreasing the unsaturation level goes on increasing so different temperature conditions can be monitored to improve the qualitative as well as quantitative production of PUFAs (Renaud et al., 1995).

In addition, stress conditions can be monitored to improve the accumulation or production of PUFAs. Genetic transformation protocols are also available for these organisms, enabling the development of overproducing strains and the manipulation of the PUFA profile by metabolic engineering (Behrens & Kayle, 1996). Some algal species can be induced to overproduce particular fatty acids as single cell oil through manipulations of the physical and chemical properties of culture conditions (Yap & Chen, 2001). Diverse studies have been carried out on fatty acid profile of various algae can be grouped as microalgae and macroalgae, marine algae and freshwater algae, cold water and warm water (Table 5).

Freshwater microalgae and macroalgae as a source of PUFA

High levels of EPA and DHA have been detected in many species of both micro- and macroscopic marine algae. In contrast, very few species of freshwater algae contain significant amount of EPA and DHA (Bajpai & Bajpai, 1993). Freshwater microalgae are potential sources of many highly valuable products such as PUFAs, carotenoids and antioxidants. The unicellular freshwater red algal species *Porphyridium* contains a large amount of arachidonic acid and significant amount of EPA (Radwan, 1991; Yongmanitchai & Ward, 1991; Mukharjee, 1999). Table 6 represents the range of PUFAs in biomass of selected freshwater microalgae and macroalgae from earlier reports. Bigogno et al. (2002) reported that, the chlorophyte (*Trebuxiophyceae*) *Parietochloris incisa* isolated from Mt. Tateyama, Japan, was found to be the richest plant source of the pharmaceutically valuable LC-PUFA, arachidonic acid (AA, 20:4ω6). This alga is also extremely rich in triacylglycerols (TAG), which reaches 43% (of total fatty acids) in the logarithmic phase and up to 77% in the stationary phase. Renaud et al. (1995) and Patil et al. (2007) in their respective study reported the presence of high percent composition of DHA in *Isochrysis* spp. (6-15.8%) and *Pavlova* spp. (13.2%). Some species belonging to class *Prymnesiophyceae* (Pavlova spp., 18%), *Bacillariophyceae* (*Nitzschia paleacea*, *Phaeodactylum tricornutum*, 18.1-28.4%), *Eustigmatophyceae* (*Nannochloropsis oceanica*, 23.4) and *Cryptophyceae* (*Rhodomonas*, 11-15.8%) showed high percent composition of EPA (Table 6). *Synechococcus* (*Cyanophyceae*) was found to be a rich source of GLA among all classes of freshwater algae (Table 6). Species of *Chlorophyceae* and *Cryptophyceae* were reported for the higher percentage of C18 fatty acids (LA, upto 17% and ALA, upto 28.9%) (Table 6).

Lipids in actively growing and dividing algae are mainly glycolipids located in thylakoid membranes, which are typically rich in ω-3 PUFAs. Algae belonging to class *Rhodophyceae* are mainly macroscopic. They may contain relatively large amounts of C20 PUFAs such as AA and EPA. More economical method for obtaining PUFAs from these sources is harvesting macroalgae from its natural habitat because cultures of these algae are very difficult. *Sirodotia* (*Rhodophyceae*) is one of the few freshwater species that produce high levels of DHA (up to 10% of total fatty acids) (Bhosale et al., 2009) and another fresh water algae *Monodus subterraneus* belonging to class *Xanthophyceae* produces high levels of EPA (up to 34% of total fatty acid) (Vazhappilly & Chen, 1998).

Pharmaceutical and nutraceutical applications

Evidence of the possible medical effects of PUFA deficiencies have, coupled with the growing acceptance of pharmafoods (nutraceuticals) by consumers, brought these compounds to the attention of food and pharmaceutical companies, which have been quick to exploit markets in the biomedical and pharmafood arenas. A variety of speciality PUFA lipids are available for medical uses, ranging from antiaging, anti thrombotic, anti-inflammatory, anticholesterolaemic and anticancer drugs to immunostimulant and immuno-suppresant therapeutics (Table 7).

But the most obvious commercial impact of PUFAs has been in health supplements, with a host of plant- and fish-derived GLA, EPA and DHA products now being efficacies remain to be proved. Unregulated applications for esters, glycerides and phospholipids, such as nutraceutical additives for foods, nutritional formulae and cosmetics ingredients available in the marketplace for uncontrolled dietary use (Ackman et al., 1988; Gill & Valivety, 1997).

TABLE 7. Biomedical and nutraceutical applications of commercial polyunsaturated lipids (Gill & Valivety, 1997)

PUFA product	Application
GLA/EPA/ETRA/DHA/DPA oils	Antiaging and anti-inflammatory agents for smokers
Ascorbyl esters of GLA/ETRA	Anti-inflammatory,antiatherosclerotic, thrombolytic anticholesterolaemic, and anticancer therapeutics
EPA and DHA oils	Anti-inflammatory and immunosuppressant therapeutics
EPA/DHA/GWAA oils	Therapeutics for drug- or alcohol-induced liver damage
GLA/ETA/EPA/DHA oils	Therapeutics for intestinal, liver and biliary conditions
GLA/ETRA TAGs	Parenternal and enteral therapeutics and nutritionals
ALA/EPA/DHA oils	Therapeutics for diarrhoea
EPA/DHA oils	Presurgery immunostimulants
EPA/DHA/GWAA oils	Parenternal and infant food supplements
GLA/ETRA/EPA/DHA TGs	Various therapeutics, nutraceuticals and cosmetics
EPA/DHA fats/oils	Thrombolytic and antiatherosclerolitic chocolates
EPA, DHA and AA oils	Nutraceutical additives for processed foods

This brings us to a point of contention in the PUFA arena, namely whether they should be treated as exceptional nutritional products or as pharmaceuticals. As they occur in foodstuffs, there is a strong case for considering them as functional foods; on the other hand, they give rise to potent bioactives and, in view of the serious disease states that may result from eicosanoid imbalances, there is justification for regarding them as biomedicals. In the absence of sufficient data on the long-term effects of consuming large amounts of purified polyunsaturates, it is desirable to regulate supplements, and perhaps assign them for controlled medical use only.

CONCLUSIONS

In last two decades, research has highlighted the biological roles of PUFAs as progenitors of a large variety of bioactive metabolites with diverse physiological functions. The realization that many of the chronic illnesses that afflict modern societies may be linked to imbalanced PUFA intakes has focused attention on correcting possible dietary deficiencies and developing PUFA-based therapies – indeed, food fortification has reached the marketplace and a range of PUFA pharmaceuticals are also available that are aimed at treating various illnesses. Also, PUFA-containing health supplements are now widely available, despite there being no control over their use. This explosion of PUFA applications has created an increasing demand for purified PUFA lipids, and the inadequacy of present plant, mammal and fish sources has led to the search for alternatives, especially algal, fungal and bacterial production systems.

Microbial processes are now in place, and it is forecast that they will eventually dominate the supply of high-grade PUFAs to the pharmaceutical and food sectors. Although we are just beginning to comprehend the biological roles of PUFAs, their impacts on disease and the consequences of dietary modification, it is clear that they are critical nutrients, and a general consensus is emerging that food supplementation can affect the incidence and progression of at least some illnesses. Future research will undoubtedly clarify the exact roles to improved nutritional guidelines and therapies. Advances in their incorporation into foods and pharmaceuticals should provide a spectrum of improved pharma and biomedical products.

Some species of microalgae and macroalgae have been proposed as alternative source of PUFAs. The production potential of PUFAs by these organisms especially depends upon the culture conditions in which they grow. For macroalgae environment conditions affect the production of PUFAs. Intensive studies should be conducted for each potential microalgal species in order to work out the optimal parameters and nutritional conditions for its growth and PUFA production. But macroalgae are very difficult to culture so some alternatives should be found such that these algae can be grown in its natural conditions in massive amounts. So PUFAs in quantitative manner can be produced in higher amounts.

Also freshwater red algae have shown their potential for producing significant amount of PUFA. These algae can be grown at low temperature so accumulation of PUFA in them can be greatly increased. These algae have one crucial advantage that they are growing in cold fresh running water so no accumulation of pesticides and heavy metals. The one of the study carried by Bhosale et al. (2009), which is the first of its type, provides a profile of some fatty acids in cold water inhabiting alga *Sirodotia* populations belonging to family *Rhodophyceae* that are commonly encountered and abundant in the streams of the Western Ghats. In this region, *Sirodotia* appears in the first week of July – a period coinciding with the stabilisation of the Monsoon – and remains until January. It is possible to cultivate this alga on artificial substratum such as nylon nets as it also reproduces asexually by monospores. Fatty acid analysis of *Sirodotia* indicated the existence of PUFAs such as 18:3n6 (0.36-6.62%), 20:3n6 (0.26-3.25%), 20:3n3 (1.04-2.25%), 20:4n6 (1.7-2.16), 20:5n3 (1.05-3.02%) and 22:6n3 (3.72-10.63% of total fatty acids) which have shown to have biomedical and nutraceutical applications, indicating the potential utility of this alga for human welfare.

Application of genetically modified organisms for PUFA production may be another feasible approach to attaining improved yields of PUFAs. Many microbial production systems such as open ponds and a variety of bioreactors have been developed. Different culture strategies should be adopted for the production of a particular PUFA depending on the microalgal or microbial species used. The choices among the production models and/ or the bioreactors will depend upon the type of product desired and the economic constraints imposed. Freshwater microalgae offer an unlimited and natural resource of PUFAs. However a greater understanding of the factors that affect PUFA production is needed in order to develop a cost effective process for the commercial production of high-quality PUFA.

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Algal Species Diversity from the Everglades (Florida, USA)*

T.E. SMITH

Department of Biology and Chemistry, Ave Maria University,
Ave Maria, FL, 34142-5015, USA
email: thomas.smith@avemaria.edu

ABSTRACT

This study was an algal species diversity and taxonomic survey of WCA-2A and Big Cypress National Preserve (Florida, USA). 121 species were identified with 60 *Cyanophyta*, 57 *Chlorophyta*, 3 *Euglenophyta*, 1 *Bacillariophyta* and 1 unknown structure. This was the first report for 9 *Cyanophyta* and 2 *Chlorophyta* species from the United States and 56 *Cyanophyta*, 21 *Chlorophyta* and 3 euglenoid species to the state of Florida.

KEYWORDS: algal species diversity, taxonomy, *Cyanophyta*, *Chlorophyta*, *Euglenophyta*, *Bacillariophyta*, USA.

INTRODUCTION

Cyanophyta (= Cyanobacteria) taxonomy is primarily based on morphology and more recently genetic, biochemistry and ultrastructure comparisons (Anagnostidis & Komárek, 1985). Historically, there have been difficulties in determining relevant criteria because *Cyanophyta* have few morphological characteristics and those have a wide range of variability. Criteria most commonly used for classifying *Cyanophyta* are colony shape, extracellular sheaths presence/absence and laminations, sheath thickness and color, and cells differentiation, arrangement, content, and dimensions.

Cyanophyta are important in algal assemblages in the Everglades (Browder et al., 1981; Swift, 1984, Belanger & Platko, 1986; McCormick & O'Dell, 1996; McCormick et al., 1996). *Cyanophyta* are being used to assess effects of phosphorus on the ecological integrity of the Everglades. *Cyanophyta* identification is essential to assess biodiversity and biotic integrity. The taxonomic keys that are being used to identify the Everglades *Cyanophyta* are from temperate and northern United States and India. These keys are based upon the taxonomic work accomplished by Geitler (1932) from Germany. The Everglades, however, is located in the subtropical region of the southern United States, so the species encountered there should be a mixture of tropical and temperate species.

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The objective of this project was to describe the observed non-diatom algal species in a monograph. This will be accomplished by providing a species image, distinguishing morphological features (e.g. size), habitat, and comments about the unidentified algal species. Also noted are species that were not previously reported from the United States and to the State of Florida.

MATERIALS AND METHODS

Eleocharis periphyton and *Cyanophyta* algal mats were sampled from Big Cypress National Preserve and from WCA-2A. These samples were surveyed to observe algal species, which were identified with the following taxonomic keys: Forest (1954), Desikichary (1959), Prescott (1962), Whitford and Schumacher (1984), Dillard (1989a, b, 1990, 1991a, b, 1993), and Komárek and Anagnostidis (1999, 2005). Notes on each algal species identified included literature references with the page, plate, figure specified, and cell measurements. Although identification and description of the *Cyanophyta* was a priority, each species description will be accomplished by noting the cell measurements and other distinguishing morphological features (e.g. spine and arm length, reproduction structure physical size). I also included other taxa from the divisions *Chlorophyta*, *Euglenophyta*, and *Bacillariophyta*. The *Chlorophyta* and *Euglenophyta* identification were accomplished with Dillard's and Forest's taxonomic keys. Dillard's keys only include the division *Chlorophyta* from southeastern United States. Forest's keys are from Tennessee, Virginia and North Carolina and include all algal divisions. Photographs were made with a Nikon microscope and digital camera at 1000X unless otherwise stated.

Comparing the species with previously reported locations of all the taxa will identify new records of species for the State of Florida.

RESULTS AND DISCUSSION

There were 124 species identified from the Everglades' algae. *Cyanophyta* was the most numerous with 62 different species, 50% of the population identified; *Chlorophyta* had 46 different species (46%). *Euglenophyta* had 3 species (2%), and *Bacillariophyta* and unknown structure had 1 species each (1%).

Of the 61 – *Cyanophyta* species identified to the species level, this is the first report for 13 species to the United States and 53 to the State of Florida (Table 1). There are 35 *Cyanophyta* species that are cosmopolitan and found from India to the United States. Fifteen species have only been reported in United States from New England and northern Midwestern states (*Calothrix consociata*, *Chroococcus disperses*, *Ch. prescottii*, *Gloeocapsa calcarea*, *Gomphosphaeria aponina* var. *gelatinosa*, *Microcystis elabens*, *Schizothrix lacustris*, *Phormidium aerugineo-caerulea*, *Ph. articulata*, *Ph. mucicola*, *Pelogpoea bacillifera*, *Pseudanabaena limnetica*, *Rhabdoderma sigmoidea* f. *minor*, *Schizothrix lacustris*, *Tychonema bornetii*). There are 27 species not previously reported from the temperate United States. Of which, 12 species (*Aphanocapsa koordersi, Calothrix viguieri*, *Gloeocapsa quaternata*, *Gloeothece palea*, *Planktolyngbya bipunctata*, *Porphyroiphon luteus*, *Lyngbya subconfervoides*, *Johannesbaptistia pellucida*, *Microcystis stagnalis*, *Oscillatoria capitata*, *Scytonematopsis kachyapi*, and *Symplocastrum cuspidatum*) were only reported from tropical environments in India, West Indies, and Hawaii, and subsequently may be tropical endemic species.

There were 57 *Chlorophyta* species identified (Table 2) to the species level, 21 species have not been reported from the State of Florida. Sixteen of the 21 species were found in the temperate United States, 3 species (*Scenedesmus denticulatus* var. *linearis* f. *granulatus*, *S. verrucosus*, and *S. tibiscensis*) were only previously reported from Europe, and 2 species (*Actinotaenium cruciferum* and *Tetraedron muticum*) from midwestern or northern United States. There were 3 *Euglenophyta* species identified to the species level and these species have not been previously reported from the State of Florida but were found in the temperate United States.

