Preslia, Praha, 51 : 289—312, 1979

Taxonomic position of three planktonic blue-green algae from the genera *Aphanizomenon* and *Cylindrospermopsis*

Taxonomie tří planktonních sinic z rodů *Aphanizomenon* a *Cylindrospermopsis*

Mária Horecká and Jiří Komárek

Horecká M.[1]) et J. Komárek[2]) (1979): Taxonomic position of three planktonic blue-green algae from the genera *Aphanizomenon* and *Cylindrospermopsis*. — Preslia, Praha, 51 : 289—312.

Two freshwater planktonic blue-green algae with well developed spores, *Anabaena aphanizomenoides* and *Anabaenopsis raciborskii*, occurring mainly in tropical countries and in warmer areas of the temperate zone were found in southern parts of Czechoslovakia (SW. Slovakia, Central Moravia) and in Hungary (near Dabas). The morphological variation of all the populations found was studied. Comparing the diacritical generic features, *Anabaena aphanizomenoides*, which occurs mainly in tropical and subtropical Asia and SE. Europe, has been transferred into the genus *Aphanizomenon*: *A. aphanizomenoides* (Forti) Horecká et Komárek. From the tropical Asia another similar *Aphanizomenon* species (*A. tropicalis* Horecká et Komárek) has been separated from *A. aphanizomenoides*, and defined. *Anabaenopsis raciborskii* must be excluded from the genus *Anabaenopsis* because of quite different development of heterocysts. "*A. raciborskii*" is most related to the genus *Cylindrospermum*; however, on the basis of numerical evaluation of nostocacean genera, the classification of this alga to the separate genus *Cylindrospermopsis* Seenayya et Subba Raju 1972 is supported. *Cylindrospermopsis raciborskii* is spread in tropical countries all over the world, and occurs occasionally also in temperate zone: SE. Europe, USA (Kan., Minn.) and southern parts of the USSR.

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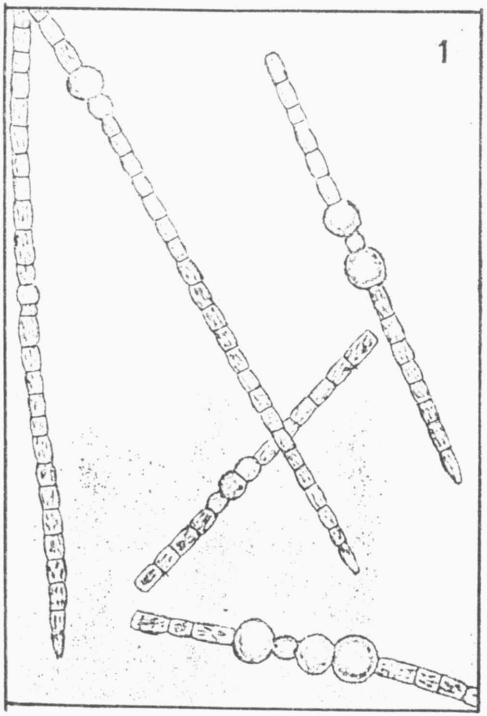
During the year 1978 we found, in the Pannonian region (NW. part), two assemblages of blue-green algae containing several interesting planktonic species, the systematic position of which had not yet been satisfactorily clarified. We tried to evaluate statistically both samples and to solve the taxonomy of two dominant species, *Anabaena aphanizomenoides* Forti 1912 and *Anabaenopsis raciborskii* (Woloszynska) Elenkin 1923. They occurred with well developed spores in both localities.

Description of samples:

1. An artificial reservoir Boričky (approx. 28 ha, depth 1.5—2 m) at Kopčany near Senica in SW. Slovakia, Czechoslovakia, originated as a gravel-pit lake, fed with ground water and by the polluted creek Cunínský potok. The samples were repeatedly taken during the period 29th May to 15th September 1978 (Horecká). In the end of May, the water had a green colour and contained water bloom, caused by filamentous and coccal blue-green and chlorococcal algae. The dominant filamentous blue-green algae were *Oscillatoria agardhii*, *O. acuiformis*, *O. redekei*, *Pseudanabaena limnetica*, from the chlorococcal species *Microcystis aeruginosa* and *Merismopedia glauca*. After the rapid death of this community in the first days of June, the *Oscillatoria* species mentioned occurred again and, rarely, *Anabaena aphanizomenoides*, *Anabaenopsis elen-*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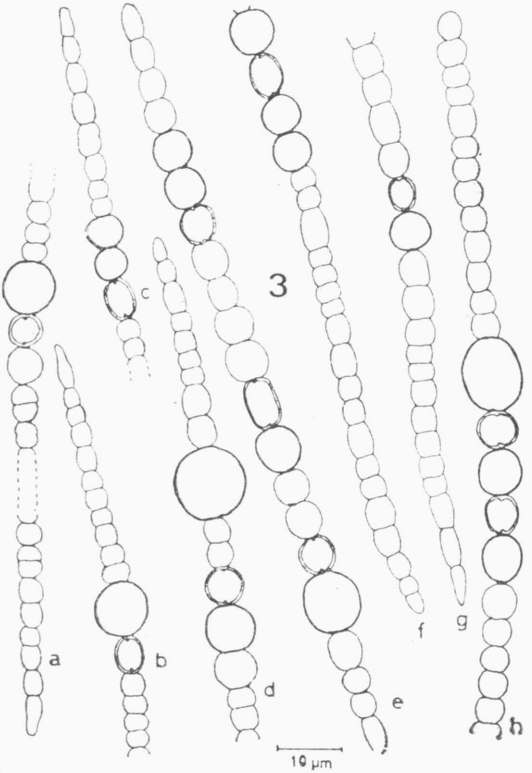
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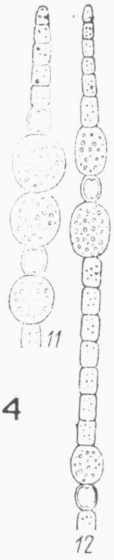
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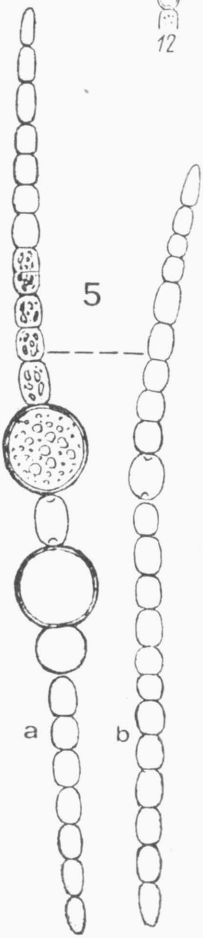
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kinii and *Aphanizomenon issatschenkoi*. *Anabaenopsis raciborskii* was first recognized at the end of July (without heterocysts), and it occurred commonly during August and September (the trichomes with heterocysts and spores). Water temperature ranged in this period from 18 to 27 °C, pH from 6.9 to 9.3, the amount of O_2 soluble in the water ranged from 1.3 to 16.2 mg.l^{-1}.

2. Rapidly floating water in an artificial stream (probably the outflow from the reservoir) near Dabas, Hungary. The sample was collected on 24th September 1978 (KOMÁREK). The water had a green colour; it contained many dispersed planktonic blue-green algae with gas vacuoles. The sample was dominated by *Anabaenopsis raciborskii; Anabaena aphanizomenoides, Anabaena flos-aquae* and *Microcystis wesenbergii* occurred in small amounts. No more ecological data were recorded.

Aphanizomenon aphanizomenoides (FORTI) HORECKÁ et KOMÁREK

FORTI (1912) described, from one lake in Anatolia (Turkey), the planktonic blue-green alga *Anabaena aphanizomenoides* with the following features (according to GEITLER 1932): „Trichome einzeln, gerade oder leicht gebogen, 1—2 mm lang, 4—5 μ breit, an den Querwänden schwach eingeschnürt. Zellen tonnenförmig-zylindrisch, 1—3mal länger als breit, mit Gasvakuolen. Heterocysten fast kugelig oder leicht ellipsoidisch, 5.5—7 μ breit, 6—7.5 μ lang. Dauerzellen einzeln oder zu wenigen neben den Heterocysten, kugelig, 8—14 μ breit, mit glatter, farbloser Membran." (Fig. 1, iconotype).

This species was later found in Malaysia (PROWSE 1972), where it is "common in fish ponds and often forms blooms" (Fig. 2). Besides, PROWSE described another *Aphanizomenon*-like alga, "*Raphidiopsis mediterranea* SKUJA with heterocysts and oval spores, adjacent to the heterocysts from one or both sides", with cells 4.5—6 × 2.5—3.5 μm and spores 9—14 × 4—4.5 μm; the ends of the trichomes of this alga are extremely long-attenuated and sharply pointed. DESIKACHARY (1959) mentions *Anabaena aphanizomenoides* from India (Madras) with the heterocysts only about 4.5 μm wide and the spores 10.5 μm long and about 7 μm wide (i.e., with oval spores). The identity of this material with Malayan specimens with oval spores is probable.

