

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

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

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HORECKÁ M.<sup>1)</sup> et J. KOMÁREK<sup>2)</sup> (1979): Taxonomic position of three planktonic blue-green algae from the genera *Aphanizomenon* and *Cylindrospermopsis*. — Preslia, Praha, 51 : 289—312.

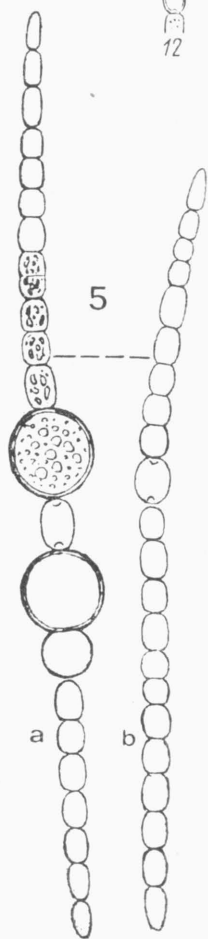
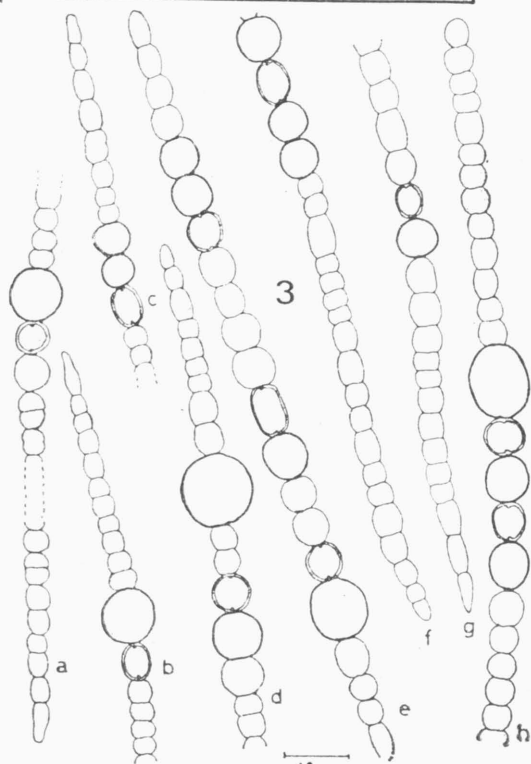
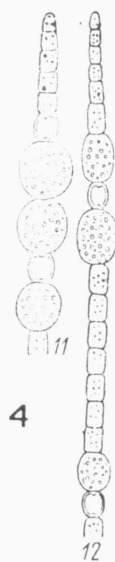
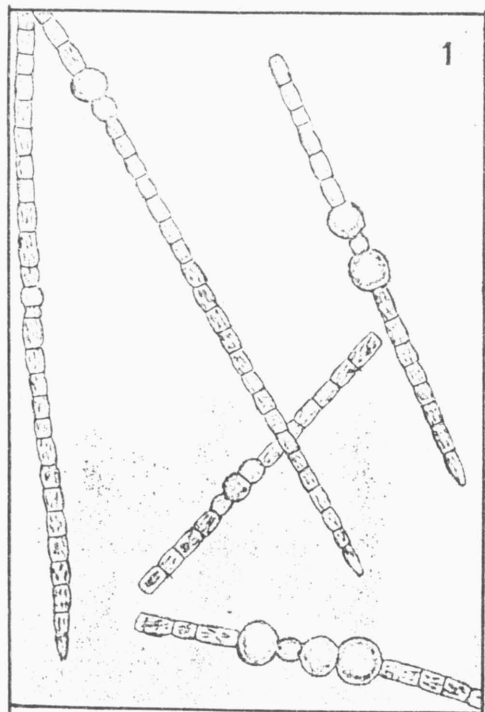
Two freshwater planktonic blue-green algae with well developed spores, *Anabaena aphanizomenoides* and *Anabaenopsis raciborskii*, occurring mainly in tropical countries and in warmer areas of the temperate zone were found in southern parts of Czechoslovakia (SW. Slovakia, Central Moravia) and in Hungary (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* (WOLOSZ.) ELENK. 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 coecal blue-green and chlorococcal algae. The dominant filamentous blue-green algae were *Oscillatoria agardhii*, *O. acuiiformis*, *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-*



*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<sub>2</sub> soluble in the water ranged from 1.3 to 16.2 mg.l<sup>-1</sup>.