TABLE 1. *Cyanophyta* species previously reported locations and species that are bolded are newly reported from Florida

CYANOPHYTA	Locations Previously Reported*
Aphanocapsa delicatissima	India[1], MI, WI[2], and NC[4]
A. elachista	India[1], MI, WI[2], West Indies[3], and NC[4]
A. koordersi	India[1]
A. pulchra	India[1], MI, WI[2], and NC[4]
Aphanothece pallida	India[1], WI[2], PA, MN[3], and NC[4]
A. stagnina	India[1], MI, WI[2], and NC, AK[3]
Calothrix consociate	WA[3]
C. viguieri	India[1]
Chroococcus disperses	India[1], and MI, WI[2]
Ch. minimus	India[1], WI[2], and NC[4]
Ch. minor	India[1], WI[2], NE, West Indies[3], and NC[4]
Ch. minutus	India[1], MI, WI[2], ME[3]
Ch. multicoloratus	India[1], PA[3], and NC[4]
Ch. prescottii	MI, WI[2]
Ch. refractus	PA, IA[3], and NC[4]
Ch. turgidus	India[1], WI, MI[2], and NC[4]
Ch. varius	WI[2], MA, MT, WY[3], and NC[4]
Cyanothece aeruginosa	India[1], MI, WI[2], Greenland, NH, WY[3] and NC[4]
Gloeocapsa calcarea	India[1]and WI[2]
G. decorticans	India[1], and NC[4]
G. quaternata	West Indies, HI[3]
G. polydermatica	India[1], and AK, MA, PA, HI[3]
Gloeothece membranacea	NC, India[1], and North America[3]
G. palea	India[1]
Gomphosphaeria aponina	India[1], MI, WI[2], RI, NJ, MN, IA, NE, WA, HI, Guatemala[3], and NC[4]
G. aponina var. *gelatinosa*	WI[2]
Johannesbaptistia pellucida	India[1] and Everglades[5]
Leibleinia porphyrosiphonis	India[1]
Leptolyngbya lagerheimii	India[1], MI, WI,[2] and NC[4]
Lyngbya major	India[1], MI, WI[2], and NC [4]
L. martensiana	India[1], MI, WI[2], and NC [4]

End of Table 1

Lyngbya subconfervoides	India[1]
Merismopedia punctata	India[1], MI, WI[2], and NC[4]
Microcystis elabens	India[1], and ME, NH, NH, CT, NY[3]
M. stagnalis	India[1]
Nostoc commune	India[1], MI, WI[2], HI, AK, MA, RI, CT, NJ, MD, GA, TX, IN, MN, IA, KA, NE, MT, WY, NM, WA, Mexico, West Indies, Bermuda, Artic Region, Canada, Greenland[3], and NC[4]
Oscillatoria capitata	HI[3]
Pelogpoea bacillifera	MI, WI[2]
Phormidium aerugineo-caerulea	MI, WI[2]
Ph. articulate	MI, WI[2]
Ph. limosum	India[1], MI, WI[2], and NC[4]
Ph. mucicola	India[1], and MI, WI[2]
Planktolyngbya bipunctata	India[1]
P. limnetica	India[1], MI, WI[2], and NC[4]
Planktothrix prolifica	India[1], MI, WI[2], NC[4] and Everglades[5]
Porphyrosiphon luteus	India[1]
Pseudanabaena limnetica	WI[2], and India[1]
Rhabdoderma sigmoidea f. *minor*	WI[2]
Schizothrix lacustris	AK, CT[3]
Scytonema hofman-bangii	AK, NH, MA, CT, NJ, NE, CA, West Indies[3] and Everglades[5]
S. myochroum	AK, RI, CT, NY, PA, IA, NC, CO, Bermuda, Greenland, Canada[3]
Scytonematopsis kashyapi	India[1]
Symplocastrum cuspidatum	West Indies[3]
Synechocystis aquatilis	CA[3]
Tychonema bornetii	WI[2]

* As cited in [1]Desikachary (1959), [2]Prescott (1962), [3]Tilden (1968), [4]Whitford and Schumacher (1984) and [5]Swift (1984).

TABLE 2. *Chlorophyta* and *Euglenophyta* species previously reported locations and species that are bolded are newly reported from Florida

CHLOROPHYTA	Locations Previously Reported*
Actinotaenium cruciferum	OK, WA[4]
Ankistrodesmus fusiformis	NC[1]
Chaetophora attenuate	GA, NC, SC, TN[2]
Closteriopsis longissima	AL, FL, KY, NC, TN, VA, WV[1]
Closterium acutum var. *variabile*	LA[3]
C. parvulum	FL, GA, KY, LA, NC, TN, SC, VA, WV[3]
Coelastrum indicum	FL, LA, NC, SC[1]
C. sphaericum	AL, FL, GA, KY, LA, SC, TN, VA[1]
Cosmarium bioculatum	GA, KY, SC, TN[4]
C. botrytis	FL, KY, NC, VA, WV[4]
C. contractum var. *minutum*	MS[4]
C. granatum	FL, GA, KY, NC, SC, VA[4]
C. minimum	FL, LA[4]
C. pachydermum var. *incrassatum*	FL, VA[4]
C. pseudoretusum	MS[4]
C. pseudotaxichondrum var. *foggii*	LA, MS, NC[4]
C. regnesi	AL, FL[4]
C. reniforme var. *apertum*	KY[4]

End of Table 2

Cosmarium subcucumis	AL, KY, LA, VA[4]
C. trilobulatum	KY, MS, NC, SC[4]
C. undulatum var. *minutum*	CA, CT, IA, MI, MY, NY, NC, OH, OK, SC, WA, WI[4] and Everglades[11]
C. variolatum	FL, LA, MS[4] and Everglades[11]
Desmidium aptogonum var. *ehrenbergii*	FL, KY[6]
Epibolium dermaticola	NC[2]
Euastrum binale var. *gutwinskii*	FL, GA, KY, MS, LA, NC[6] and Everglades[11]
E. cornubiense var. *medianum* f. *subgranulatum*	FL[6]
E. lapponicum f. *leave*	MS[6]
Gloecystis vesiculosa	GA, NC, SC, VA, WV[1]
Gonatozygon brebissonii	FL, NC, WV[3] and Everglades[11]
G. pilosum	FL, GA, NC, VA[3]
Monoraphidium mirabile	KY, LA, NC, TN[1] and Everglades[11]
Oedogonim capitellatum	AL, FL, MS[2]
Oocystis novae-semliae	FL[1]
O. solitaria	GA, TN, VA[1]
Pleurotaenium maximum	AL, FL, KY, MS, SC, TN, VA[3]
Raphidocelis subcapitata	AL, GA, KY. NC, SC[1]
Scenedesmus denticulatus var. *linearis* f. *granulatus*	Europe[7]
S. ecornis	Europe[8], and NC[1]
S. incrassatulus	Europe[8], and FL, SC, VA[1] and Everglades[11]
S. quadricauda var. *longispina*	Europe[8], and FL, NC, SC, TN, VA[1]
S. tibiscensis	Europe[8]
S. verrucosus	Europe[8]
Selenastrum gracile	AL, FL, GA, KY, LA, NC, TN, and VA[1]
Staruastrum pingue	North America, not SE U.S.A.[5]
S. dejectum var. *apiculatum*	GA, NC, SC, VA[5]
S. dilatum	FL, GA, MS, SC, TN, and VA[1]
S. gracile	FL, GA, KY, MS, NC, SC, TN, and VA[1]
Stauridium tetras	AL, FL, GA, SC, KY, LA, NC, TN, VA[1]
Stigeclonium tenue	FL, KY, NC, SC, TN, VA, WV[2] and Everglades[11]
Tetradron minimum	AL, GA, KY, LA, MS, NC, SC, TN, VA, WV[1]
T. muticum	MI and WI[9]
T. regulare var. *granulate*	AL, FL, GA, KY, LA, NC, SC, TN, VA, WV[1], MI, WI[8] and Everglades[11]
EUGLENOPHYTA	Locations Previously Reported
Strombomonas fluviatilis	LA[7]
Trachelomonas volvocina	TN, VA[10]
T. volvocina var *compressa*	TN, VA[10]

* As cited in [1]Dillard, part 1 (1989a), [2]Dillard, part 2 (1989b), [3]Dillard, part 3 (1990), [4]Dillard, part 4 (1991a), [5]Dillard, part 5 (1991b), [6]Dillard, part 6 (1993), [7]Dillard, part 7 (2000), [8] Uherkovich (1966), [9]Prescott (1962), [10]Forest (1954) and [11]Swift (1984).

Characteristics, Identification, and References of Everglades Species

CYANOPHYTA

APHANOCAPSA Näg., 1849

1. *Aphanocapsa delicatissima* W. West et G.S. West Plate **I**, *1-3*
Cells 1 µm in diameter
Habitat: Big Cypress on an *Eleocharis* stem, WCA-2A on a *Nymphaea* stem

2. *A. elachista* W. West et G.S. West Plate **I**, *4*
Cells 2 µm in diameter
Habitat: Big Cypress on an *Eleocharis* stem

3. *A. koordersi* Ström Plate **I**, *5, 6*
Cells 2.5-3 µm in diameter
Habitat: WCA-2A on a *Nymphaea* stem

4. *A. pulchra* (Kütz.) Rabenh. Plate **I**, *7*
Cells 4.5 µm in diameter
Habitat: WCA-2A floating *Cyanophyta* mat

5. *Aphanocapsa* sp. Plate **I**, *8*
Cell 15 µm in diameter
Habitat: WCA-2A floating *Cyanophyta* mat

APHANOTHECE Näg., 1849

6. *Aphanothece pallida* (Kütz.) Rabenh. Plate **I**, *9, 10*
Cell 2-3 µm in diameter, 5-6 µm in length
Habitat: WCA-2A on a *Nymphaea* stem

7. *A. stagnina* (Spreng.) A. Br. Plate **I**, *11*; Plate **II**, *1-3*
Cell 3-4-5 µm in width, 5-8 µm in length
Habitat: WCA-2A floating *Cyanophyta* mat and on a *Nymphaea* stem

8. *Aphanothece* sp. Plate **II**, *4*
Cells 1 µm in width, 5-8 µm in length
Habitat: WCA-2A mesocosm site #2 channel #6 *Cyanophyta* mat at 2 m

9. *Aphanothece* sp. Plate **II**, *5, 6*
Cell 3 µm in width, 6 µm in length
Notes: Variation of *Aphanothece stagnina* (Spreng.) A. Br. fits the size but not with respect to shape, *Aphanothece* sp. B has a fold or a twist form
Habitat: WCA-2A on a *Nymphaea* stem

CALOTHRIX Ag. ex Born. & Flah. in 1824, 1886

10. *Calothrix consociata* Kütz. ex Born. et Flah. Plate **III**, *1*
Cell 6 µm in width, 2 µm in length
Heterocyst 10 µm in width
Habitat: Big Cypress on an *Eleocharis* stem

11. *C. viguieri* Frémy Plate **II**, *7*
Cell 15 µm in width
Habitat: WCA-2A in sediments

CHROOCOCCUS Näg., 1849

12. *Chroococcus dispersus* (Keissl.) Lemm. Plate **II**, *8*
SYNONYM: *Ch. limnetica* var. *subsalsa* Plate **III**, *2*
Cell 3-4 µm in diameter
Habitat: WCA-2A on a *Nymphaea* stem

13. *Ch. minimus* (Keissl.) Lemm. Plate **III**, *3*
Cell 2 µm in diameter
Habitat: Big Cypress on an *Eleocharis* stem

14. *Ch. minor* (Kütz.) Näg. Plate **III**, *4, 5*
Cell 3 µm in diameter
Habitat: Big Cypress on an *Eleocharis* stem, WCA-2A in a floating *Cyanophyta* mat

15. *Ch. minutus* (Kütz.) Näg. Plate **III**, *6*
Cell 7 µm in diameter
Habitat: WCA-2A in a floating *Cyanophyta* mat

16. *Ch. multicoloratus* Wood Plate **III**, *7*
Cell 2 µm in diameter, 3 µm in length
Notes: The Everglades species was larger than the description size
Habitat: WCA-2A on a *Nymphaea* stem

17. *Ch. prescotii* Drouet et Daily in Drouet Plate **III**, *8, 9*
Cell 4.5-5 µm in diameter
Habitat: WCA-2A on a *Nymphaea* stem

18. *Ch. refractus* Wood Plate **III**, *10*
Cells 1 µm in diameter
Habitat: Big Cypress on an *Eleocharis* stem

19. *Ch. turgidus* (Kütz.) Näg. Plate **III**, *11*
Cell 8 µm in diameter, Sheath 23 µm in diameter
Habitat: WCA-2A in the sediments

20. *Ch. varius* A. Br. in Rabenh. Plate **III**, *12*
Cell 3.5 µm in diameter
Habitat: WCA-2A on a *Nymphaea* stem

CYANOTHECE Komárek, 1976

21. *Cyanothece aeruginosa* (Näg.) Komárek Plate **X**, *6-9*
SYNONYM: *Synechococcus aeruginosus* Näg.
Cell 4-5 µm in diameter, 7-8-9 µm in length
Notes: This species was smaller in width and length than the description size
Habitat: WCA-2A in a floating *Cyanophyta* mat on a *Nymphaea* stem

ENTOPHYSALIS Kütz., 1843

22. *Entophysalis* sp. Plate **III**, *13*; Plate **IV**, *1, 2*
Cell 7-8-9 µm in diameter, 11-14-19 µm in length
Habitat: WCA-2A in a floating *Cyanophyta* mat

GLOEOCAPSA Kütz., 1843

23. *Gloeocapsa calcarea* Tild. Plate **IV**, *3*
    Cell 3 µm in width, 6 µm in length
    Habitat: WCA-2A on a *Nymphaea* stem

24. *G. decorticans* (A. Br.) Richt. Plate **IV**, *4, 5*
    Cell 6-9 µm in diameter
    Habitat: WCA-2A in a floating *Cyanophyta* mat

25. *G. quaternata* (Bréb.) Kütz. Plate **IV**, *8*
    Cell 4 µm in diameter
    Habitat: WCA-2A in a floating *Cyanophyta* mat

GLOEOCYSTIS Näg., 1849

26. *Gloeocystis polydermatica* (Kütz.) Hind. Plate **IV**, *6, 7*
    SYNONYM: *Gloeocapsa polydermatica* Kütz.
    Cell 3-4.5 µm in diameter, 8-9 µm in length
    Habitat: WCA-2A in a floating *Cyanophyta* mat

GLOEOTHECE Näg., 1849

27. *Gloeothece membranacea* (Rabenh.) Born. Plate **IV**, *9*
    Cell 4-5 µm in width, 6-7 µm in length
    Habitat: WCA-2A in a floating *Cyanophyta* mat

28. *G. palea* (Kütz.) Näg. Plate **V**, *1*
    Cell 3 µm in width, 6-8 µm in length
    Habitat: WCA-2A in a floating *Cyanophyta* mat

GOMPHORSPHEARIA Kütz., 1836

29. *Gomphosphaeria aponina* Kütz. Plate **V**, *2, 3*
    Cell 3-4 µm in width, 6-8 µm in length
    Habitat: WCA-2A in a floating *Cyanophyta* mat

30. *G. aponina* var. *gelatinosa* Prescott in Prescott, Silva et& Wade Plate **V**, *4*
    Cell 5 µm in diameter, 5 µm in length
    Habitat: WCA-2A on a *Nymphaea* stem

JOHANNESBAPTISTIA De Toni, 1936

31. *Johannesbaptistia pellucida* (Dickie) Taylor et Drouet Plate **V**, *6*
    Cell 7 µm in width, 3 µm in length
    Notes: This species was larger in width than the description size
    Habitat: WCA-2A in a floating *Cyanophyta* mat

LEIBLEINIA (Gom.) Hoff., 1985

32. *Leibleinia porphyrosiphonis* (Frémy) Anagn. & Komárek Plate **VII**, *3*
    SYNONYM: *Lyngbya porphyrosiphonis* Frémy
    Cell 1.5 µm in width, 2.5 µm in length
    Notes: This species was larger in length than the description size
    Habitat: WCA-2A in the sediments

LEPTOLYNGBYA Anagn. & Komárek, 1988

33. *Leptolyngbya lagerheimii* (Gom.) Anagn. et Komárek Plate **V**, *8*
SYNONYM: *Lyngbya lagerheimii* (Moeb.) Gom.
Cell 1.5 µm in width, 1.5 µm in length
Habitat: Big Cypress on an *Eleocharis* stem

LYNGBYA Ag., 1824

34. *Lyngbya major* Menegh. ex Gom. Plate **VI**, *6*
Cell 12 µm in width, 3 µm in length
Habitat: WCA-2A in a floating *Cyanophyta* mat

35. *L. martensiana* Menegh. ex Gom. Plate **VI**, *7*
Cell 10 µm in width, 2 µm in length
Habitat: WCA-2A in a floating *Cyanophyta* mat

36. *L. subconfervoides* Borge Plate **VII**, *4-6*
Cell 15 µm in width, 5 µm in length
Habitat: WCA-2A in a floating *Cyanophyta* mat

MERISOPEDIA Meyen, 1839

37. *Merismopedia punctata* Meyen Plate **V**, *5*
Cells 2-3 µm in diameter
Habitat: Big Cypress on an *Eleocharis* stem

MICROCYSTIS Kütz., 1833

38. *Microcystis elabens* (Bréb.) Kütz. Plate **VII**, *7-10*
Cells 2-3 µm in diameter, 4-6 µm in length
Notes: This species was larger in width and length than the description size
Habitat: WCA-2A on a *Nymphaea* stem and in a floating *Cyanophyta* mat

39. *M. stagnalis* Lemm. Plate **VII**, *11*
Cells 2 µm in diameter
Habitat: Big Cypress on an *Eleocharis* stem

NOSTOC Vauch. ex Born. et Flah., 1886

40. *Nostoc commune* Vauch. ex Born. et Flah. Plate **VIII**, *1-3*
Cell 8 µm in width, 5 µm in length
Notes: This species was larger in width but shorter in length than the description size
Habitat: WCA-2A on a *Nymphaea* stem and in a floating *Cyanophyta* mat

OSCILLATORIA Vauch., 1803

41. *Oscillatoria capitata* West et West Plate **IX**, *2*
Cell 5 µm in width, 3 µm in length
Habitat: WCA-2A on a *Nymphaea* stem

PELOGLOEA Laut., 1913

42. *Pelogloea bacillifera* Laut. Plate **IX**, *6, 7*

Cell 1 µm in diameter, 3.5-6 µm in length
Habitat: WCA-2A on a *Nymphaea* stem

PHORMIDIUM Kütz. ex Gom., 1892

43. *Phormidium aerugineo-coeruleum* (Gom.) Anagn. et Komárek Plate **VI**, *1*
SYNONYM: *Lyngbya aerugineo-coerulea* Gom.
Cell 2 µm in width, 6 µm in length
Habitat: WCA-2A on a *Nymphaea* stem