Typical *Anabaena aphanizomenoides* with spherical spores was recently found (in summer) in warmer areas of SE. Europe, e.g. in Hungary (near Szeged — HORTOBÁGYI 1955, HEGEWALD et al. 1975; in Szelidi lake — A. SCHMIDT 1975; near Dabas — leg. KOMÁREK) and in Czechoslovakia (water reservoir Chomoutov near Olomouc — leg. ŠTĚRBA; water reservoir Boričky near Senica — leg. HORECKÁ). The morphological features of some of these materials are given in Table 1.

In the year 1955, another species was described by KISELEV from the lake Staryj Forpost in Kazachstan (USSR). It was *Aphanizomenon sphaericum*, with the following features: Trichomes solitary, more or less straight, attenuated to the ends (usually 3 terminal cells are elongated, without gas vacuoles, sometimes hyaline). Trichomes are constricted on the cross walls. Cells cylindrical or barrel-shaped, with gas vacuoles, 3—7 × 3—3.5 μm, rounded or rounded-pointed at their ends. Heterocysts spherical or oval, 5—7.5 × 5—6 μm. Spores spherical, solitary or up to 3 joined from both sides to the heterocysts, 6—10 μm in diameter (comp. Table 1).

Figs. 1—5. — *Aphanizomenon aphanizomenoides* (FORTI) HORECKÁ et KOMÁREK, 1 — after FORTI from HUBER-PESTALOZZI 1928 (iconotype from Turkey); 2 — after PROWSE 1972 (from Malaysia); 3 — after HEGEWALD et al. 1975 (from Hungary); 4 — after A. SCHMIDT 1975 (from Hungary); 5 — orig. KOMÁREK (from Hungary).

Table 1

	Anabaena aphanizomenoides Forti 1912 (orig. descr.)	*Anabaena aphanizomenoides* (Prowse 1972)	*Anabaena aphanizomenoides* (Hegewald et al. 1975)	*Anabaena aphanizomenoides* (A. Schmidt 1975)
Filaments	solitary, straight or slightly curved	solitary	solitary, straight	straight
Ends of filaments (μm)	attenuated (acc. to figures)	attenuated	attenuated	attenuated (acc. to figures)
Length of filaments (μm)	to 2000		to 400	
Shape of cells	barrel-shaped to cylindrical	barrel-shaped (acc. to figs.)	barrel-shaped	barrel-shaped to cylindrical (acc. to figs.)
Length of cells (μm)	4—5		3—5.5	2.5—5.5
Width of trichomes (μm)	4—15		2—6.5	
Size of apical cells (μm)			3—10.7 × 1.4—3.5	
Shape of apical cells	rounded-conical (acc. to figures)	rounded-conical (acc. to figures)	rounded-conical (acc. to figures)	rounded conical
Htc. — size (μm)	6—7.5 × 5.5—7		4.2—7.4 × 4.5—5.8	
Htc. — shape	spherical or slightly ellipsoidal		spherical to ellipsoidal	
Spores — position	à 1 or few joined to Htc.		à 1 or few joined to Htc.	à 1—2 joined to Htc.
Spores — shape	spherical		spherical, (to ellips.)	spherical or almost spherical
Spores — size (μm)	8—14 ∅		6.6—13.6 × 6.6—12.7	10—12 × 7.5—9.5
Gas vacuoles	+		+	+
Ecology	planktic in a lake	planktic in fishponds	planktic in fishponds	planktic in a lake
Locality	Anatolia, Turkey	Malaysia	near Szeged, Hungary	Szelidi-lake, Hungary
Note		acc. to Prowse in all other features identical with the typical material		

Anabaena aphanizomenoides (orig. HORECKÁ)	*Anabaena aphanizomenoides* (orig. KOMÁREK)	*Aphanizomenon sphaericum* KISEL. 1955 (orig. descr.)	Resulting data	*Anabaena karakumica* KOGAN 1967
solitary, straight or slightly curved	solitary, straight or slightly curved	solitary	solitary, straight or slightly curved	solitary, straight
attenuated (1—5 apical cells)	attenuated	attenuated (3 apical cells)	attenuated	attenuated, but without elongated cells
< 300			— 2000	— > 1000
barrel-shaped to cylindrical	barrel-shaped	barrel-shaped to cylindrical	barrel-shaped to cylindrical	barrel-shaped to cylindrical
1.7—2.3	3.6—4.5	3—3.5	(1.7—)2.5—5.5	5.4—8
2.2—4	3.5—8	3—7	2—8(—15)	
3.5—10 × 0.9—2.8	4.5—8.5 × 2—3.2		3—10.7 × 0.9—3.5	
rounded-conical	rounded-conical	rounded to pointed	rounded-conical, rarely almost pointed	rounded
3.5—6.7 × 2.5—5.4	4—6.5 × 5—6	5—7.5 × 5—6	3.5—7.5 × (2.5—)4.5—7	7—9 ∅
cylindrical	spherical to oval	spherical to ellipsoidal	spherical, slightly oval to almost cylindrical	spherical
à 1—4 joined to Htc. or 1—2 distant from Htc.	à 1—2 joined to Htc.	à 1—3 joined to Htc.	à 1—4 joined to Htc., rarely à 1-2 distant from Htc.	à 1—2 joined to Htc.
spherical	spherical	spherical	spherical, rare slightly elongated (widely oval)	spherical to widely ellipsoidal
6—8 ∅	to 9 ∅	6—10 ∅	6—14(—18) × × 6—14	10—14(—18) × × 10—14
+	+	+	+	+
planktic in an artificial water-reservoir	planktic in a canal	planktic	planktic in water reservoirs (lakes, ponds) and artificial canals	summer plankton
near Senica, Czechoslovakia	near Dabas, Hungary	Kazachstan, USSR	tropical and sub-tropical countries, and warmer areas of temperate zone, SE. Europe, Asia	near Aščhabad, Turkmenia, USSR
				probably only a variety from *Anabeana aphanizomenoides*

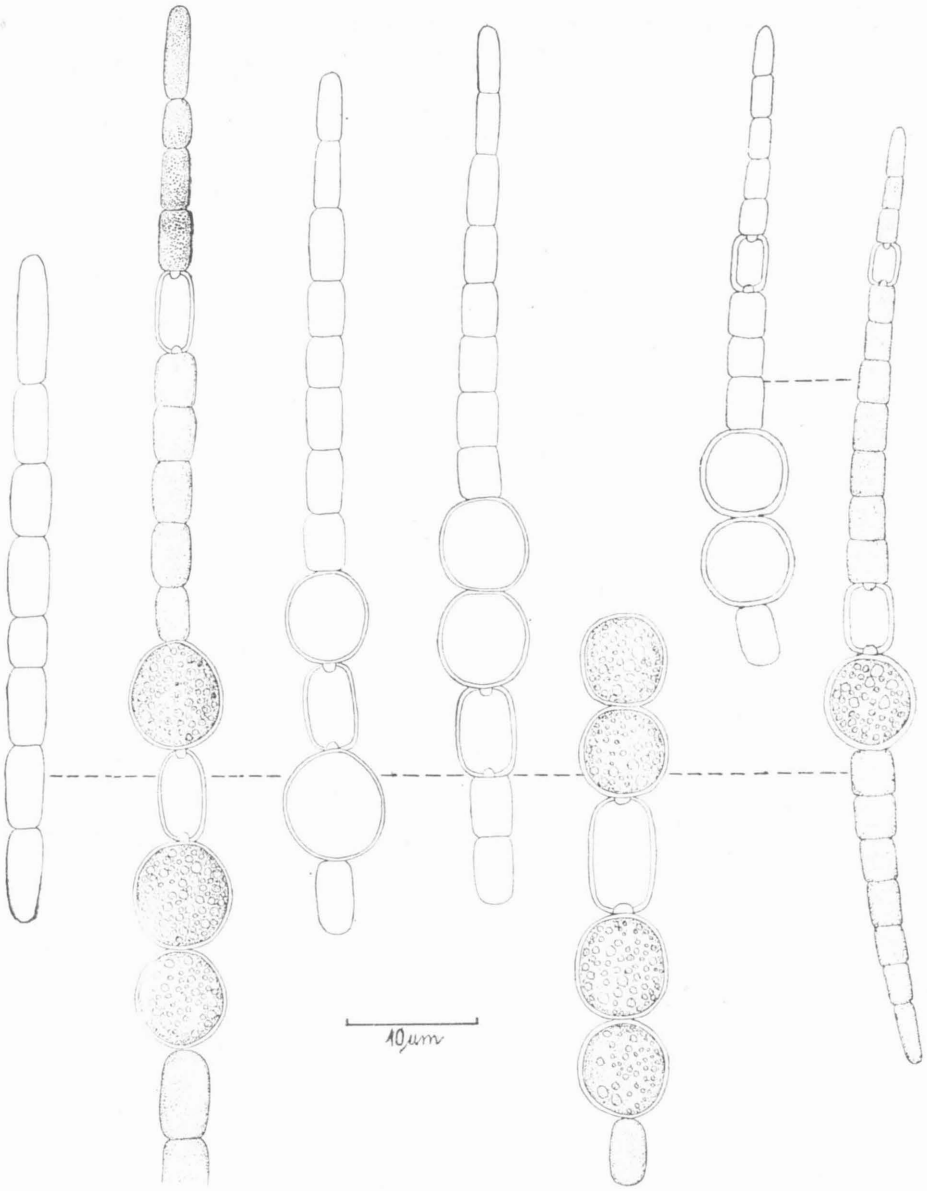


Fig. 6. — *Aphanizomenon aphanizomenoides* (Forti) Horecká et Komárek. Orig. Horecká (from SW. Slovakia, Czechoslovakia).