44. *Ph. articulatum* (Gardn.) Anagn. et Komárek Plate **VIII**, *4, 5*
SYNONYM: *Oscillatoria articulata* Gardn.
Cell 2 µm in width, 1.5 µm in length
Habitat: Big Cypress on an *Eleocharis* stem

45. *Ph. limosum* (Dillw.) P.C. Silva Plate **IX**, *3*
SYNONYM: *Oscillatoria limosa* (Roth) C.A. Ag.
Cell 15 µm in width, 5 µm in length
Habitat: WCA-2A on a *Nymphaea* stem
SYNONYM: *Oscillatoria tenuis* Ag. ex Gom. Plate **VIII**, *8*; Plate **IX**, *5*
Cell 5-6 µm in width, 2.5-3 µm in length
Habitat: WCA-2A in a floating *Cyanophyta* mat and on a *Nymphaea* leaf

46. *Ph. mucicola* Lemm. Plate **X**, ***3***
Cell 5 µm in width, 7 µm in length
Notes: This species was larger in width and length than the description size. It looks like Prescott's species but does not fit the size dimensions
Habitat: WCA-2A in the Sediments

47. *Phormidium* sp. Plate **X**, *4*
Cell 2 µm in width, 3 µm in length
Habitat: WCA-2A in a floating *Cyanophyta* mat

PLANKTOLYNGBYA Anagn. & Komárek, 1988

48. *Planktolyngbya bipunctata* (Lemm.) Anagn. et Komárek Plate **VI**, *2, 3*
SYNONYM: *Lyngbya bipunctata* Lemm.
Cell 1 µm in width, 4 µm in length
Habitat: WCA-2A in a floating *Cyanophyta* mat

49. *P. limnetica* (Lemm.) J. Komárková-Legnerová et Cronberg Plate **VI**, *9*; Plate **V**, *4, 5*
SYNONYM: *Lyngbya limnetica* Lemm.
Cell 1.5-2 µm in width, 5-8 µm in length
Habitat: WCA-2A in a floating *Cyanophyta* mat and on a *Nymphaea* stem

PLANKTOTHRIX Anagn. & Komárek, 1988

50. *Planktothrix prolifica* (Gom.) Anagn. et Komárek Plate **IX**, *4*; Plate **X**, *1, 2*
SYNONYM: *Oscillatoria prolifica* (Grev.) Gom.
Cell 2-3.5 µm in width, 2-4 µm in length
Habitat: WCA-2A in a floating *Cyanophyta* mat and on a *Nymphaea* stem, Big Cypress on an *Eleocharis* stem

PORPHYROSIPHON Kütz. ex Gom., 1892

51. *Porphyrosiphon luteus* (Gom.) Anagn. et Komárek Plate **VII**, *1, 2*
SYNONYM: *Lyngbya lutea* C. Ag. ex Gom.
Cell 2-5 µm in width, 4-5 µm in length
Habitat: WCA-2A in a floating *Cyanophyta* mat

PSEUDOANABAENA Laut., 1915

52. *Pseudoanabaena limnetica* (Lemm.) Komárek Plate **VIII**, *6, 7*
SYNONYM: *Oscillatoria limnetica* Lemm.
Cell 1 µm in width, 5 µm in lengths
Habitat: WCA-2A on a *Nymphaea* stem

RHABDODERMA Schmidle & Laut., 1900

53. *Rhabdoderma sigmoideum* f. *minor* Moore et Carter Plate **XI**, *1*
Cell 1.5 µm in width, 16 µm in length
Habitat: WCA-2A in a floating *Cyanophyta* mat

SCHIZOTHRIX Kütz. ex Gom., 1892

54. *Schizothrix lacustris* A. Braun ex Gom. Plate **V**, *7*
SYNONYM: *Inactis lacustris* (Gom.) Forti
Cell 1.5 µm in width, 1 µm in length
Habitat: WCA-2A on a *Nymphaea* stem

SCYTONEMA C. Ag. ex Born. & Flah., 1887

55. *Scytonema hofman-bangii* C. Ag. ex P.C. Silva Plate **XI**, *4*; Plate **XII**, *2*; Plate **XIII**, *1*
SYNONYM: *Scytonema hofmanni* Ag. ex Born. et Flah.
Cell 5-7 µm in width, 3-30 µm in length, heterocysts 6 µm in width, 22 µm in length
Habitat: WCA-2A in a floating *Cyanophyta* mat and on a *Nymphaea* stem

56. *S. myochroum* (Dillw.) C. Ag. ex Born. et Flah. Plate **XI**, *2, 3*; Plate **XII**, *1*
Cell 4-5 µm in diameter
Heterocyst 5-7 µm in diameter
Habitat: WCA-2A in a floating *Cyanophyta* mat

SCYTONEMATOPSIS E. Kissel., 1930

57. *Scytonematopsis kashyapi* (Bharad.) Geitl. Plate **X**, *10*
Cell 8 µm in width, 8 µm in length
Notes: This species was smaller in length than the description size
Habitat: WCA-2A in a floating *Cyanophyta* mat

SYMPLOCASTRUM Gom., 1893

58. *Symplocastrum cuspidatum* (West et West) De Toni Plate **XII**, *3-6*; Plate **XIII**, *2*
Cell 1-2 µm in width, 3.5-10 µm in length
Habitat: WCA-2A on a *Nymphaea* stem and in a floating *Cyanophyta* mat

SYNECHOCYSTIS Sauv., 1892

59. *Synechocystis aquatilis* Sauv. Plate **X**, *5*
Cell 6 µm in diameter, 7 µm in length
Habitat: WCA-2A on a *Nymphaea* stem

TYCHONEMA Anagn. & J. Komárek, 1988

60. *Tychonema bornetii* (Zukal) Anagn. et Komárek Plate **IX**, *1*
SYNONYM: *Oscillatoria bornetii* Zukal
Cell 12 µm in width, 4 µm in length
Habitat: WCA-2A in a floating *Cyanophyta* mat

CHLOROPHYTA

ACTINOTEANIUM (Näg.) Teil., 1954

61. *Actinotaenium cruciferum* f. *latius* (De Bary) Teil. Plate **XIII**, *3*
Cells 20 µm in width, 23 µm in length, 14 µm isthmus width
Habitat: WCA-2A in a floating *Cyanophyta* mat

ANKISTRODESMUS Corda, 1838

62. *Ankistrodesmus fusiformis* Corda ex Korsh. Plate **XIII**, *6*
Cells 2 µm in width, 24 µm in length
Habitat: Big Cypress on an *Eleocharis* stem

BULBOCHAETE Ag., 1817

63. *Bulbochaete* sp. Ag. Plate **XIV**, *1*
Cells 12-15 µm in width, 22-30 µm in length
Habitat: Big Cypress on an *Eleocharis* stem

CHAETOPHORA Schrank, 1783

64. *Chaetophora attenuata* Hazen Plate **XIII**, *7*
Cells 7 µm in width, 36-42 µm in length
Notes: This species was larger in length than the description size
Habitat: Big Cypress on an *Eleocharis* stem

CLOSTERIOPSIS Lemm., 1899

65. *Closteriopsis longissima* (Lemm.) Lemm. Plate **XIV**, *4*
Cells 6 µm in width, 170 µm in length
Habitat: Big Cypress on an *Eleocharis* stem

CLOSTERIUM Nitzsch, 1817

66. *Closterium acutum* var. *variabile* (Lemm.) Krieg. Plate **XIV**, *2*
Cells 5 µm in width, 106 µm in length
Habitat: WCA-2A on a *Nymphaea* stem

67. *C. parvulum* Näg. Plate **XV**, *1*
Cells 17.5 µm in width, 115 µm in length
Habitat: Big Cypress on an *Eleocharis* stem

COELASTRUM Näg., 1849

68. *Coelastrum indicum* Turn. Plate **XIII**, *8*
Cells 10 µm cells in width
Habitat: Big Cypress on an *Eleocharis* stem

69. *Coelastrum sphaericum* Näg. Plate **XIII**, *9*
Cells 6 µm in width
Habitat: WCA-2A in a floating *Cyanophyta* mat

COSMARIUM Corda ex Ralfs, 1848

70. *Cosmarium bioculatum* Bréb. ex Ralfs Plate **XIII**, *10*
Cells 19 µm in width, 25 µm in length, 5 µm isthmus width
Habitat: WCA-2A in a floating *Cyanophyta* mat

71. *C. botrytis* (Meneg.) Ralfs Plate **XVI**, *1, 2*
Cells 70 µm in width, 90 µm in length, 38 µm isthmus width
Notes: This species was larger in isthmus width than the description size
Habitat: WCA-2A on a *Nymphaea* stem

72. *C. contractum* var. *minutum* (Delp.) Coesel Plate **XIII**, *11*
Cells 9 µm in width, 12 µm in length, 3 µm isthmus width
Habitat: WCA-2A in a floating *Cyanophyta* mat

73. *C. granatum* Bréb. ex Ralfs Plate **XIII**, *12*
Cells 22 µm in width, 37 µm in length, 5 µm isthmus width
Habitat: WCA-2A in a floating *Cyanophyta* mat

74. *C. minimum* West et West Plate **XIII**, *13*
Cells 13 µm in width, 14 µm in length, 4 µm isthmus width
Habitat: WCA-2A in a floating *Cyanophyta* mat

75. *C. pachydermum* var. *incrassatum* Scott et Grönbl. Plate **XIV**, *3*
Cells 42 µm in width, 55 µm in length, 15 µm isthmus width
Habitat: Big Cypress on an *Eleocharis* stem

76. *C. pseudoretusum* Ducellier Plate **XIV**, *5*
Cells 15 µm in width, 18 µm in length, 4 µm isthmus width
Notes: This species is slightly smaller in cell width, length and isthmus width than the description size
Habitat: WCA-2A in a floating *Cyanophyta* mat

77. *C. pseudotaxichondrum* var. *foggii* Taylor Plate **XIV**, *6*
Cells 21 µm in width, 25 µm in length, 4 µm isthmus width
Notes: This species is slightly smaller in cell width and isthmus width than the description size
Habitat: WCA-2A in a floating *Cyanophyta* mat

78. *C. regnesi* Reinch. Plate **XIII**, *14, 15*
Cells 8-9 µm in width, 10-11 µm in length, 2-8 µm isthmus width
Habitat: Big Cypress on an *Eleocharis* stem, WCA-2A Natural Gradient (#15)

79. *C. reniforme* var. *apertum* West et West Plate **XV**, *7, 8*; Plate **XVII**, *1*
Cells 42-50 µm in width, 55-60 µm in length, 13-18 µm isthmus width
Habitat: Big Cypress on an *Eleocharis* stem WCA-2A in a floating *Cyanophyta* mat

80. *C. subcucumis* Schmidle Plate **XIV**, *7*, *8*
Cells 12-14 µm in width, 20-23 µm in length, 4 µm isthmus width
Notes: This species is smaller in cell width, length and isthmus width than the description size
Habitat: Big Cypress on an *Eleocharis* stem, WCA-2A on a *Nymphaea* stem

81. *C. trilobulatum* Reinch. Plate **XIV**, *9*
Cells 18 µm in width, 29 µm in length, 5 µm isthmus width
Habitat: Big Cypress on an *Eleocharis* stem

82. *C. undulatum* var. *minutum* Wittr. Plate **XV**, *2*, *3*
Cells 19-20 µm in width, 25-29 µm in length, 5µm isthmus width
Habitat: Big Cypress on an *Eleocharis* stem

83. *C. variolatum* Lund. Plate **XV**, *4-6*
Cells 20 µm in width, 33-35 µm in length, 5-8 µm isthmus width
Habitat: WCA-2A on a *Nymphaea* stem

DESMIDIUM Ag. ex Ralfs, 1848

84. *Desmidium aptogonum* var. *ehrenbergii* Kütz. Plate **XVI**, *3*
Cells 26 µm in width, 13 µm in length
Habitat: WCA-2A in a floating *Cyanophyta* mat

EPIBOLIUM Printz, 1916

85. *Epibolium dermaticola* Printz Plate **XVI**, *4*
Cells 4-6 µm in width, 5-12 µm in length
Habitat: WCA-2A in a floating *Cyanophyta* mat

EUASTRUM Ehr. ex Ralfs, 1848

86. *Euastrum binale* var. *gutwinskii* (Schmidle) Homfeld Plate **XVI**, *5*
Cells 13 µm in width, 18 µm in length, 4 µm isthmus width
Habitat: WCA-2A on a *Nymphaea* stem

87. *E. cornubiense* var. *medianum* f. *subgranulatum* Prescott Plate **XVI**, *6*
Cells 19 µm in width, 31 µm in length, 7 µm isthmus width
Habitat: WCA-2A in a floating *Cyanophyta* mat

88. *E. lapponicum* f. *leave* Prescott Plate **XVI**, *7*; Plate **XVII**, *2*
Cells 15 µm in width, 20 µm in length, 3 µm isthmus width
Notes: This species is slightly smaller in cell width, length and isthmus width than the description size
Habitat: WCA-2A in a floating *Cyanophyta* mat and on a *Nymphaea* stem

89. *Euastrum* sp. Ehr. ex Ralfs Plate **XVII**, *3*
Cells 22 µm in width, 37 µm in length, 8 µm isthmus width
Habitat: WCA-2A Natural Gradient (#15)

GLOEOCYSTIS Näg., 1849

90. *Gloeocystis vesiculosa* Näg. Plate **XVII**, *4*, *5*
Cells 4 µm in diameter
Habitat: Big Cypress on an *Eleocharis* stem, WCA-2A on a *Nymphaea* stem

GONATOZYGON De Bary, 1856

91. *Gonatozygon brebissonii* De Bary Plate **XVII**, *6*
Cells 5 µm in width, 114 µm in length
Habitat: WCA-2A Natural Gradient (#15)

92. *G. pilosum* Wolle Plate **XVII**, ***7***
Cells 10 µm in width, 210 µm in length
Habitat: WCA-2A in a floating *Cyanophyta* mat

MONORAPHIDIUM Komárková-Legnerová, 1969

93. *Monoraphidium mirabile* (W. West et G.S. West) Pankow Plate **XIII**, *4, 5*
SYNONYM: *Ankistrodesmus falcatus* var. *mirabilis* (West et West) G.S. West
Cells 2-3 µm in width, 22 µm in length
Habitat: WCA-2A on a *Nymphaea* stem

OEDOGONIUM Link, 1820

94. *Oedogonium capitellatum* Wittr. Plate **XVIII**, *1*
Cell 5 µm in width, 18 µm in length
Oegonium 18 µm in width, 15 µm in length
Notes: This species is slightly smaller than the description size
Habitat: WCA-2A in the sediments

95. *Oedogonium* sp. Plate **XVIII**, *2*
Cells 4.5-5 µm in width, 16-20 µm in length
Notes: This species fits the description size for *Oedogonim capitellatum* Wittr. species but without reproductive structure I am not sure
Habitat: WCA-2A on a *Nymphaea* stem

96. *Oedogonium* sp. Plate **XVIII**, *3*
Cells 5 µm in width, 27 µm in length
Habitat: WCA-2A on a *Nymphaea* stem

97. *Oedogonium* sp. Plate **XVIII**, *4*
Cells 7 µm in width, 36 µm in length
Habitat: WCA-2A on a *Nymphaea* stem

OOSYSTIS Näg. ex A. Braun, 1855

98. *Oocystis novae-semliae* Wille Plate **XVIII**, *5*
Cells 5 µm in width, 9 µm in length
Habitat: WCA-2A in a floating *Cyanophyta* mat

99. *O. solitaria* Wittr. Plate **XVIII**, *6-8*
Cells 6-8-9 µm in width, 10-12-14 µm in length
Habitat: WCA-2A in a floating *Cyanophyta* mat, Big Cypress on an *Eleocharis* stem

RAPHIDOCELIS Hindák, 1977

100. *Raphidocelis subcapitata* (Korsh.) Nyg. et al. Plate **XVII**, *8*
SYNONYM: *Kirchneriella subcapitata* Korsch.

Cells 3 µm in width, 6 µm in length
Habitat: WCA-2A in a floating *Cyanophyta* mat

STAURIDIUM Corda

101. *Stauridium tetras* (Ehrenb.) Hegewald Plate **XVIII**, *9*
SYNONYM: *Pediastrum tetras* (Ehrenb.) Ralfs
Cells 5 µm in width, 5-7 µm in length
Habitat: Big Cypress on an *Eleocharis* stem

PLEUROTAENIUM Näg., 1849

102. *Pleurotaenium maximum* (Reinch.) Lund. Plate **XVIII**, *10*, *11*; Plate **XIX**, *1*
Cells 32 µm in width, 360 µm in length
Habitat: WCA-2A in a floating *Cyanophyta* mat

SCENEDESMUS Meyen, 1829

103. *Scenedesmus denticulatus* var. *linearis* f. *granulatus* Hort. Plate **XIX**, *2*
Cells 5 µm in width, 15 µm in length
Habitat: Big Cypress on an *Eleocharis* stem

104. *S. ecornis* (Ralfs) Chod. Plate **XIX**, *3-6*
Cells 5-6 µm in width, 10-12-15 µm in length
Habitat: Big Cypress on an *Eleocharis* stem, WCA-2A in a floating *Cyanophyta* mat

105. *S. verrucosus* Roll Plate **XIX**, *7*, *8*
SYNONYM: *Scenedesmus ecornis* var. *disciformis* Chod.
Cells 3-4 µm in width, 5-8-10 µm in length
Habitat: WCA-2A on a *Nymphaea* stem

106. *S. incrassatulus* Bohl. Plate **XIX**, *9-11*
Dillard p. 112 Pl. 30, Fig. 4
Cells 3-5 µm in width, 8-10-15 µm in length, with mucilage
Habitat: Big Cypress on an *Eleocharis* stem

107. *S. quadricauda* var. *longispina* (Chod.) G. Sm. Plate **XIX**, *12*
Cells 4-5 µm in width, 15-17 µm in length
Habitat: WCA-2A in a floating *Cyanophyta* mat

108. *S. tibiscensis* Uherkov. Plate **XIX**, *13*
Notes: This species is slightly larger than the description size
Habitat: WCA-2A in a floating *Cyanophyta* mat

SELENASTRUM Reinch, 1867

109. *Selenastrum gracile* Reinch Plate **XIX**, *14*
Cells 3 µm in width, 20 µm in length
Habitat: Big Cypress on an *Eleocharis* stem

STAURASTRUM Meyen, 1829

110. *Staurastrum pingue* Teil. Plate **XX**, *1*, *2*
Cell 12 µm in width, 40 µm in length, 10 µm isthmus width

Arms 30 µm in width, 64 µm in length
Notes: This species is slightly larger than the description size
Habitat: WCA-2A on a *Nymphaea* stem

111. *S. dejectum* var. *apiculatum* (Bréb.) Lund. Plate **XIX**, *15*
Cell 19 µm in width, 24 µm in length, 7 µm isthmus width
Habitat: WCA-2A on a *Nymphaea* stem

112. *S. dilatatum* (Ehr.) Ralfs Plate **XIX**, *16, 17*
Cell 17 µm in width, 34 µm in length, 13 µm isthmus width
Notes: This species is slightly smaller than the description size
Habitat: WCA-2A in a floating *Cyanophyta* mat

113. *S. gracile* Ralfs ex Ralfs Plate **XI**, *18, 19*; Plate **XX**, *3*
Cell 20 µm in width, 24 µm in length, 5 µm isthmus width
Notes: This species is smaller than the description size
Habitat: Big Cypress on an *Eleocharis* stem, WCA-2A in a floating *Cyanophyta* mat

STIGEOCLONIUM Kütz., 1843

114. *Stigeoclonium tenue* (Ag.) Kütz. emend. Cox et Bold Plate **XX**, *14;* Plate **XXI**, *1, 2*
Cells 5-9 µm in width, 5-9-11-15-18-25 µm in length
Habitat: Big Cypress on an *Eleocharis* stem

TETRAEDRON Kütz., 1845

115. *Tetraedron minimum* (Braun) Hansg. Plate **XX**, *4-8*
Cells 5-13 µm in width
Habitat: Big Cypress on an *Eleocharis* stem, WCA-2A on a *Nymphaea* stem

116. *T. muticum* (Braun) Hansg. Plate **XX**, *9, 10*
Cells 11-12.5 µm in width
Habitat: WCA-2A in a floating *Cyanophyta* mat, Big Cypress on an *Eleocharis* stem

117. *T. regulare* var. *granulata* Prescott Plate **XX**, *11-13*
Cells 16 µm in width
Notes: This species is smaller than the description size
Habitat: WCA-2A in a floating *Cyanophyta* mat

EUGENOPHYTA

STROMBOMONAS Defl., 1930

118. *Strombomonas fluviatilis* (Lemm.) Defl. Plate **XXI**, *5*
Cells 20 µm in diameter, 20 µm in length
Collar 7 µm in diameter, 5 µm in length
Habitat: Big Cypress on an *Eleocharis* stem

TRACHELOMONAS Ehrenb., 1835

119. *Trachelomonas volvocina* Ehrenb. Plate **XXI**, 3
Cells 11 µm in diameter
Habitat: WCA-2A on a *Nymphaea* stem

120. *T. volvocina* var. *compressa* Drez. Plate **XXI**, *4*
Cells 12 μm in diameter
Habitat: Big Cypress on an *Eleocharis* stem

BACILLARIOPHYTA

TRICERATIUM Ehrenb., 1839

121. *Triceratium favus* f. *octogonum* T.V. Desikachary et P. Prema Plate **XXI**, *6-8*
Cells 28-29 μm in width
Habitat: WCA-2A on a *Nymphaea* stem

UNKNOWN STRUCTURE

122. *Sigmoid* Forsk. Plate **XXI**, *9*
Cells 3 μm in width, 100 μm in length
Habitat: Big Cypress on an *Eleocharis* stem

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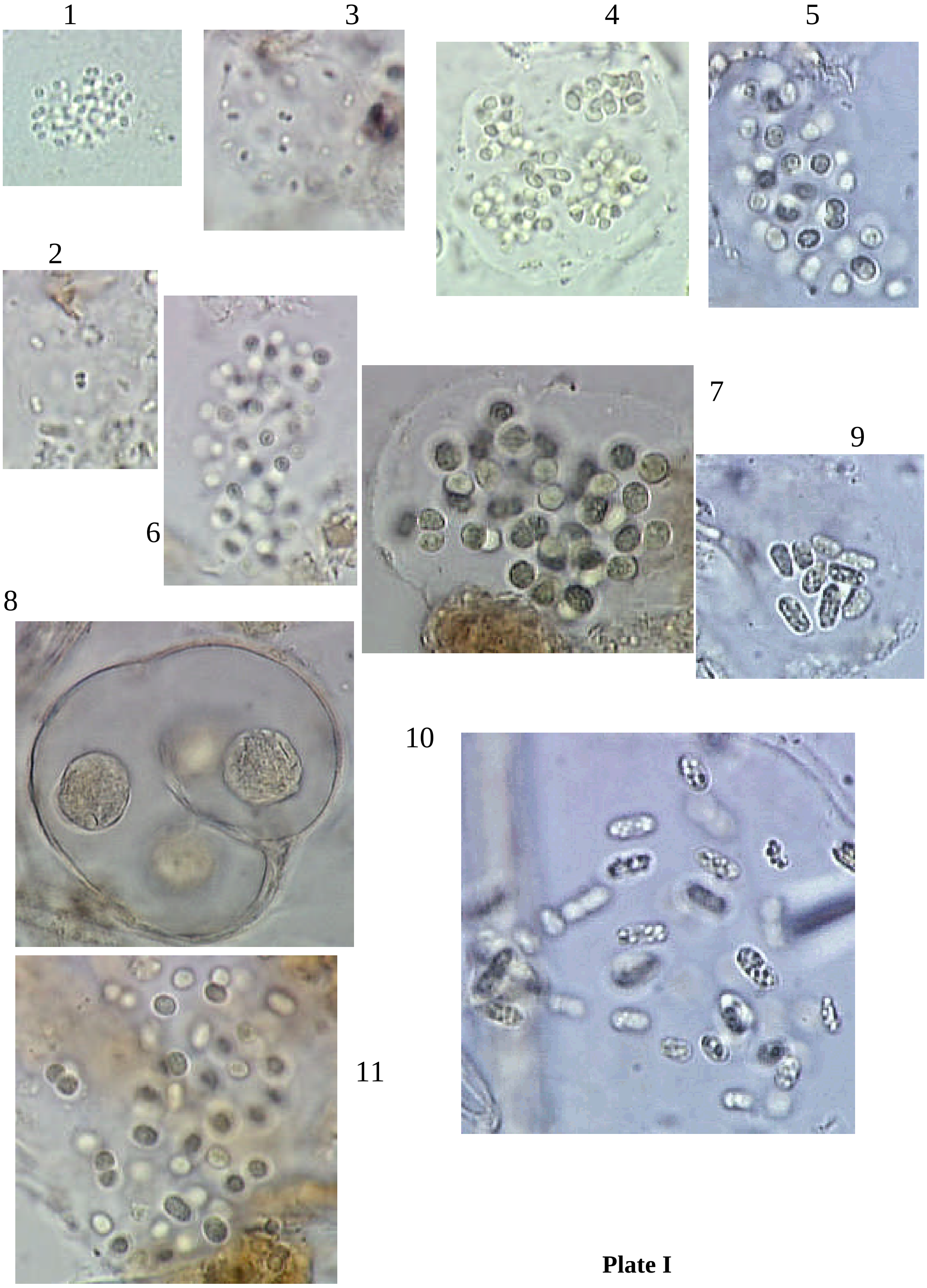

Plate I

1-3 – *Aphanocapsa delicatissima* (cell 1 µm diam.), 4 – *A. elachista* (2 µm), 5 – *A. koordersi* (3 µm), 6 – *A. koordersi* (2.5 µm), 7 – *A. pulchra* (4.5 µm), 8 – *Aphanocapsa* sp. (15 µm); 9 – *Aphanothece pallida* (2 µm, 5 µm L), 10 – *A. pallida* (2 µm, 6 µm L), 11 – *A. stagnina* (3 µm W, 6 µm L)

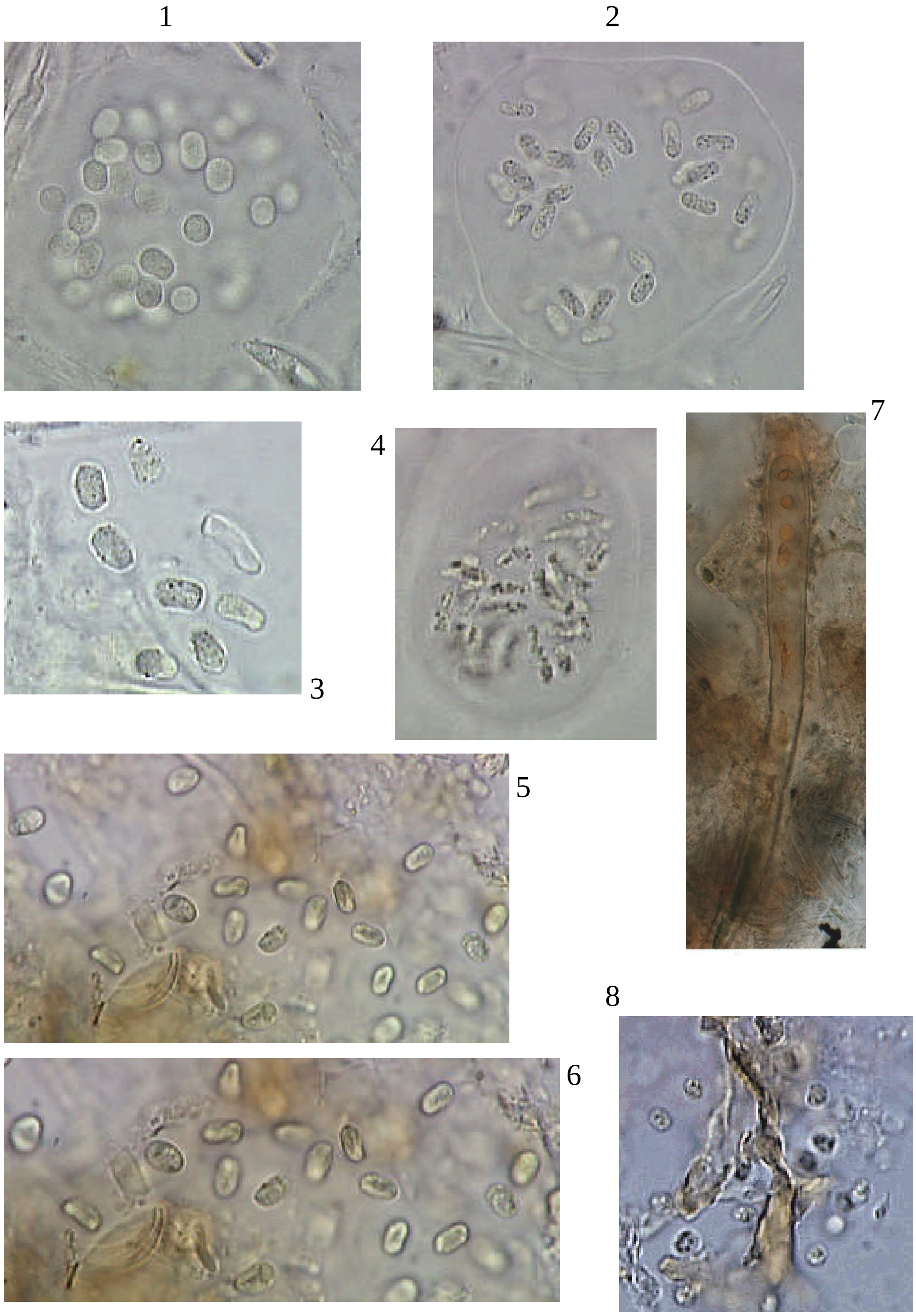

Plate II

1 – *Aphanothece stagnina* (cell 3-5 µm diam.), 2 – *A. stagnina* (3 µm W, 5-8 µm L), 3 – *A. stagninai* (4 µm W, 8 µm L), 4-6 – *Aphanothece* sp. (3 µm W, 6 µm L), 7 – *Calothrix viguieri* (15 µm W), 8 – *Chroococcus dispersus* (3 µm)

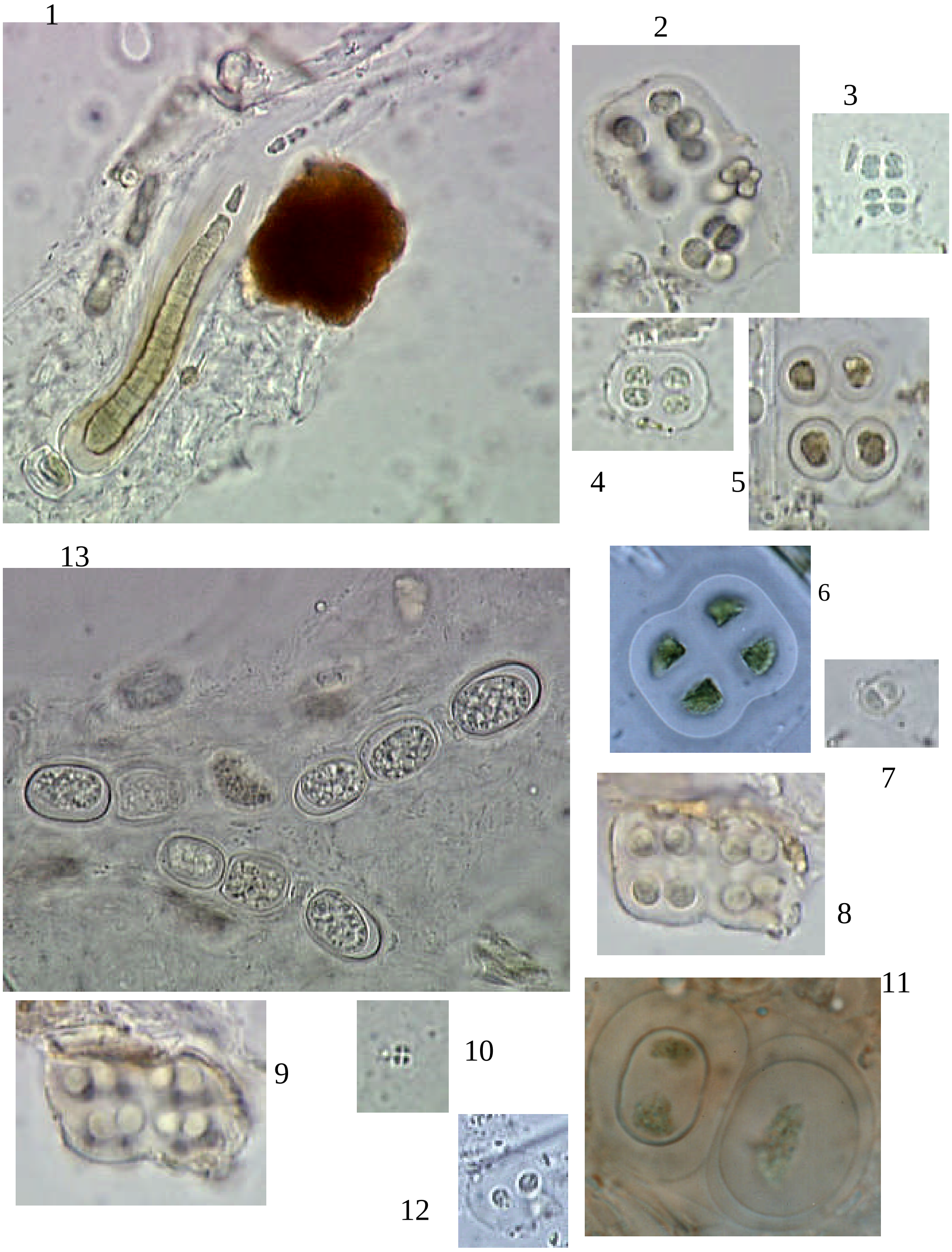

Plate III

1 – *Calothrix consociata* (cell 6 µm W, 2 µm L, heterocyst 10 µm W), 2 – *Chroococcus dispersus* (4 µm in diam.), 3 – *Ch. minimus* (2 µm in diam.), 4, 5 – *Ch. minor* (3 µm in diam.), 6 – *Ch. minutus* (7 µm in diam.), 7 – *Ch. multicoloratus* (2 µm in diam., 3 µm L), 8, 9 – *Ch. prescotii* (4.5-5 µm in diam.), 10 – *Ch. refractus* (1 µm in diam.), 11 – *Ch. turgidus* (8 µm in diam., sheath 23 µm in diam.), 12 – *Ch. varius* (3.5 µm in diam.), 13 – *Entophysalis* sp. (7 µm in diam., 19 µm L)