Hegewald et al. (1975) note that they found no difference between *Anabaena aphanizomenoides* and *Aphanizomenon sphaericum*. This opinion is evidently correct; however, it promotes the question, whether this blue-green alga belongs to the genus *Aphanizomenon* or *Anabaena*. The formation of fascicles is not a generic feature in *Aphanizomenon*; the solitary filaments as

well as the fascicles occur in both genera mentioned (comp., e.g., *Aphanizomenon flos-aquae* and *Anabaena affinis*). The only differential feature between them are the elongated, narrowed and hyaline (vacuolised) terminal cells (in old trichomes!) in the genus *Aphanizomenon*. No sharp boundary exists between the two genera, but it is possible to distinguish them. From this point of view, the correct name for the blue-green alga in question is *Aphanizomenon aphanizomenoides* (FORTI) HORECKÁ et KOMÁREK.

Similar to this species is also *Anabaena karakumica* KOGAN 1967, but with larger dimensions of the cells and heterocysts (Table 1). Two other species of *Anabaena* with spherical spores joined to the heterocysts, *A. sphaerica* and *A. kisseleviana*, are clearly distinguishable from *Aphanizomenon aphanizomenoides: A. sphaerica* is a benthic species growing in strata, without gas vacuoles and with different dimensions; *A. kisseleviana* grows as a planktonic species in colder areas and has larger dimensions. Both species never have attenuated apical cells.

The trichomes of *A. aphanizomenoides* without spores are very similar to those of *Aphanizomenon issatschenkoi*. These two species differ only by the shape of the spores and by their different positions on the trichomes. In the reservoir Boričky, where both species occurred together, the trichomes without spores were not recognizable.

Aphanizomenon aphanizomenoides (FORTI) HORECKÁ et KOMÁREK, comb. nova
(Figs. 1—6)

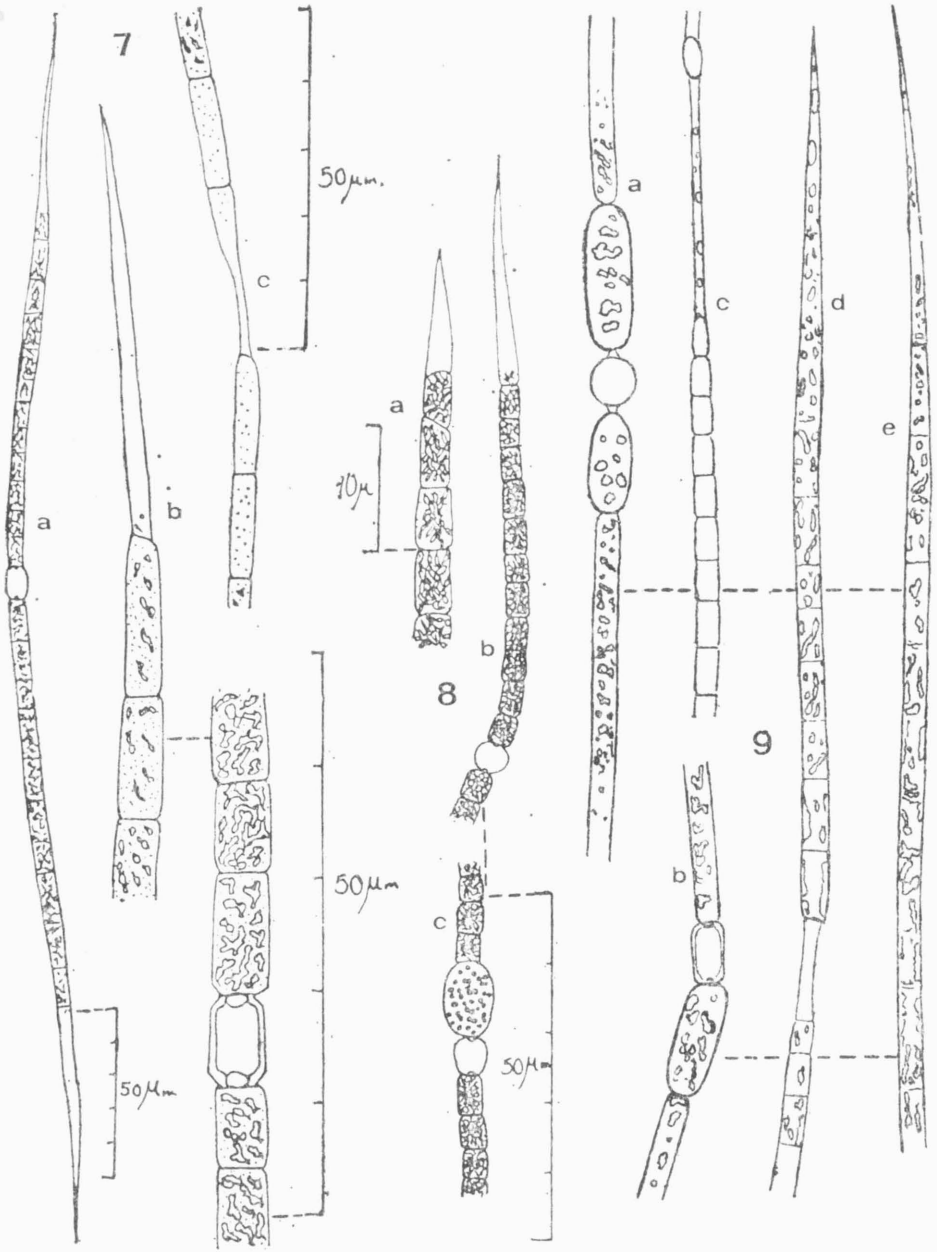
Syn.: *Anabaena aphanizomenoides* FORTI Atti Mem. Acad. agric. Sci., Lett. Arti Comm. (Verona), ser. 4, 12 : 126, fig. 2, 1912; (basionym). — *Aphanizomenon sphaericum* KISELEV Not. syst. Sect. crypt. Inst. bot. (Moskva) 10 : 36—38, 1955.

Description: Trichomes solitary, straight or slightly curved, up to 2000 μm long, to the ends attenuated and terminated with narrowed, rounded-conical cell, on the cross walls clearly constricted. Cells barrel-shaped to cylindrical, with gas vacuoles, 2—15×3—5.5 μm, at the ends only 1.4—3.5 μm wide and rarely lacking gas vacuoles. Heterocysts intercalary, spherical to slightly oval, 4—7.5×4.5—7 μm. Spores spherical (rarely slightly elongated — widely oval), solitary or in series up to 3, joined to one or both sides of the heterocysts, (6)8—14 μm in diameter.

Distribution (Fig. 24): Planktonic in eutrophic waters, mainly in tropical and subtropical countries, less in the temperate zone (SE. Europe): Czechoslovakia, Hungary, India, Malaysia, Turkey, USSR (Kazachstan, Turkmenia).

Aphanizomenon tropicalis HORECKÁ et KOMÁREK

DESIKACHARY (1959) and PROWSE (1972) described material of *Anabaena aphanizomenoides* with oval spores and with long, sharply pointed ends, which probably represents a special taxon (species). It is a question, if this alga is identical with „*Raphidiopsis mediterranea* with developed heterocysts". However, there exist data on populations of *Raphidiopsis*, in which heterocysts were never found (CRONBERG 1973, HINDÁK 1975) during the whole vegetation season or in cultures. Some other authors suppose *R. mediterranea* to be, possibly, the filaments lacking heterocysts of another species, *Anabaenopsis raciborskii* (e.g. HILL 1970). We suppose that the alga similar to *Aphanizomenon aphanizomenoides* with sharply pointed terminal cells, intercalary heterocysts and with oval spores adjacent to one or both sides of heterocysts should be described as a special species (*Aphanizomenon tropicalis* HORECKÁ et KOMÁREK).