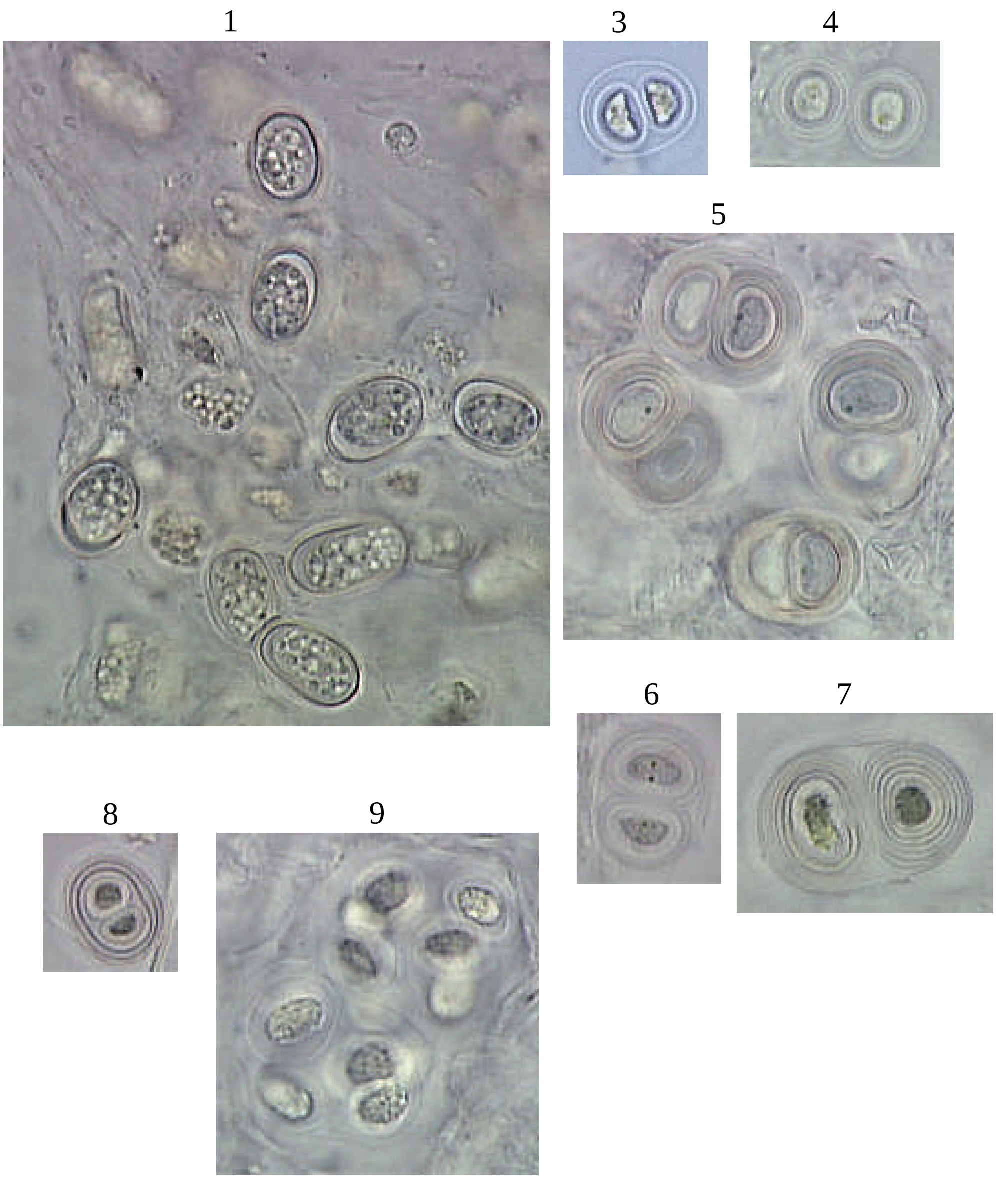

Plate IV

1, 2 – *Entophysalis* sp. (cell 8-9 μm in diam., 11-14 μm L), 3 – *Gloeocapsa calcarea* (cell 3 μm W, 6 μm L), 4, 5 – *G. decorticans* (cell 6-9 μm in diam.), 6, 7 – *Gloeocystis polydermatica* (cell 3-4.5 μm in diam., 8-9 μm L), 8 – *Gloeocapsa quaternata* (cell 4 μm in diam.), 9 – *Gloeothece membranaceae* (cell 4-5 μm W, 6-7 μm L)

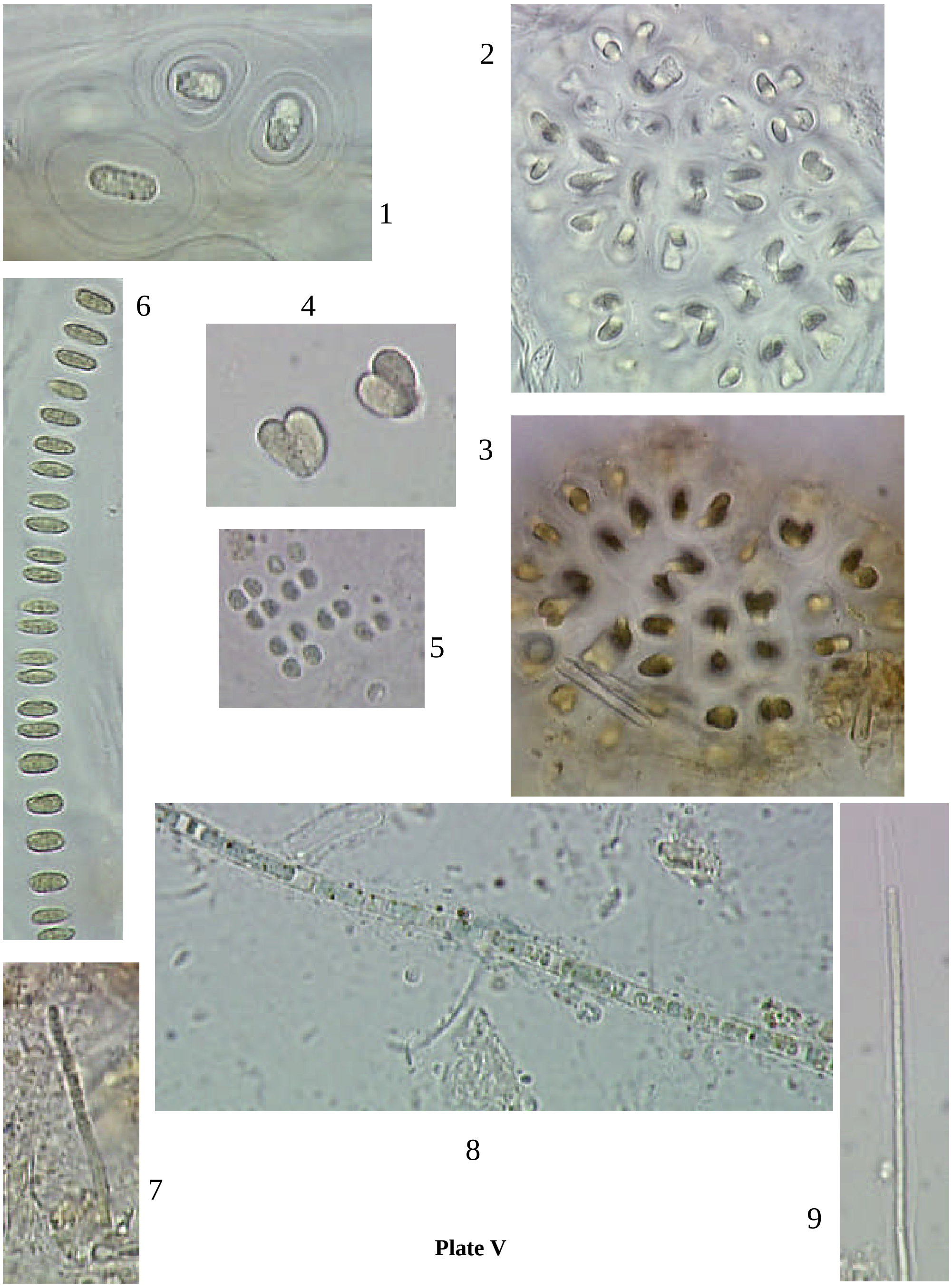

Plate V

1 – *Gloeothece palea* (cell 3 μm W, 6-8 μm L), 2 – *Gomphosphaeria aponina* (cell 3-4 μm W, 6-8 μm L), 3 – *G. aponina* (cell 4 μm W, 6 μm L), 4 – *G. aponina* var. *gelatinosa* (cell 5 μm in diam. 5 μm L), 5 – *Merisopedia punctata* (cell 2-3 μm in diam.), 6 – *Johannesbaptistia pellucida* (cell 7 μm W, 3 μm L), 7 – *Schizothrix lacustris* (cell 1.5 μm W, 1 μm L), 8 – *Leptolyngbya lagerheimii* (cell 1.5 μm W, 1.5 μm L), 9 – *Planktolyngbya limnetica* (cell 1 μm W, 5 μm L)

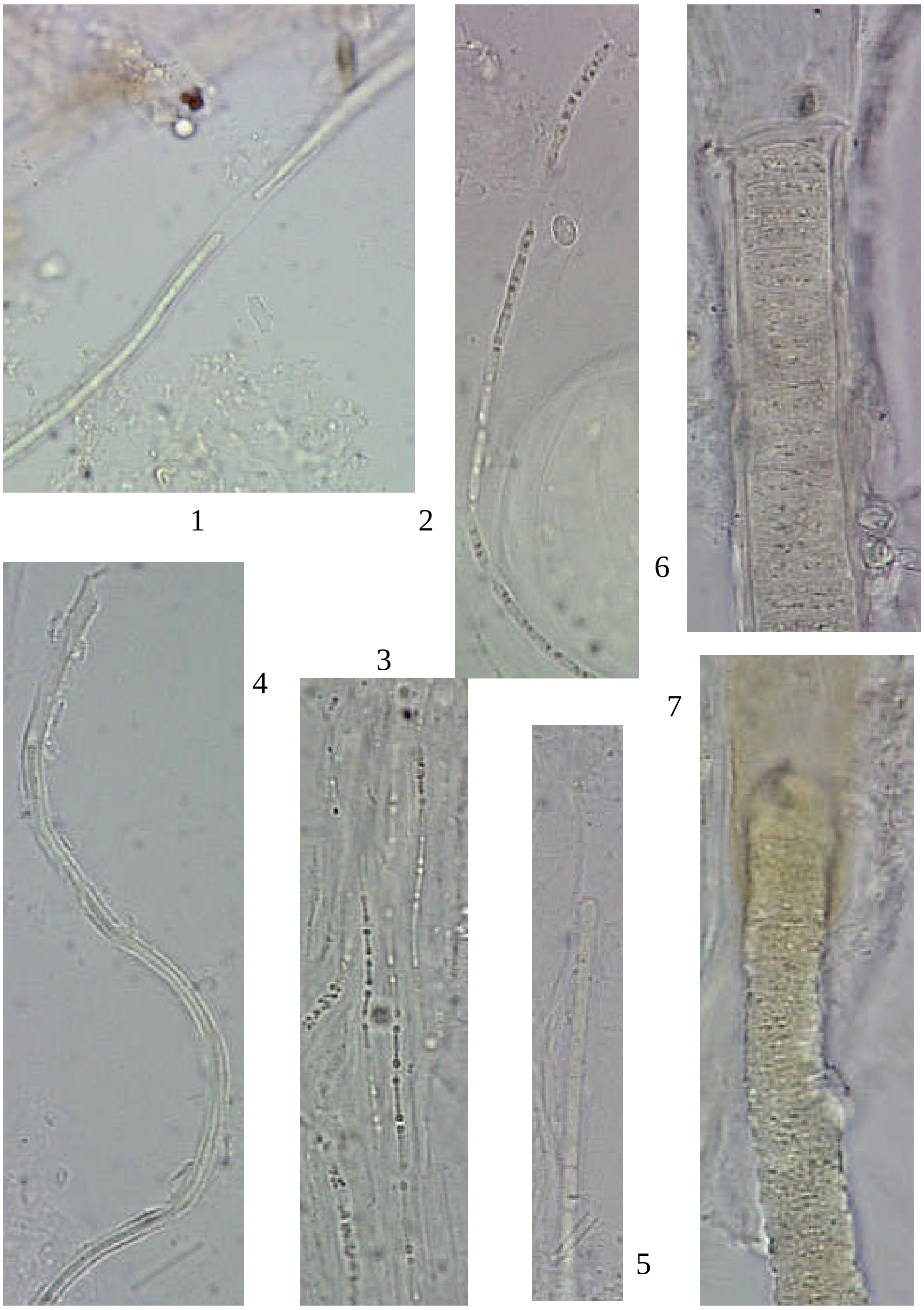

Plate VI

1 – *Phormidium aerugineo-coeruleum* (cell 2 µm W, 6 µm L), 2, 3 – *Planktolyngbya bipunctata* (cell 1 µm W, 4 µm L), 4 – *P. limnetica* (cell 1.5 µm W, 8 µm L), 5 – *P. limnetica* (cell 2 µm W, 10 µm L), 6 – *Lyngbya major* (cell 12 µm W, 3 µm L), 7 – *L. martensiana* (cell 10 µm W, 2 µm L)

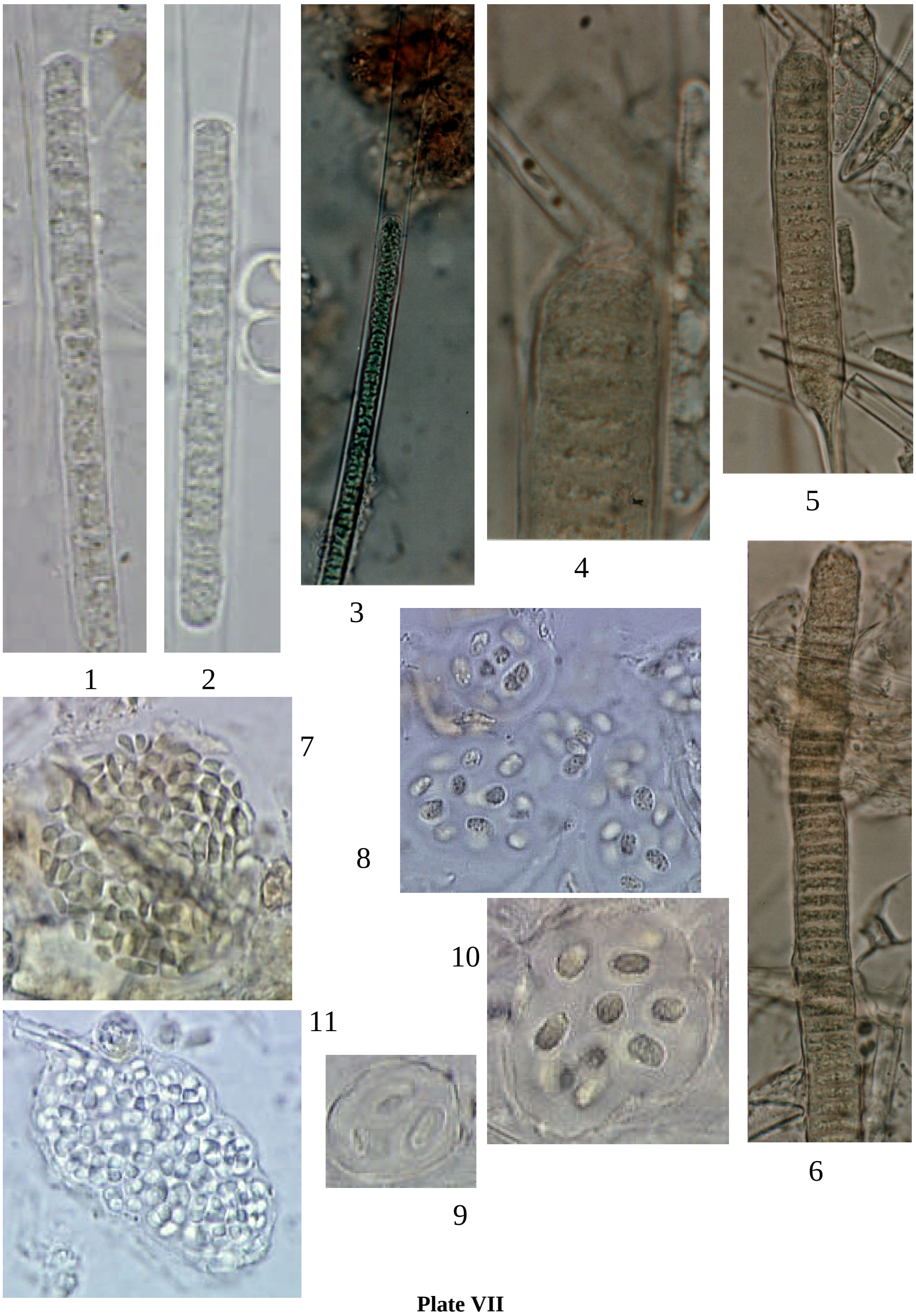

Plate VII

1, 2 – *Porphyrosiphon luteus* (cell 2 μm W, 5 μm L), 3 – *Leibleinia porphyrosiphonis* (cell 1.5 μm W, 2.5 μm L), 4 – *Lyngbya subconfervoides* (cell 15 μm W, 5 μm L), 5, 6 – *L. subconfervoides* 40x, 7-10 – *Microcystis elabens* (cells 2 μm in diam., 4-6 μm L), 11 – *M. stagnalis* (cells 2 μm in diam.)

Plate VIII

1 – *Nostoc commune* (cell 8 μm W, 5 μm L), 2 – *N. commune* (cell 8 μm W, 4 μm L, heterocyst 6 μm in diam.), 3 – *N. commune* (cell 9-10 μm W, 4-9 μm L, heterocyst 5-7 μm in diam.), 4, 5 – *Phormidium articulatum* (cell 2 μm W, 1.5 μm L), 6, 7 – *Pseudoanabaena limnetica* (cell 1 μm W, 5 μm L), 8 – *Phormidium limosum* (cell 6 μm W, 2.5 μm L)

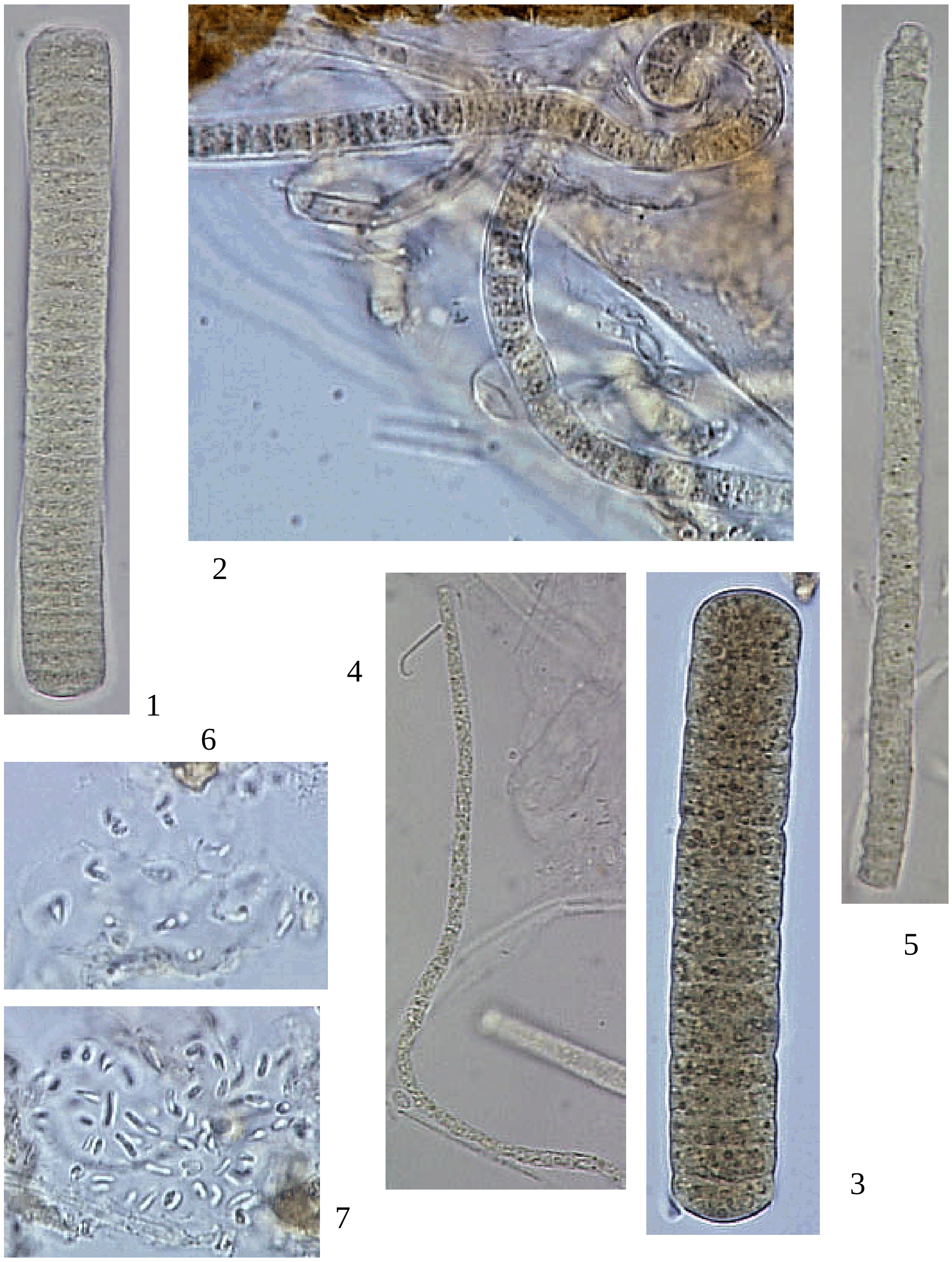

Plate IX

1 – *Tychonema bornetii* (cell 12 µm W, 4 µm L), 2 – *Oscillatoria capitata* (cell 5 µm W, 3 µm L), 3 – *Phormidium limosum* (cell 15 µm W, 5 µm L), 4 – *Planktothrix prolifica* (cell 2 µm W, 2 µm L), 5 – *Phormidium limosum* (cell 5 µm W, 3 µm L), 6 – *Pelogloea bacillifera* (cell 1 µm in diam., 3.5 µm L), 7 – *P. bacillifera* (cell 1 µm in diam., 4-6 µm L)

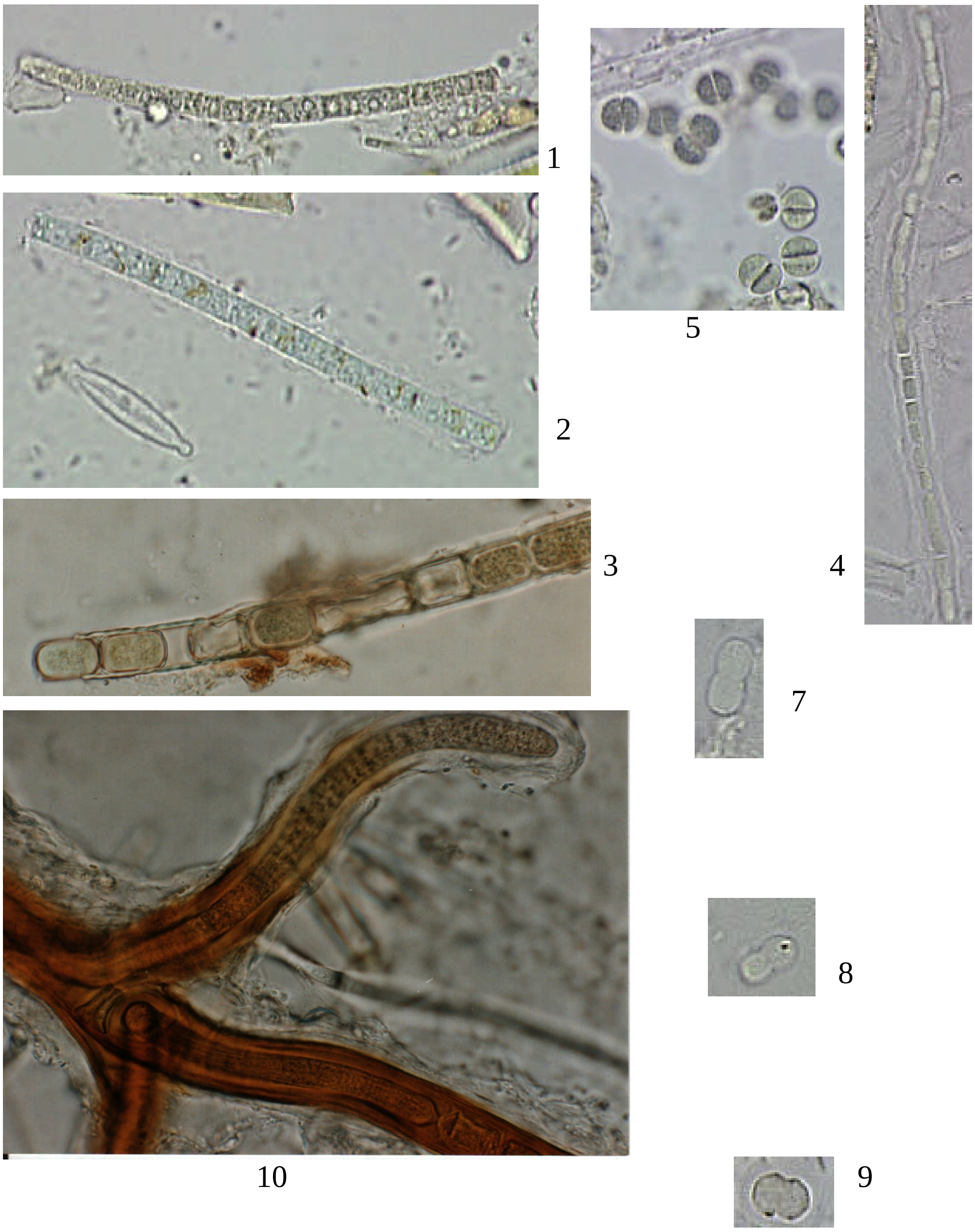

Plate X

1 – *Planktothrix prolifica* (cell 3.5 µm W, 2.5 µm L), 2 – *P. prolifica* (cell 2.5 µm W, 4 µm L), 3 – *Phormidium mucicola* (cell 5 µm W, 7 µm L), 4 – *Phormidium* sp. (cell 2 µm W, 3 µm L), 5 – *Synechocystis aquatilis* (cell 6 µm in diam., 7 µm L), 6, 7 – *Cyanothece aeruginosa* (cell 4 µm in diam., 8-9 µm L), 8 – *C. aeruginosa* (cell 5 µm in diam., 7 µm L), 9 – *C. aeruginosa* (cell 6 µm in diam., 8 µm L), 10 – *Scytonematopsis kachyapi* (cell 8 µm W, 8 µm L)

Plate XI

1 – *Rhabdoderma sigmoidea* f. *minor* (cell 1.5 µm W, 16 µm L), 2 – *Scytonema myochroum* (cell 4-5 µm diam., heterocyst 5-7 µm diam.), 3 – *S. myochroum* (cell 6-9 µm diam., heterocyst 7-12 µm diam.), 4 – *Scytonema hofman-bangii* (cell 7 µm W, 3 µm L)

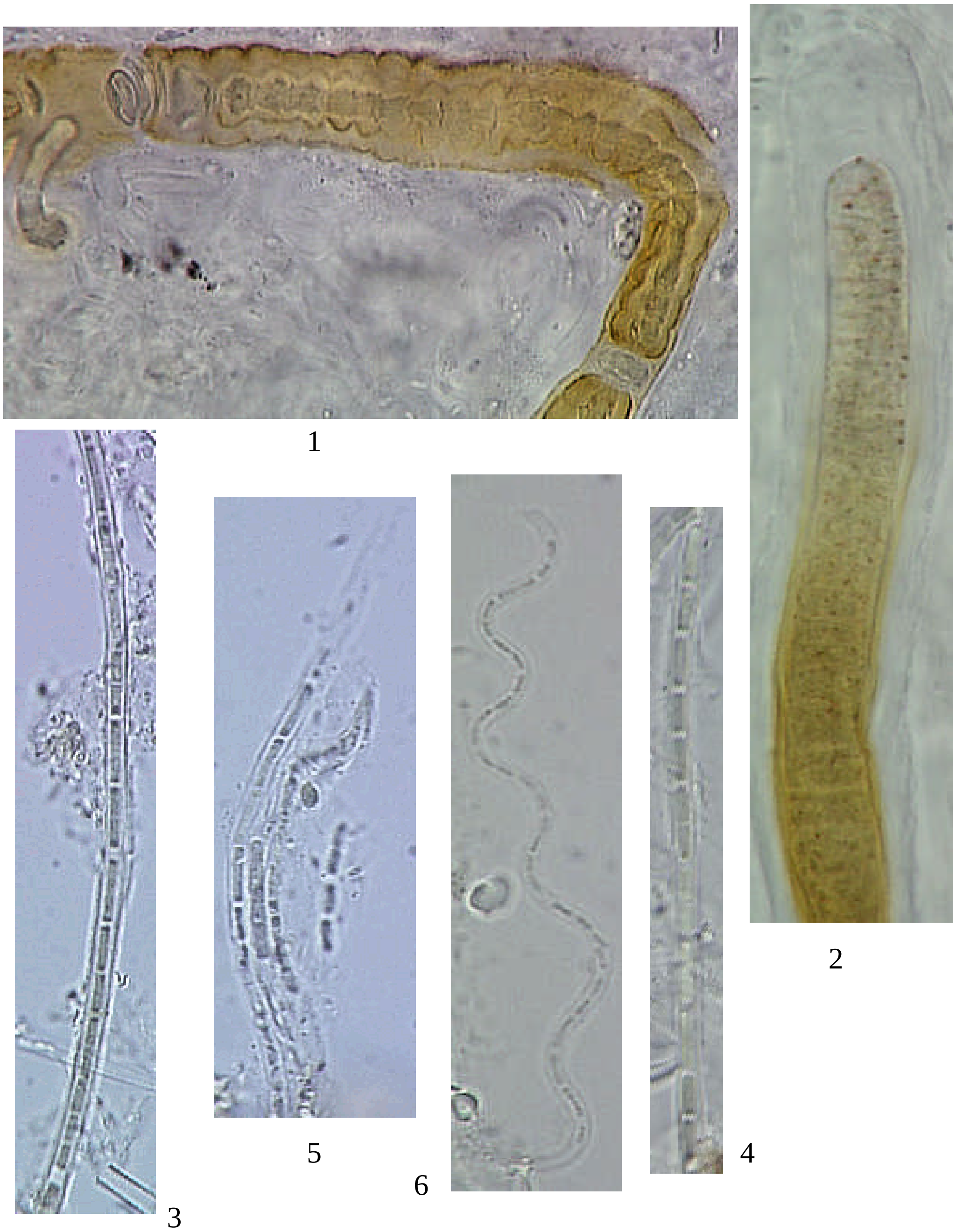

Plate XII

1 – *Scytonema myochroum* (cell 6-9 µm diam., heterocyst 7-12 µm diam.), 2 – *S. hofman-bangii* (cell 7 µm W, 3 µm L), 3 – *Symplocastrum cuspidatum* (cell 8 µm W, 8 µm L), 4 – *S. cuspidatum* (cell 2 µm W, 8 µm L), 5 – *S. cuspidatum* (cell 1.5 µm W, 5 µm L), 6 – *S. cuspidatum* (cell 1 µm W, 3.5 µm L)