Figs. 7—9. — *Aphanizomenon tropicalis* HORECKÁ et KOMÁREK. 7 — after PROWSE (sub "*Raphidiopsis mediterranea* SKUJA", from Malaysia); 8 — after PROWSE 1972 (sub "*Anabaena aphanizomenoides* FORTI with long bristle-like end cell", from Malaysia); 9 — redrawn from photos from PROWSE 1972 (sub "*Raphidiopsis mediterranea*", from Malaysia, iconotype).

Aphanizomenon ***tropicalis*** HORECKÁ et KOMÁREK, sp. nova (Figs.7—9)

Syn.: *Anabaena aphanizomenoides* FORTI sensu PROWSE Taxon. Biol. Blue-green Algae, p. 49—51, figs. 1, 2b—d, Pl. I, 1972. — ?*Anabaena aphanizomenoides* FORTI sensu DESIKACHARY Cyanophyta, I.C.A.R. Monographs, p. 405, 1959, p.p. (Madras material).

Diagnosis: Filamenta libere natantia, solitaria, recta vel arcuata, ad apices attenuata, ad dissepimenta constricta. Cellulae apicales elongatae, hyalinae, conice acutae. Cellulae intercalares cylindricae, vacuolis gaseosis impletae, 4.5—7×2.5—4.5 μm. Heterocystae solitariae, intercalares, sphaericae vel ellipsoideae, sporae ellipsoideae to cylindricae, heterocystas contingentae, 9—14 μm longae, 4—7 μm latae. — Habitatio: In lacubus piscinasque Indiae et Malaysiae. — Iconotypus: Fig. 9.

Description: Trichomes solitary, more or less straight or slightly curved, long, on the cross walls constricted, to the ends attenuated, with the elongated conical (sometimes extremely long) and pointed, hyaline apical cell. Cells more or less cylindrical, with gas vacuoles, 4.5—7×2.5 to 4.5 μm, to the end conical, lacking gas vacuoles and sometimes vacuolised. Heterocysts intercalary, solitary, spherical to oval, somewhat wider than the vegetative cells (4—5 μm). Spores oval to cylindrical, solitary, joined to one or both sides of the heterocysts, 9—14×4—7 μm.

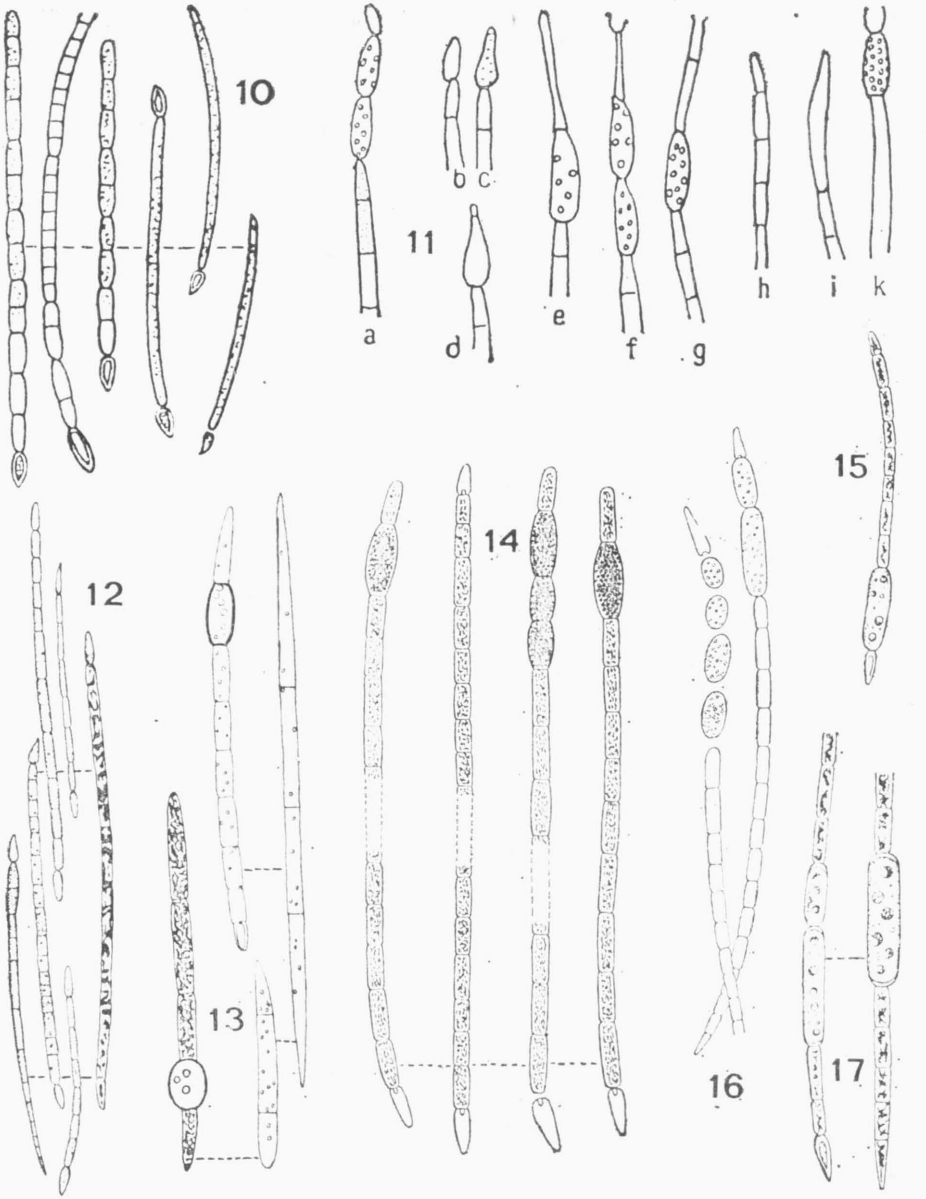
Distribution (Fig. 24): Planktonic in water reservoirs (tanks, fishponds) in tropical countries (S. Asia): India (Madras), Malaysia.

Cylindrospermopsis raciborskii (WOŁOSZ.) SEENAYYA et SUBBA RAJU

This alga was found more times all over the world. It was described from Indonesian lakes (Java) and occurs mainly in tropical regions (Fig. 10). However, it has also been found a few times in the temperate zone, in Czechoslovakia, Hungary, USA and USSR. Now, its variation is known and it is clear that this species comprises, beyond doubt, *Cylindrospermum kaufmannii* (SCHMIDLE) HUB.-PEST. 1938 (= *Aphanizomenon kaufmannii* SCHMIDLE in BRUNNTH. 1914; Fig. 11), further three species, described by OBUCHOVA (OBUCHOVA et KOSENKO 1964; Figs. 13—16) and probably also *Cylindrospermum doryphorum* BRUHL et BISWAS 1922 (Fig. 18).

A. raciborskii has a special morphology which created problems with taxonomic evaluation of this species. Problems of this species have been reviewed thoroughly by JEEJI-BAI et al. (1977). The formation of heterocysts is quite different from that in the genus *Anabaenopsis*. In *Anabaenopsis*, the heterocysts develop in an intercalary position in pairs, the trichomes break between them, and thus the heterocysts occupy secondarily the terminal position. This feature is the main criterion defining the genus *Anabaenopsis*. In *Anabaenopsis raciborskii*, the heterocysts develop primarily from one terminal cell, which is the diacritical feature of the genus *Cylindrospermum* (Fig. 23).

From the genus *Cylindrospermum*, *Anabaenopsis raciborskii* differs in three features: 1. The cells contain gas vacuoles, which have never been found in another *Cylindrospermum* species; however, in the very closely related genera *Anabaena* and *Nostoc* both kinds of species also occur with or without gas vacuoles, and this single feature can hardly be used as a diacritical one in nostocacean genera. 2. The end of trichomes (lacking both heterocysts and spores) have attenuated and pointed ends like in *Aphanizomenon* or *Raphidiopsis*. 3. In *Anabaenopsis raciborskii*, the spores are situated mostly near either to one or both ends of the trichomes, but sometimes 2—3 vegetative cells are present between the terminal heterocysts and the spores. For these reasons, SEENAYYA et SUBBA RAJU (1972) established a new genus *Cylindrospermopsis* for *Anabaenopsis raciborskii*. However, it should be noted that



Figs. 10—17. — *Cylindrospermopsis raciborskii* (Wołosz.) Seenayya et Subba Raju. 10 — after Wołoszyńska from Huber-Pestalozzi 1928 (iconotype, from Indonesia); 11 — after Brunnthaler from Huber-Pestalozzi 1928 (sub "*Cylindrospermum* (?) *Kaufmannii*", from Egypt); 12 — after Skuja from Kondrateva 1968 (sub "*Anabaenopsis raciborskii*", from Greece); 13 — after Singh from Kondrateva 1968 (sub "*Anabaenopsis koganii*", from India) 14 — after Kogan from Kondrateva 1968 (sub "*Anabaenopsis koganii*", from Turkmenia, USSR); 15 — after Obuchova from Kondrateva 1968 (sub "*Anabaenopsis wustericum*", from Kazachstan, USSR); 16 — after Prescott et Andrews from Kondrateva 1968 (sub "*Anabaenopsis seriata*" and "*A. wustericum*", from the USA); 17 — after Obuchova from Kondrateva 1968 (sub "*Anabaenopsis maksimilianii*" from Kazachstan, USSR).

the position of spores joined to the heterocysts or of intercalar position also has only an interspecific value in *Anabaena*.