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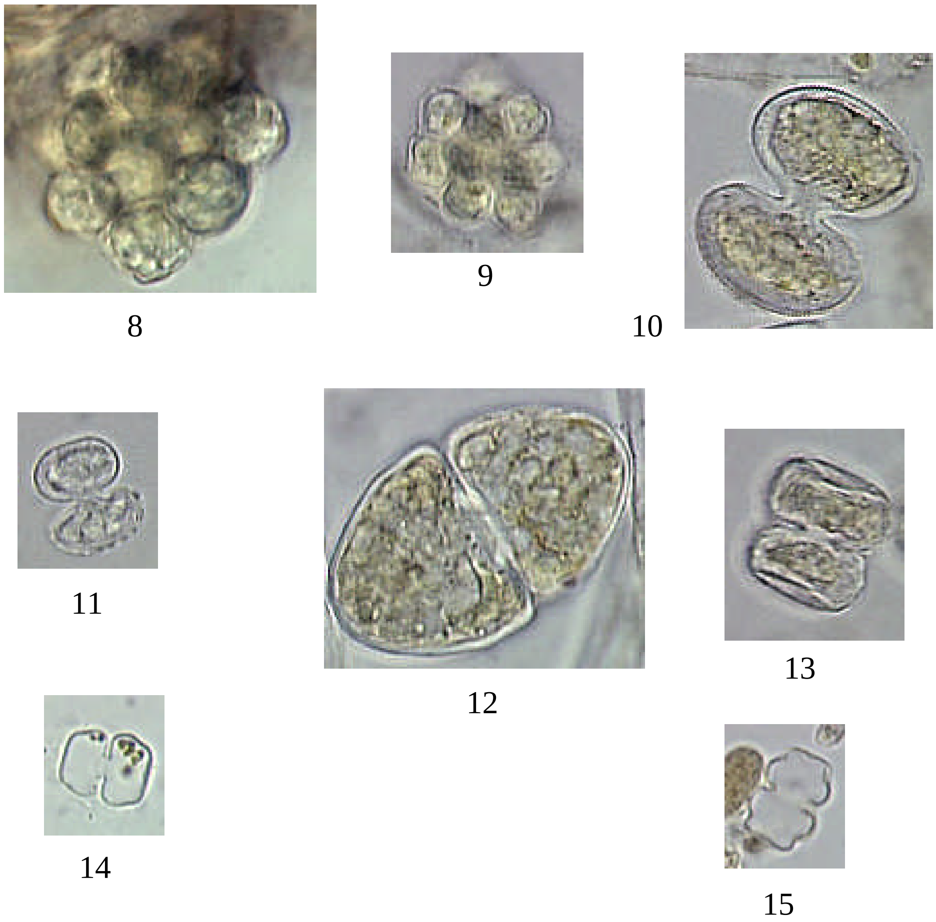

Plate XIII

1 – *Scytonema hofman-bangii* (heterocysts 6 µm W, 22 µm L), 2 – *Symplocastrum cuspidatum* (cell 1 µm W, 8-9 µm L), 3 – *Actinotaenium cruciferum* f. *latius* (cell 20 µm W, 23 µm L, isthmus 14 µm W), 4, 5 – *Monoraphidium mirabile* (cell 2-3 µm W, 22 µm L), 6 – *Ankistrodesmus fusiformis* (cell 2 µm W, 24 µm L), 7 – *Chaetophora attenuata* (cell 7 µm W, 36-42 µm L), 8 – *Coelastrum indicum* (cell 10 µm W), 9 – *C. sphaericum* (cell 6 µm W), 10 – *Cosmarium bioculatum* (cell 19 µm W, 25 µm L, isthmus 5 µm W), 11 – *C. contractum* var. *minutum* (cell 9 µm W, 12 µm L, isthmus 3 µm W), 12 – *C. granatum* (cell 22 µm W, 37 µm L, isthmus 5 µm W), 13 – *C. minimum* (cell 13 µm W, 14 µm L, isthmus 4 µm W), 14 – *C. regnesi* (cell 9 µm W, 10 µm L, isthmus 2 µm W), 15 – *C. regnesi* (cell 8 µm W, 11 µm L, isthmus 8 µm W)

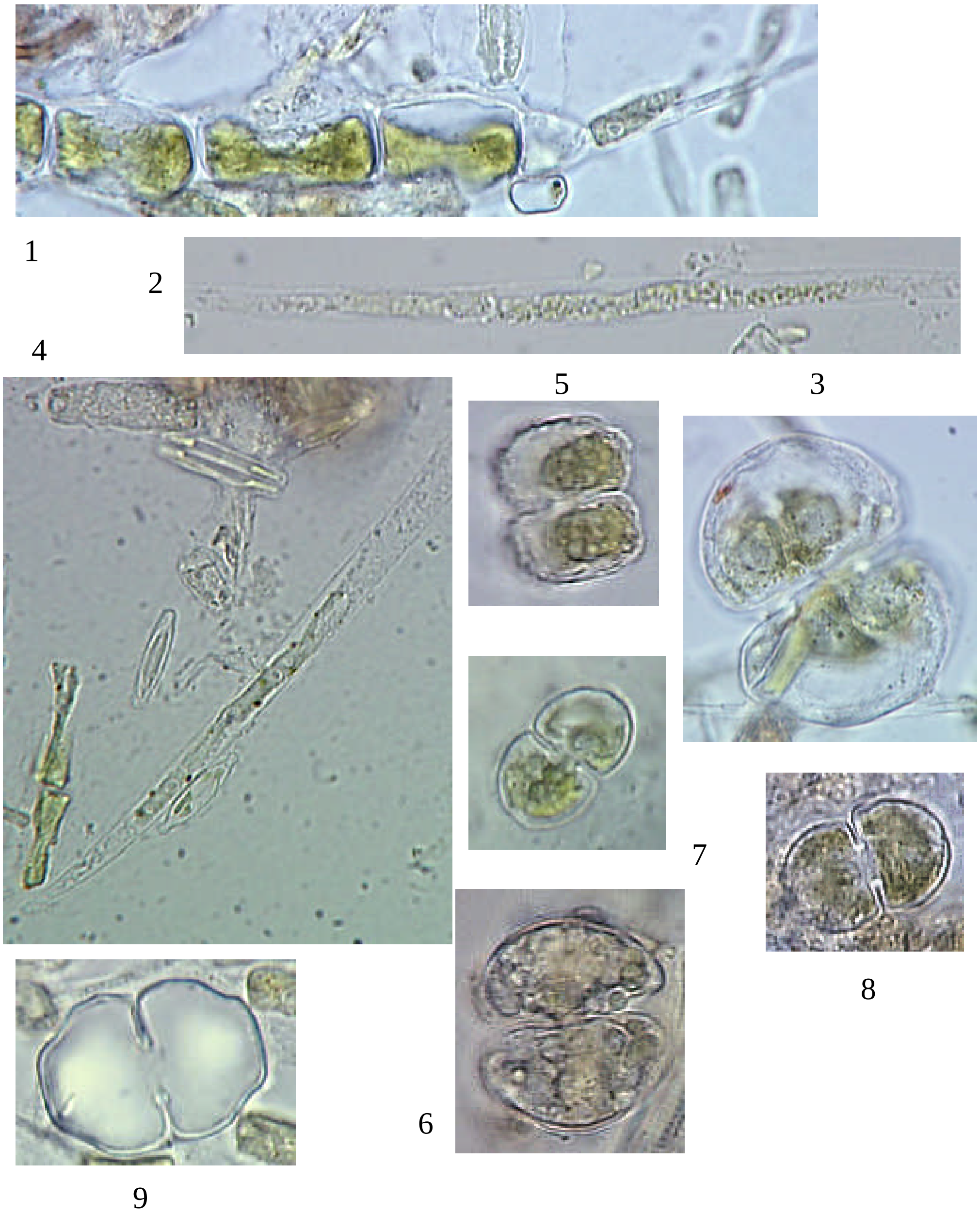

Plate XIV

1 – *Bulbochaete* sp. (cell 12-15 µm W, 22-30 µm L), 2 – *Closterium acutum* var. *variabile* (cell 5 µm W, 106 µm L), 3 – *Cosmarium pachydermum* var. *incrassatum* (cell 42 µm W, 55 µm L, isthmus 15 µm W), 5 – *Closteriopsis longissima* (cell 6 µm W, 170 µm L), 6 – *Cosmarium pseudoretusum* (cell 15 µm W, 18 µm L, isthmus 4 µm W), 7 – *C. pseudotaxichondrum* var. *foggii* (cell 21 µm W, 25 µm L, isthmus 4 µm W), 8 – *C. subcucumis* (cell 12 µm W, 23 µm L, isthmus 4 µm W), 9 – *C. subcucumis* (cell 14 µm W, 20 µm L, isthmus 4 µm W), 10 – *C. trilobulatum* (cell 18 µm W, 29 µm L., isthmus 5 µm W)

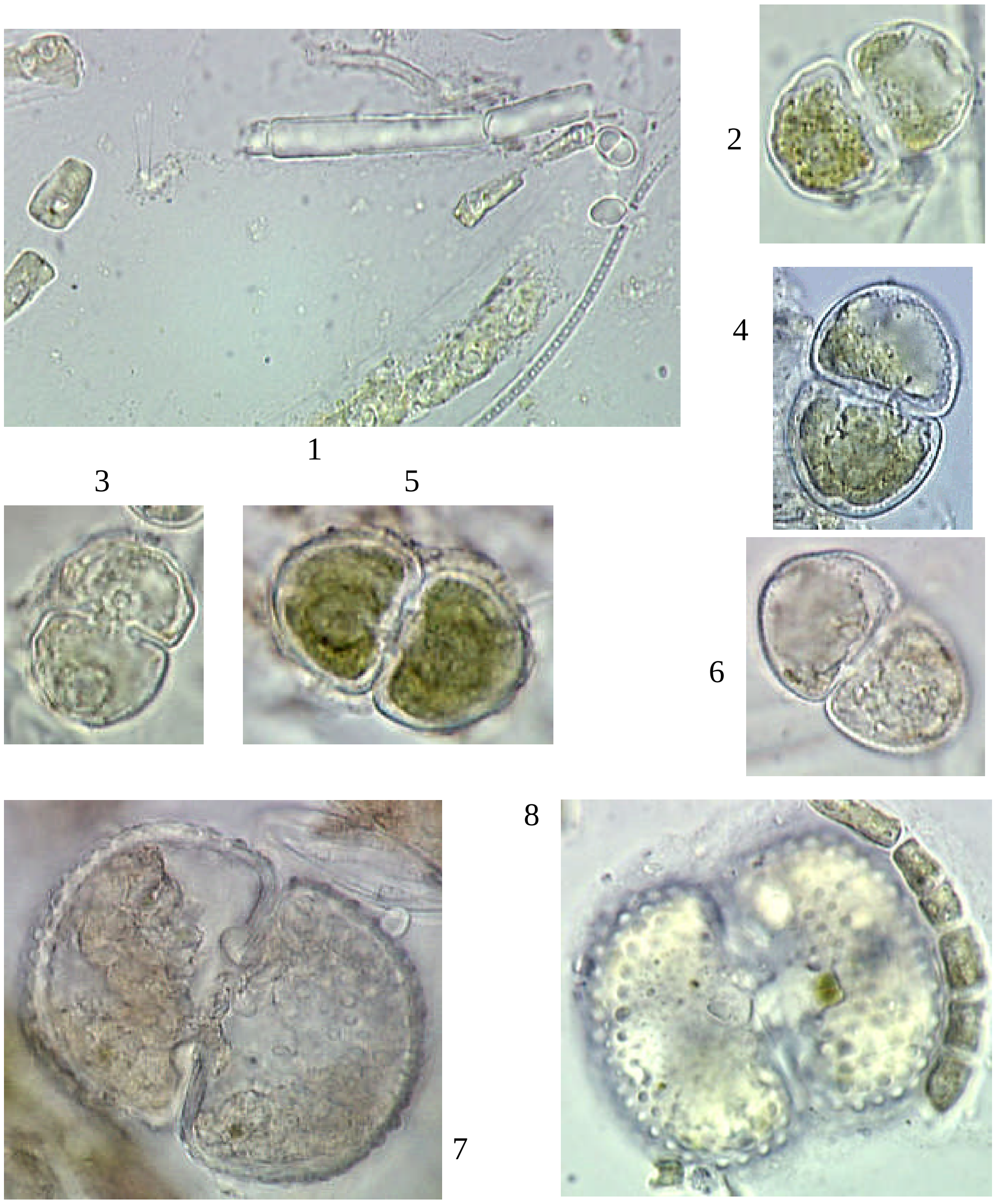

Plate XV

1 – *Closterium parvulum* (cell 17.5 µm W, 115 µm L), 2 – *Cosmarium undulatum* var. *minutum* (cell 19 µm W, 29 µm L, isthmus 5 µm W), 3 – *C. undulatum* var. *minutum* (cell 20 µm W, 25 µm L, isthmus 5 µm W), 4 – *C. variolatum* (cell 20 µm W, 35 µm L, isthmus 5 µm W), 5 – *C. variolatum* (cell 20 µm W, 33 µm L, isthmus 8 µm W), 6 – *C. variolatum* (cell 20 µm W, 35 µm L, isthmus 7 µm W), 7 – *Cosmarium reniforme* var. *apertum* (cell 42 µm W, 55 µm L, isthmus 13 µm W), 8 – *C. reniforme* var. *apertum* (cell 50 µm W, 60 µm L, isthmus 18 µm W)

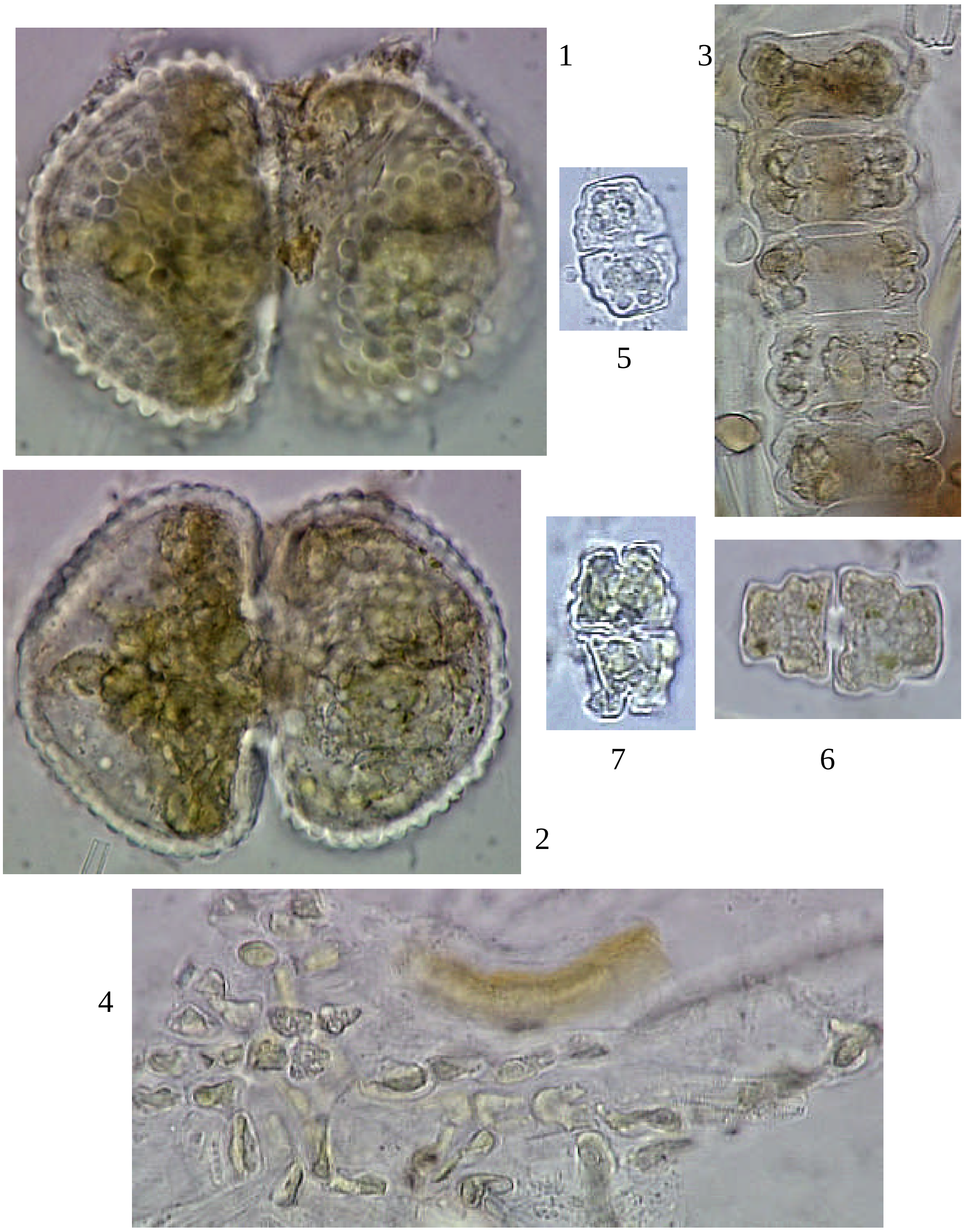

Plate XVI

1, 2 – *Cosmarium botrytis* (cell 70 µm W, 90 µm L, isthmus 38 µm W), 3 – *Desmidium aptogonum* var. *ehrenbergii* (cell 26 µm W, 13 µm L), 4 – *Epibolium dermaticola* (cell 4-6 µm W, 5-12 µm L), 5 – *Euastrum binale* var. *gutwinskii* (cell 13 µm W, 18 µm L, isthmus 4 µm W), 6 – *E. cornubiense* var. *medianum* f. *subgranulatum* (cell 19 µm W, 31 µm L, isthmus 7 µm W), 7 – *E. lapponicum* f. *leave* (cell 15 µm W, 20 µm L, isthmus 3 µm W)

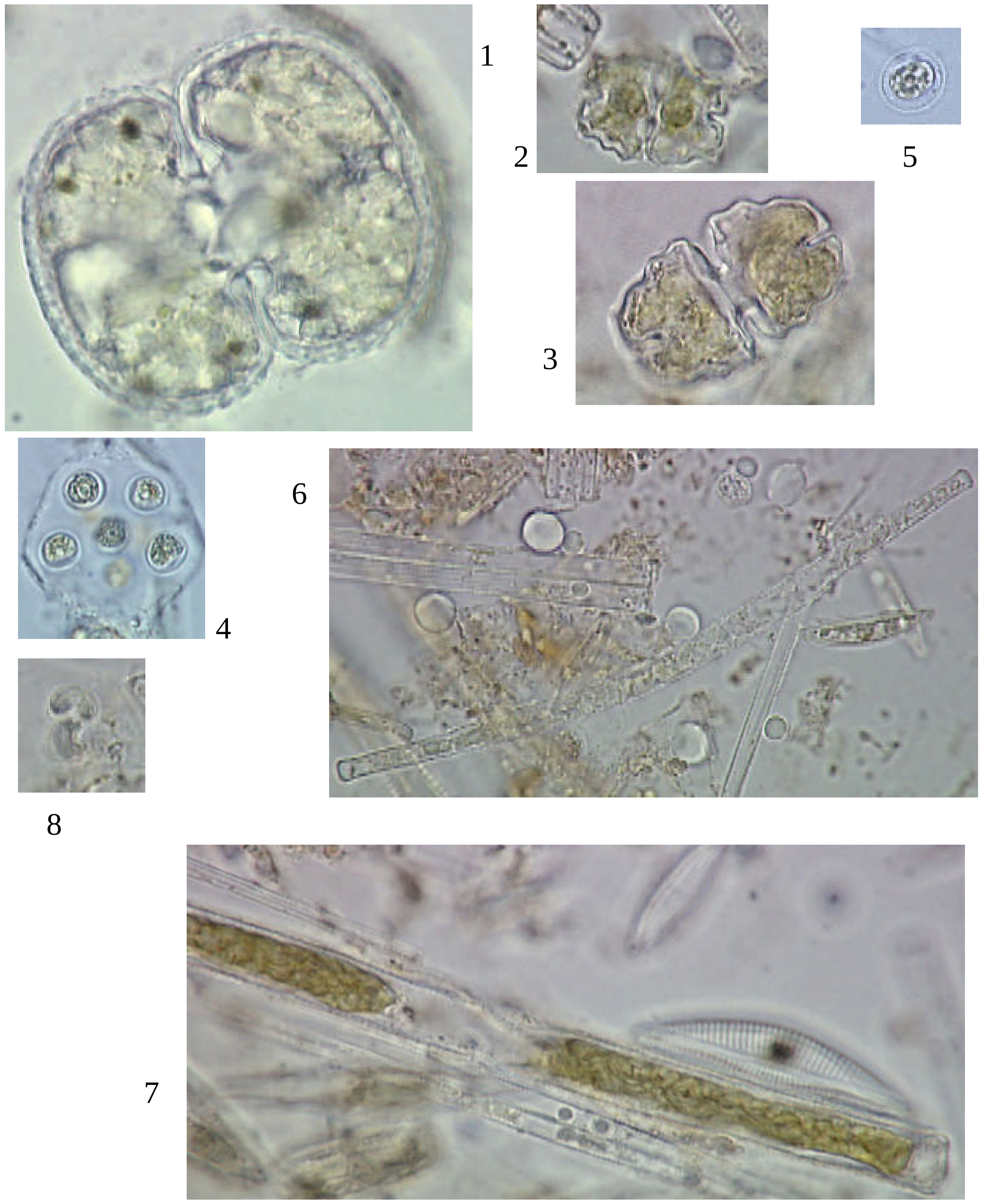

Plate XVII

1 – *Cosmarium reniforme* var. *apertum* (cell 50 μm W, 60 μm L, isthmus 18 μm W), 2 – *Euastrum lapponicum* f. *leave* (cell 15 μm W, 20 μm L, isthmus 3 μm W), 3 – *Euastrum* sp. (cell 22 μm W, 37 μm L, isthmus 8 μm W), 4 – *Gloecystis vesiculosa* (cell 4 μm in diam.), 5 – *G. vesiculosa* (cell 4 μm in diam.), 6 – *Gonatozygon brebissonii* (cell 5 μm W, 114 μm L), 6 – *G. pilosum* (cell 10 μm W, 210 μm L), 7 – *Raphidocelis subcapitata* (cell 3 μm W, 6 μm L)

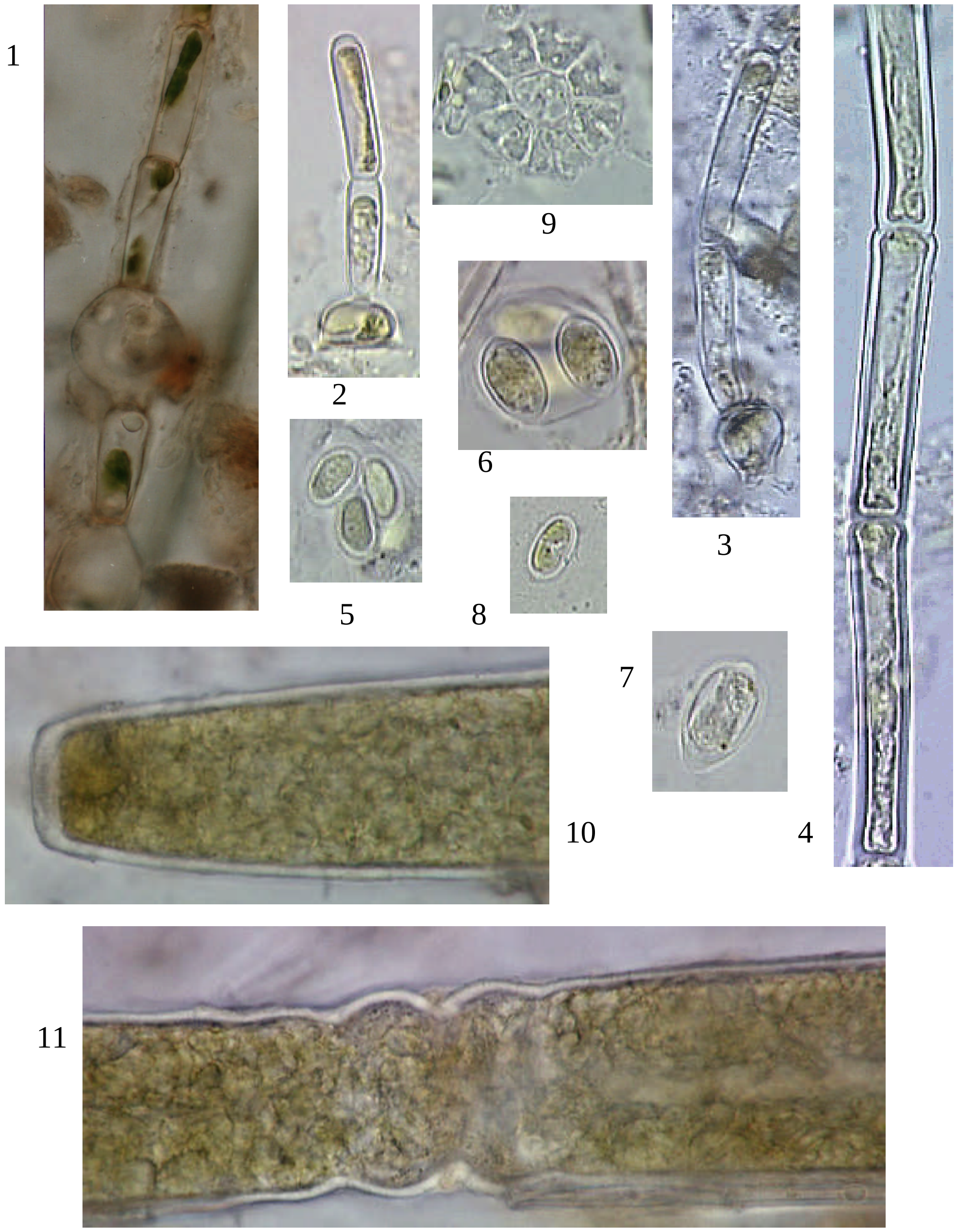

Plate XVIII

1 – *Oedogonim capitellatum* (cell 5 μm W, 18 μm L, oogonium 18 μm W, 15 μm L), 2 – *Oedogonium* sp. A (cells 4.5-5 μm W, 16-20 μm L), 3 – *Oedogonium* sp. B (cells 5 μm W, 27 μm L), 4 – *Oedogonium* sp. C (cells 7 μm W, 36 μm L), 5 – *Oocystis novae-semliae* (cells 5 μm W, 9 μm L), 6 – *O. solitaria* (cells 8 μm W, 12 μm L), 7 – *O. solitaria* (cells 9 μm W, 14 μm L), 8 – *O. solitaria* (cells 6 μm W, 10 μm L), 9 – *Stauridium tetras* (cells 5 μm W, 5-7 μm L), 10 – *Pleurotaenium maximum* (central area 100X), 11 – *P. maximum* (end area 100X)

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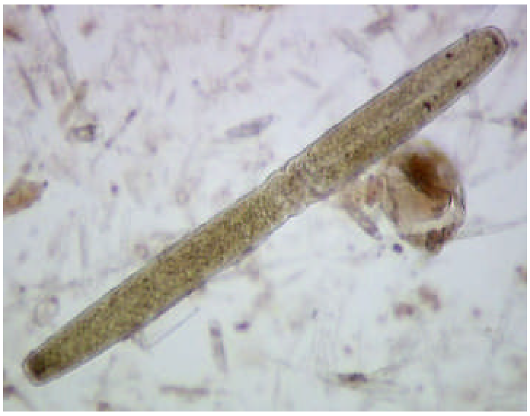

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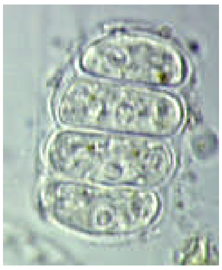

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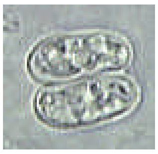

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Plate XIX

1 – *Pleurotaenium maximum* (cells 32 µm W, 360 µm L – 20X), 2 – *Scenedesmus denticulatus* var. *linearis* f. *granulatus* (cells 5 µm W, 15 µm L), 3 – *S. ecornis* (cells 6 µm W, 11-15 µm L), 4 – *S. ecornis* (cells 6 µm W, 11 µm L), 5, 6 – *S. ecornis* (cells 5 µm W, 10 µm L), 7 – *S. verrucosus* (cells 3-4 µm W, 5-8 µm L), 8 – *S. verrucosus* (cells 3-4 µm W, 8-10 µm L), 9 – *S. incrassatulus* (cells 5 µm W, 15 µm L), 10, 11 – *S. incrassatulus* (cells 3 µm W, 10 µm L), 12 – *S. incrassatulus* (cells 3 µm W, 8 µm L), 13 – *S. quadricauda* var. *longispina* (cells 4-5 µm W, 15-17 µm L), 14 – *S. tibiscensis* (cells 5 µm W, 15 µm L), 15 – *Selenastrum gracile* (cells 3 µm W, 20 µm L), 16 – *Staurastrum dejectum* var. *apiculatum* (cell 19 µm W, 24 µm L, isthmus 7 µm W), 17, 18 – *S. dilatum* (cell 17 µm W, 34 µm L, isthmus 13 µm W), 19 – *S. gracile* (cell 20 µm W, 24 µm L, isthmus 5 µm W)

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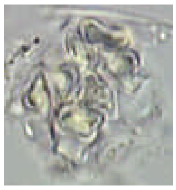

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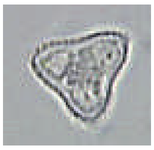
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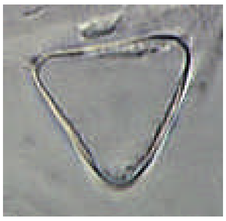
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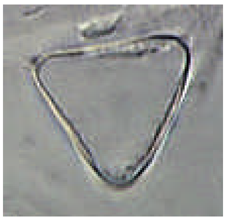
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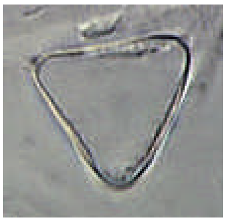
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Plate XX

1 – *Staurastrum pingue* (cell 12 µm W, 40 µm L, isthmus 10 µm W), 2 – *S. pingue* (arms 30 µm W, 64 µm L), 3 – *S. gracile* (arms 36 µm W, 36 µm L), 4, 6 – *Tetraedron minimum* (cells 8 µm W), 5 – *T. minimum* (cells 5 µm W), 7 – *T. minimum* (cells 13 µm W), 8 – *T. minimum* (asexual reproduction), 9 – *T. muticum* (cells 12.5 µm W), 10 – *T. muticum* (cells 11 µm), 11-13 – *T. regulare* var. *granulata* (cells 16 µm W), 14 – *Stigeoclonium tenue* (cells 6-7 µm W, 18-25 µm L)

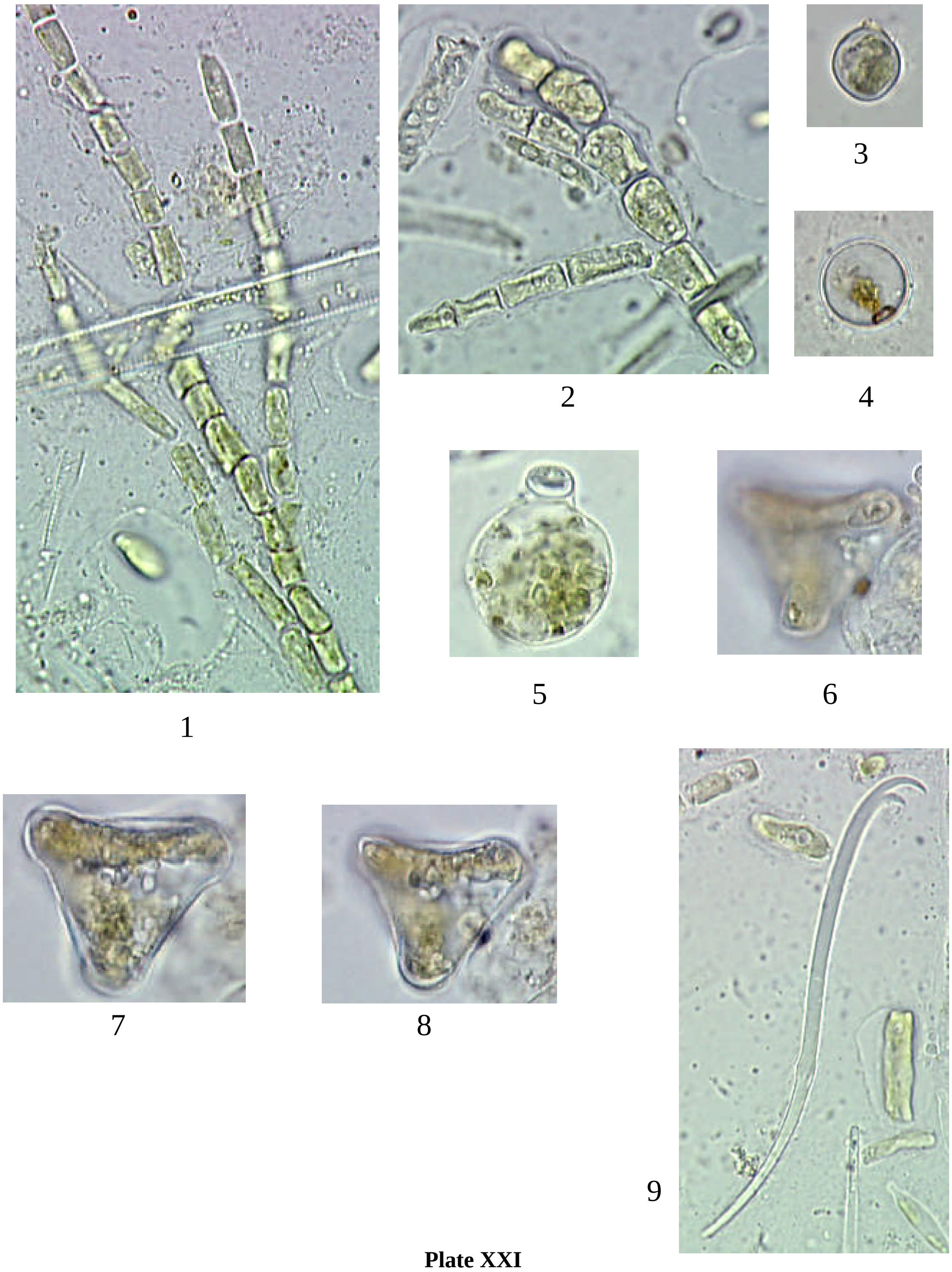

Plate XXI

1, 2 – *Stigeclonium tenue* (cells 5-9 μm W, 11-15 μm L), 3 – *Trachelomonas volvocina* (cells 11 μm in diam.), 4 – *T. volvocina* var. *compressa* (cells 12 μm in diam.), 5 – *Strombomonas fluviatilis* (cells 20 μm W, 20 μm L, Collar 7 μm W, 5 μm L), 6, 7, 8 – *Triceratium favus* f. *octogonum* (cells 28-29 μm W), 9 – *Sigmoid* (cells 3 μm W, 100 μm L)