We had the occasion to evaluate statistically two well developed populations of this alga, and to assess its variation in detail (Figs. 19, 20). The morphology of our material in comparison with important data from the

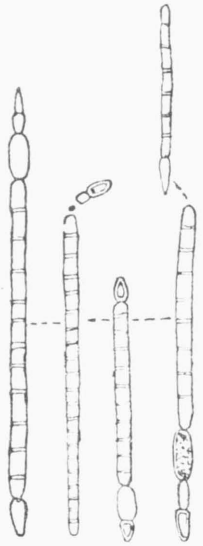


Fig. 18. — *Cylindrospermum doryphorum* BRUHL et BISWAS. After BRUHL et BISWAS from DESIKACHARY 1959 (from India).

literature, is summarized in Table 2. We can fully confirm the results of HILL (1970), who studied the variation of the same alga from the Minnesota lakes, and of JEEJI-BAI et al. (1977), concerning the variability of the position, number and shape of spores in *A. raciborskii*. We agree that the species established by OBUCHOVA (OBUCHOVA et KOSENKO 1964) on the basis of the features mentioned (position of spores; *A. koganii*, *A. maksimilianii*, *A. wustericum*), and probably also *Anabaenopsis seriata* PRESCOTT et ANDREWS 1955 (Fig. 17) can be located within the variation range of *Anabaenopsis/Cylindrospermopsis raciborskii*. The development of heterocysts from the terminal cells and the disintegration of trichomes between the vegetative cells were commonly observed in our samples.

Concerning the generic position of this alga, we regard it impossible either to join *A. raciborskii* as a member to the genus *Anabaenopsis*, or to classify it in a special section of this genus. The formation of heterocysts represents an unambiguous diacritical feature commonly accepted as part of the definition of the genera of *Nostocaceae*. *A. raciborskii* must thus be classified as belonging to different genus (*Cylindrospermopsis* SEENAYYA et SUBBA RAJU 1972) or to a special section of *Cylindrospermum* (BHARADWAYA 1933). In order to give some data elucidating this problem, we have used the method of numerical taxonomy for evaluating the nostocacean genera with the exception of *Isocystis*, *Richelia* and *Hormothamnion*, which lack sufficient sets of the features required. We have used 45 morphological features selected

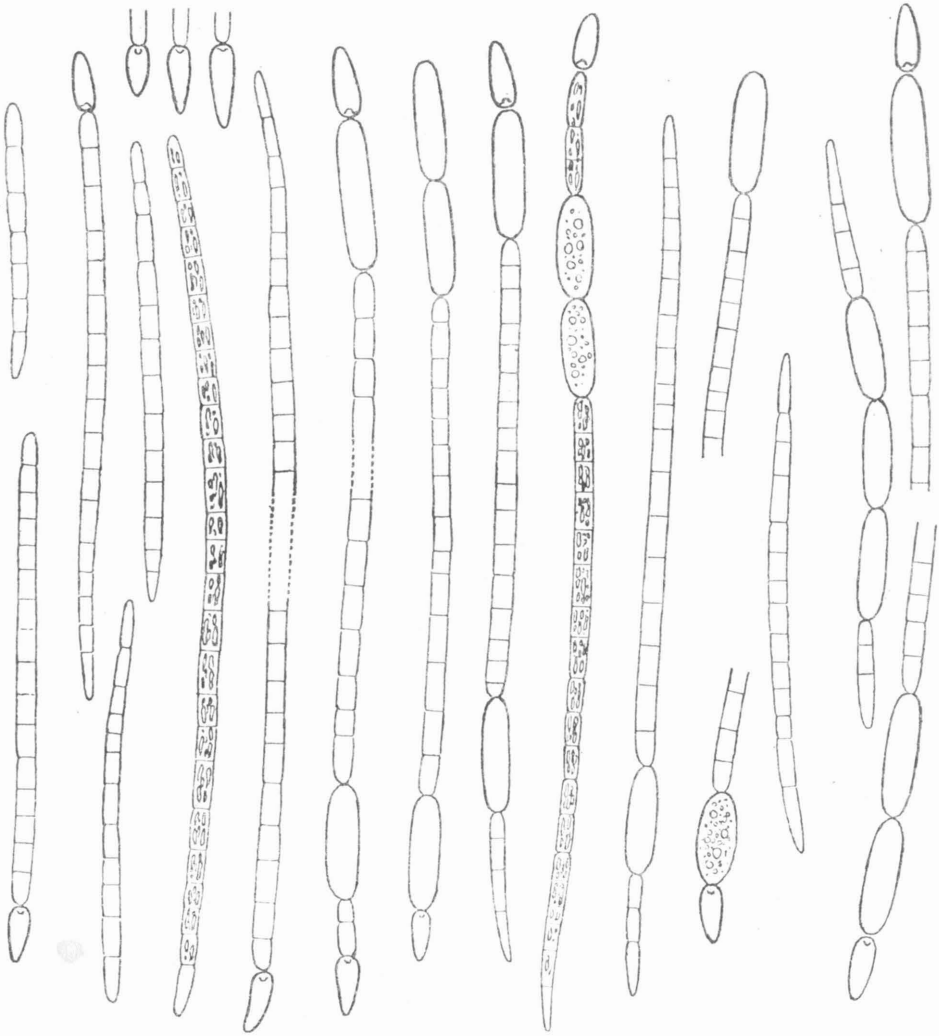


Fig. 19. — *Cylindrospermopsis raciborskii* (Wołosz.) Seenayya et Subba Raju. Orig. Komárek (from Hungary).

from the characteristics of all genera in question. The main objection to such an evaluation can be the a priori delimitation of the generic contents. For partially eliminating this situation, we evaluated separately planktonic and non-planktonic *Anabaena* species as two different groups at the level of genera. It is true that, for example, the genus *Anabaena* can be divided into more groups (according to the position of the spores, etc.), and the numerical evaluation of all nostocacean species would be best. But it was impossible to carry out such a study during this work. We tried, therefore, only to obtain introductory information on this problem. The results are shown in Figs. 21– 22.

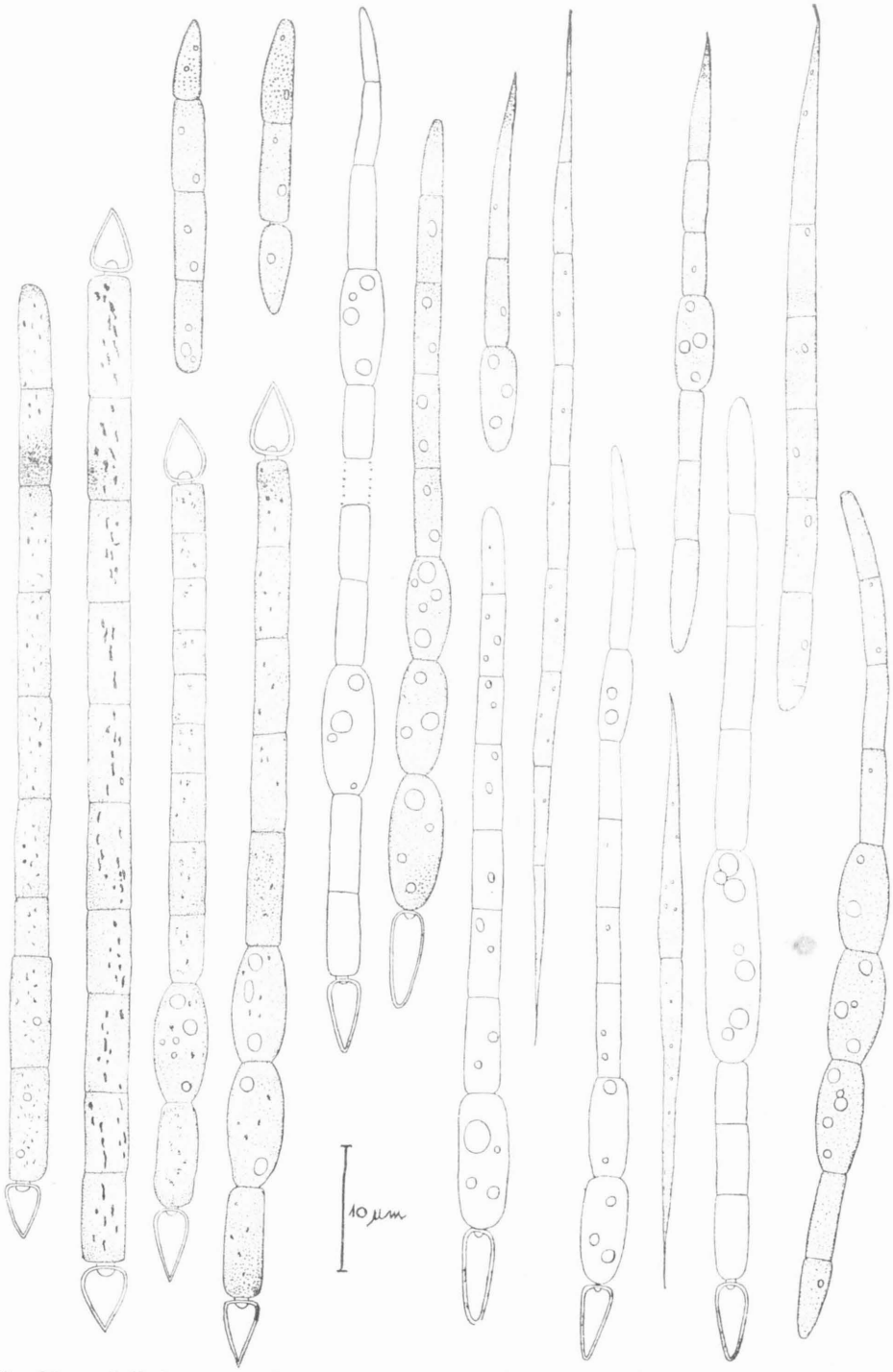


Fig. 20. — *Cylindrospermopsis raciborskii* (Wołosz.) Seenayya et Subba Raju. Orig. Horecká (from SW. Slovakia, Czechoslovakia).

However, the numerical evaluation of nostocacean genera did not yield a clear solution. The wide difference of *Cylindrospermopsis* from *Anabaenopsis* has been confirmed, as well as the close relation of *Cylindrospermopsis* to *Cylindrospermum* (and a little more distant relation to *Raphidiopsis* and *Aphanizomenon*). The question remains of evaluating the position of *Cylindrospermopsis* (or where to draw the lines between the single genera). The

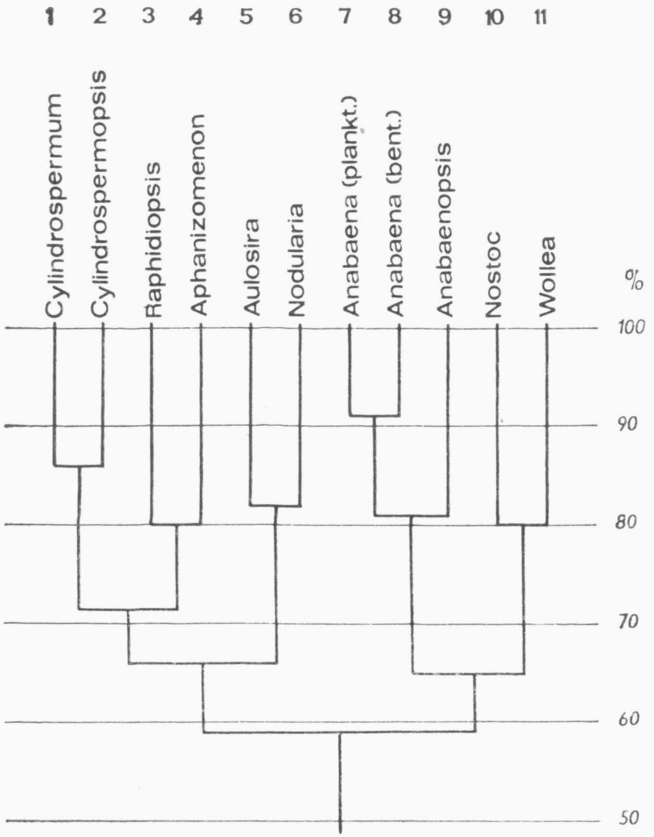


Fig. 21. — Phenogram derived from the numerical evaluation of similarity between nostocacean genera (= OTU); 45 features were used.

closest relation was found between both groups of *Anabaena* (the only similarity over 90 phenons). Then follows the similarity between *Cylindrospermum* and *Cylindrospermopsis*, which is closer than, for example, between *Aulosira* and *Nodularia*, *Anabaena* and *Anabaenopsis*, or *Nostoc* and *Wollea*.

We suppose that the intermediate types can represent the criterion; they occur in both *Anabaena*-groups but not between *Cylindrospermum* and *Cylindrospermopsis*. We propose, therefore, to accept development of the heterocysts (Fig. 23) as a main diacritical feature between *Anabaena* (+ *Aphanizomenon*), *Anabaenopsis* and *Cylindrospermum* (+ *Cylindrospermopsis*). On this basis, all three groups of genera can be clearly defined. The attenuated

ends of filaments can serve as a secondary generic feature which distinguishes the genus *Aphanizomenon* from *Anabaena* and *Cylindrospermopsis* from *Cylindrospermum*. To the genus *Cylindrospermopsis* probably also belong the species *Anabaenopsis philippinensis* TAYLOR 1932 (comp. SEENAYYA et SUBBA RAJU 1972, JEEJI-BAI et al. 1977) and *Cylindrospermum doryphorum* BRUHL et BISWAS 1922. The interspecific relations between all these species remain to be solved.

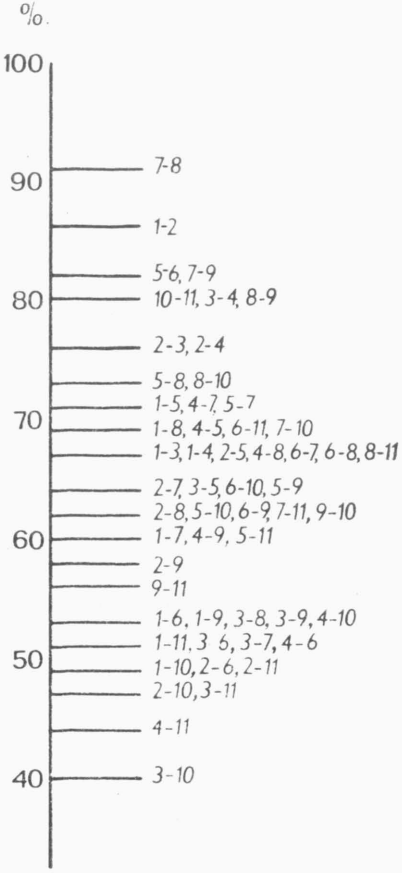


Fig. 22. — Coefficients of similarity between the single genera of *Nostocaceae* (the numbers correspond with the phenogram in the Fig. 21).

Cylindrospermopsis raciborskii (WOŁOSZ.) SEENAYYA et SUBBA RAJU Taxon. Biol. Blue-green Algae, p. 55, 1972 (Figs. 10—20)

Syn.: *Anabaena* (*Anabaenopsis*) *raciborskii* WOŁOSZ. Bull. int. Acad. Sci. Cracovie, cl. mat.-nat., ser. B : 684, fig. 10A—F, 1912; p.p. (straight trichomes = iconotype). — *Aphanizomenon kaufmannii* SCHMIDLE in BRUNNTH. Hedwigia 54 : 223, 1914. — *Anabaenopsis raciborskii* (WOŁOSZ.) ELENK. Bot. Mat. Inst. spor. Rast. glav. bot. Sada USSR 2 : 77, 1923, p.p. — *Cylindrospermum kaufmannii* (SCHMIDLE) HUB.-PEST. Die Binnengew. 16, 1 : 191, Fig. 89, 1938. — *Anabaenopsis seriata* PRESCOTT et ANDREWS Hydrobiologia 7 : 61—63, Figs. 1—3, 1955. — *Anabaenopsis koganii* OBUCH. in OBUCHOVA et KOSENKO Bot. Mat. Gerb. Inst. Bot. Acad. Nauk Kaz. SSR, 2 : 81, Pl. 2 : 1—4, 8, 1964. — *Anabaenopsis maksimilanii* OBUCH. in OBUCHOVA et

Table 2

	A. raciborskii sec. GEITLER 1932	*A. raciborskii* sensu stricto sec. KONDRATEVA 1968	*Cylindrospermum kaufmannii* sec. HUBER-PESTALOZZI 1938	*A. seriata* PRESCOTT 1955	*A. koganii* OBUCHOVA 1964 — diacr. features
Filaments	solitary, straight, rarely spirally twisted	straight or slightly curved, rarely spirally twisted	solitary, to the ends sometimes twisted	solitary, straight or slightly curved	
Ends of filaments without Htc.				attenuated	
Length of filaments (μm)	—200	90—100(—200)		—80	60—150
Shape of cells	cylindrical	cylindrical	cylindrical	cylindrical	
Constriction on the cross-walls	slightly +	— or (+)	(+)	(+)	
Width of trichomes (μm)	2.5—4	2—4	2—3	2.5—2.8	
Length of cells (μm)	2.5—16	(1)2—8× longer as wide	6—12	7.5—10	
Shape of apical cells		attenuated, rounded	attenuated, ± pointed	conical, pointed-rounded	
Htc. — size (μm)	5—7×2—2.5	3.4—12×(1.8)2—3	5—8×2—4	4.6—5×3	
Htc. — position and shape	terminal, long-conical	terminal, long-conical or long-ovoid	terminal, long-ellipsoid. to pointed	terminal, conical	
Spores-position		separated from Htc. by few veget. cells	1—3, joined to Htc. or separated	1—4, joined to Htc.	1—3, separated from Htc. by veget. cells

Spores — shape		ellipsoidal	long ellipsoidal to cylindrical	oval	ellipsoidal
Spores — size (μm)		4.5—6.4 × 2.8—3.2		9—16 × 3—3.5	7—11 × 3.3—4
Gas vacuoles	—	— or +			
Ecology	planktonic in a lake	plankt. in reservoirs and streams	planktonic in Nile	planktonic	
Locality	Java, Indonesia	(Kazachstan, Turkmenia, Ukraine) USSR	Egypt	Kansas lakes, USA	
Note	spiroid trichomes belong probably to another species				

Table 2, contd.

A. maksimilianii Obuchova 1964 — diacr. features	*A. wustericum* Obuchova 1964 — diacr. features	*A. raciborskii* sec. Hill 1970	*A. raciborskii* (orig. Horecká)	*A. raciborskii* (orig. Komárek)	Resulting data
		solitary, ± straight	solitary, straight or slightly curved	solitary, straight or slightly curved	solitary, straight or slightly curved
			slightly attenuated	slightly attenuated	slightly attenuated
		70—500(—1570)	24—208(—399)	—150	60—250(—1570)
			cylindrical	cylindrical	cylindrical
			((+))	((+))	— or (+)
		1.8—3.5(3.7)	1.9—3	2.8—3.8	(1.8)2—4
		(3.5)5—13(15)	3.5—13.5		2.5—16
		ogivally pointed to rounded	conical, pointed-rounded	conical, rounded	± conical, pointed-rounded
		6.9—14 × (1.8)2 to 3.7(4.5)	5—9.9 × 2.5—2.7	4.8—11.8 × 2.6—3.2	(3.4)4.6—12(14) × × (1.8)2—3(4)
		terminal, spear-point like	terminal, conical	terminal, conical	terminal, long-conical or long ovoid
1—2, separated from Htc. by veget. cells	1—2, joined to Htc.	1—5, joined to Htc. or separated by few veget. cells	1—2, joined to Htc. or with 1—2 interc. cells	1—3, joined to Htc. or with 1—2(3) interc. cells	1—3(5), joined to term. Htc. or separated by 1—3 (more) veget. cells

cylindrical	cylindrical	oval or barrel-shaped	cylindrical	cylindrical (to oval)	cylindrical, rarely long-oval or long-ellipsoidal
		8.5—22 × (3)3.5 to 5.3(5.5)		11.4—18 × 2.4—4.2	(4.5)7—18(22) × × (2.4)3—5(5.5)
		+	+	+	+, rarely —
			planktonic, pond	planktonic in the canal	planktonic in different water reservoirs and secondary in small streams
			near Senica, Czechoslovakia	near Dabas, Hungary	

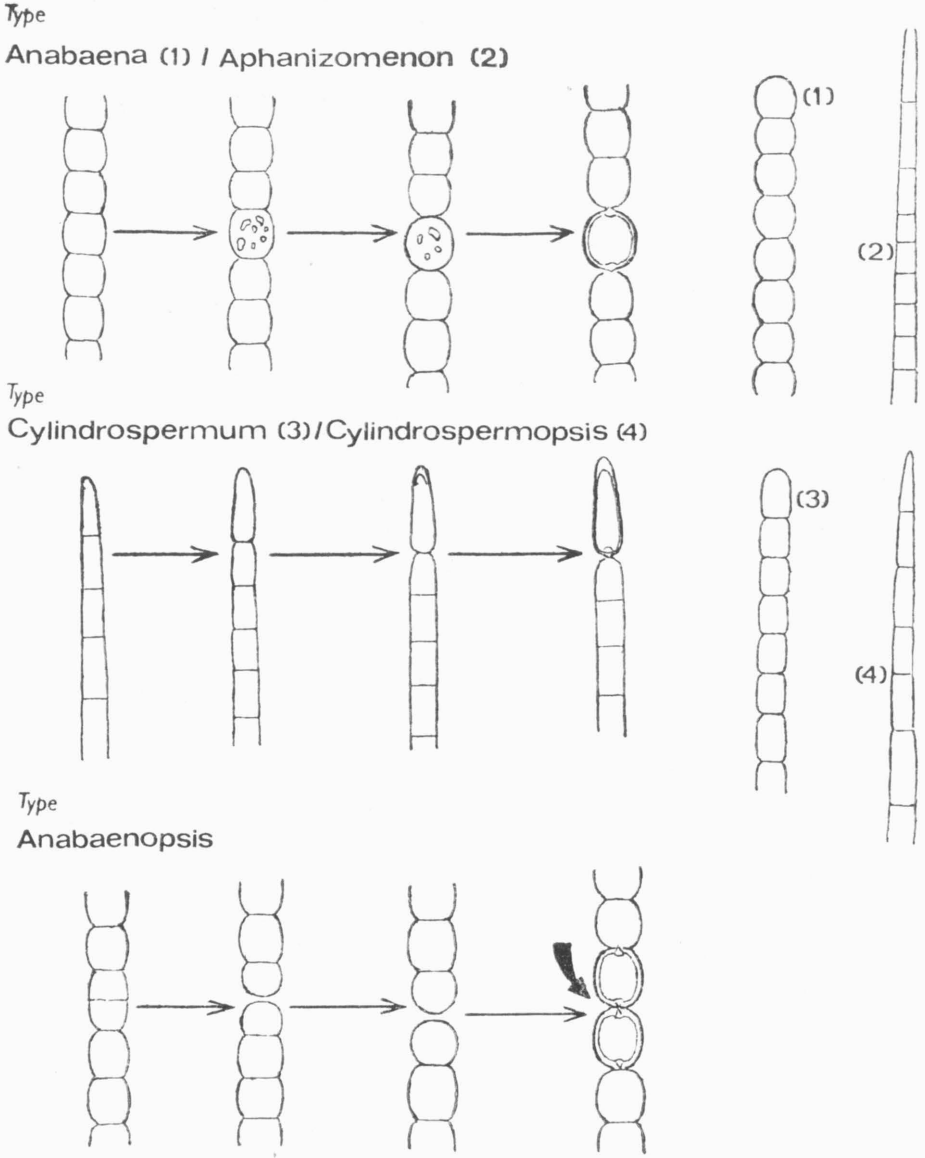


Fig. 23. — Scheme of development of heterocysts, and the ends of trichomes in selected nostocacean genera; the thick arrow indicates the site of trichome disintegration.

Kosenko Bot. Mat. Gerb. Inst. Bot. Acad. Nauk Kaz. SSR, 2 : 82, Pl. 2 : 1—3, 5—6, 10—11, 1964. — *Anabaenopsis wustericum* Obuch. in Obuchova et Kosenko Bot. Mat. Gerb. Inst. Bot. Acad. Nauk Kaz. SSR, 2 : 83, Pl. 2 : 9, 1964.

Description: Trichomes solitary, more or less straight or slightly curved, up to 250 (to 1570) μm long, with 2—28 (or more?) cells, on the cross walls finely constricted or not constricted, attenuated to the ends, with a conical, rounded-pointed terminal cell. Cells cylindrical, with gas vacuoles, sometimes with invisible cross walls, 2.5—16 × (1.8)2—4 μm. Heterocysts terminal (arise from the terminal vegetative cells on one or both ends of the trichome), solitary, conical or long-ovoid, at the ends pointed-rounded, (3.4)4.6—12(14) × (1.8)2—3(4) μm. Spores cylindrical

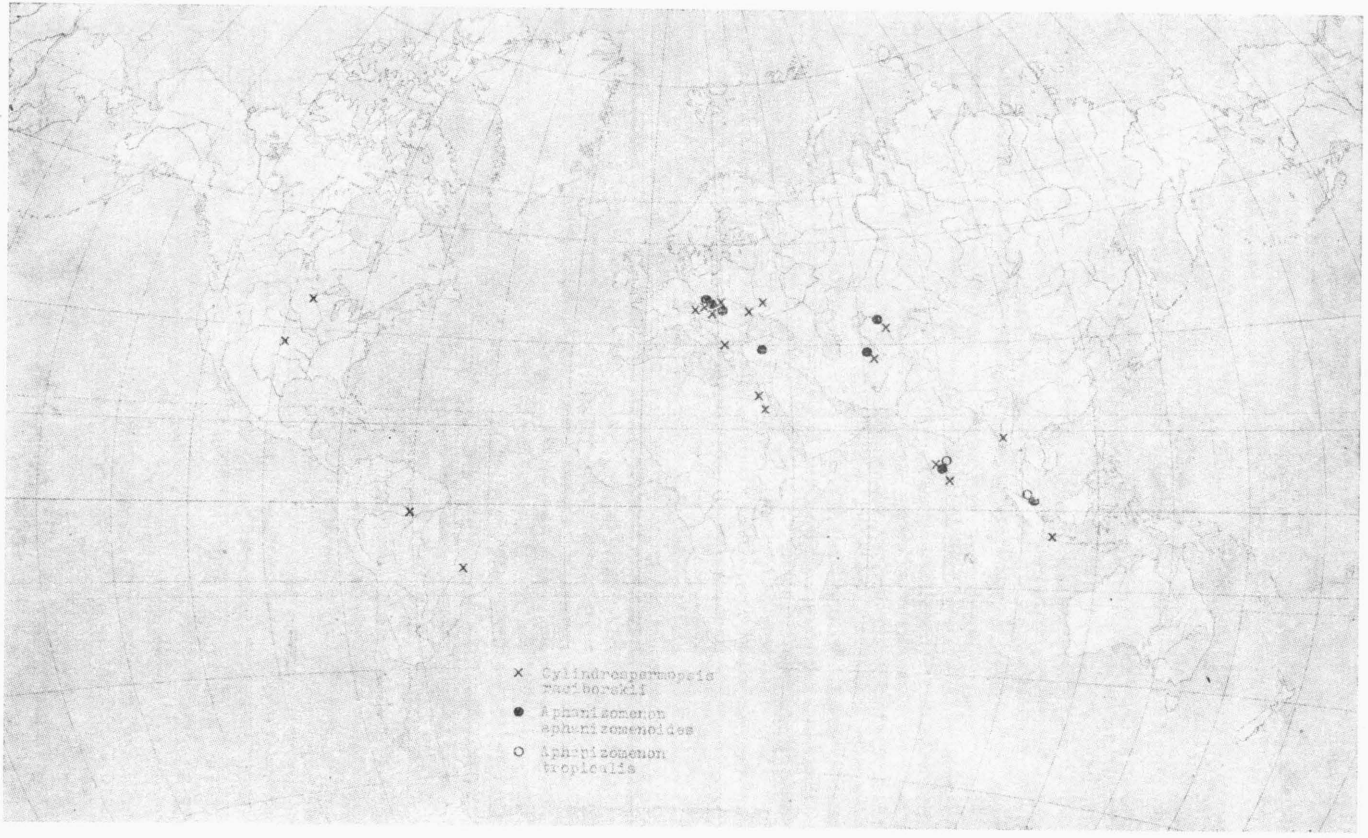


Fig. 24. — Geographical distribution of *Cylindrospermopsis raciborskii*, *Aphanizomenon aphanizomenoides* and *Aphanizomenon tropicalis*.

or oval, arising near to one or both ends of the trichomes, joined to the terminal heterocyst or separated from it by 1—3 (sometimes more?) vegetative cells, solitary or up to 3(—5) in a row, (4.5)7—18(22) × (2.4)3—5(5.5) μm.

Distribution (Fig. 24): Planktonic in stagnant and floating waters, mainly in tropical countries, rarely in the temperate zone: Austria, Brasil (Lago Paranoá, near Manaos — Cronberg 1978 in litt.), Burma, Ceylon (Cronberg in litt.), Czechoslovakia, Egypt (Nile), Greece, Hungary, India, Indonesia (Java), USA (Kansas, Minnesota), USSR (Kazachstan, Moldavia, Turkmenia, Ukraine).

Claus (1961) supposes that the species includes two types which are distinguishable according to the width of trichomes. For the type with wider trichomes (about 4 μm) he proposes the name *Anabaenopsis woloszynskae*. Of *Anabaenopsis raciborskii*, some subspecific taxa have also been described. Var. *longiscellula* Szalai 1942 has cells up to 20.2 μm long (invisible cross walls?) and probably falls within the variation range of the type. The forms described by Behre (1956) from the Philippines (f. *major* and f. *minor*) probably belong to *A. philippinensis* (Jeeji-Bai et al. 1977). Var. *lyngbyoides* Geitl. 1935 has firm sheaths and screw-like twisted trichomes with cells 3.5—4 μm wide. The populations with coiled filaments were found in a few samples from SE. Asia (Philippines, Indonesia; comp. the original material of Wołoszynska 1912) and represent probably different species (according to Jeeji-Bai et al. 1977 all the populations with coiled trichomes belong to *Anabaenopsis philippinensis*). The coiled trichomes have never been found in any European material. The material of Starmach (1962) from Poland clearly belongs to another species (*Cylindrospermum*), specimens from Belorussia, described by Micheeva 1967 belong to *Anabaenopsis cunningtonii* (according to Jeeji-Bai et al. 1977). The specimens from the USA (Prescott et Andrews 1955, Hill 1970), which have spores in series 1—5, may represent a special taxonomic form of *Cylindrospermopsis raciborskii*.

Hamar (1977) described carefully the population of *Anabeanopsis raciborskii* from the river Tisza (Hungary) in 1975, and accepted two varieties: var. *longiscellula* Szalai 1942 (differential features: cells 16.2—20 × 4—5 μm, trichomes slightly constricted at cross walls, heterocysts ovoid, 3.2 to 3.7 μm long), and var. *seriata* (Presc.) Hamar 1977 (syn. *A. seriata* Presc. 1955; differential features: heterocysts elongated cone-shaped, 4.5—8 × 3 μm, spores up to 5 in series).

SOUHRN

Během l. 1976—1978 byly nalezeny na území Československa (jz. Slovensko, pískovna Boričky u Senice; nádrž Chomoutov u Olomouce) a ve stř. Maďarsku (nedaleko Dabase) planktonní sinice *Anabaena aphanizomenoides* a *Anabaenopsis raciborskii*, rozšířené převážně v tropických a subtropických oblastech. Autoři studovali statisticky jejich morfologickou variabilitu a vývoj spor a heterocyst a revidovali jejich taxonomické zařazení.

Anabaena aphanizomenoides, která je rozšířena v tropické a subtropické Asii a v jv. Evropě, odpovídá svými znaky rodu *Aphanizomenon* a musí být převedena do tohoto rodu pod jménem *Aphanizomenon aphanizomenoides* (Forti) Horecká et Komárek. Synonymní tomuto druhu je *Aphanizomenon sphaericum* Kisel. 1955. Jménem „*Anabaena aphanizomenoides*" byl mj. označován také jiný, dobře definovaný druh z r. *Aphanizomenon*, vyskytující se v tropické Asii (Indie, Malajsie), který byl popsán jako *Aphanizomenon tropicalis* Horecká et Komárek.

Anabaenopsis raciborskii má zcela odlišný vývoj terminálních heterocyst než ostatní druhy rodu *Anabaenopsis* (= diferenční znak rodu *Anabaenopsis*) a musí být proto z tohoto rodu vyřazen. Vývoj heterocyst je totožný s rodem *Cylindrospermum*, od něhož se liší morfologií terminálních částí trichomů (= diferenční znak mezi rody *Anabaena* a *Aphanizomenon*) a pozicí spor. Autoři provedli numerické vyhodnocení rodů čeledi *Nostocaceae*; i když výsledky tohoto hodno-

cení nebyly zcela jednoznačné, podpořily oddělení studovaného druhu do samostatného rodu *Cylindrospermopsis* SEENAYYA et SUBBA RAJU 1972. Druh *Cylindrospermopsis raciborskii* tvoří vodní květy v eutrofních vodách celého tropického pásma a zasahuje až do teplejších oblastí mírného pásma (jv. Evropa, USA, jižní republiky SSSR).

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Received February 9, 1979

Výročí 1979

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