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  $\mu$  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  $\mu$  breit, 6–7.5  $\mu$  lang. Dauerzellen einzeln oder zu wenigen neben den Heterocysten, kugelig, 8–14  $\mu$  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  $\times$  2.5–3.5  $\mu$ m and spores 9–14  $\times$  4–4.5  $\mu$ m; 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  $\mu$ m wide and the spores 10.5  $\mu$ m long and about 7  $\mu$ m 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  $\times$  3–3.5  $\mu$ m, rounded or rounded-pointed at their ends. Heterocysts spherical or oval, 5–7.5  $\times$  5–6  $\mu$ m. Spores spherical, solitary or up to 3 joined from both sides to the heterocysts, 6–10  $\mu$ m 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

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

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

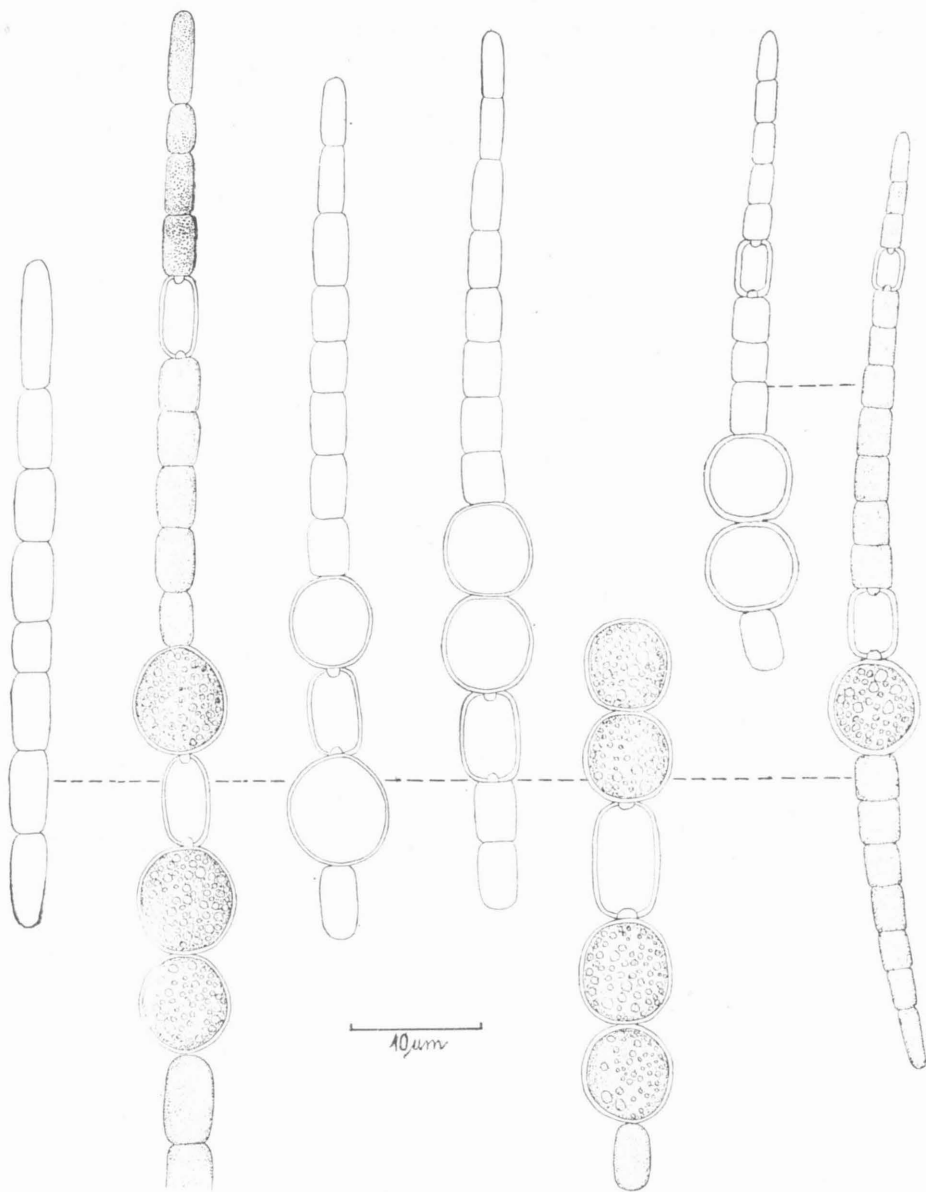


Fig. 6. — *Aphanizomenon aphanizomenoides* (FORTI) HORECKÁ et KOMÁREK. Orig. HORECKÁ (from SW. Slovakia, Czechoslovakia).

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)

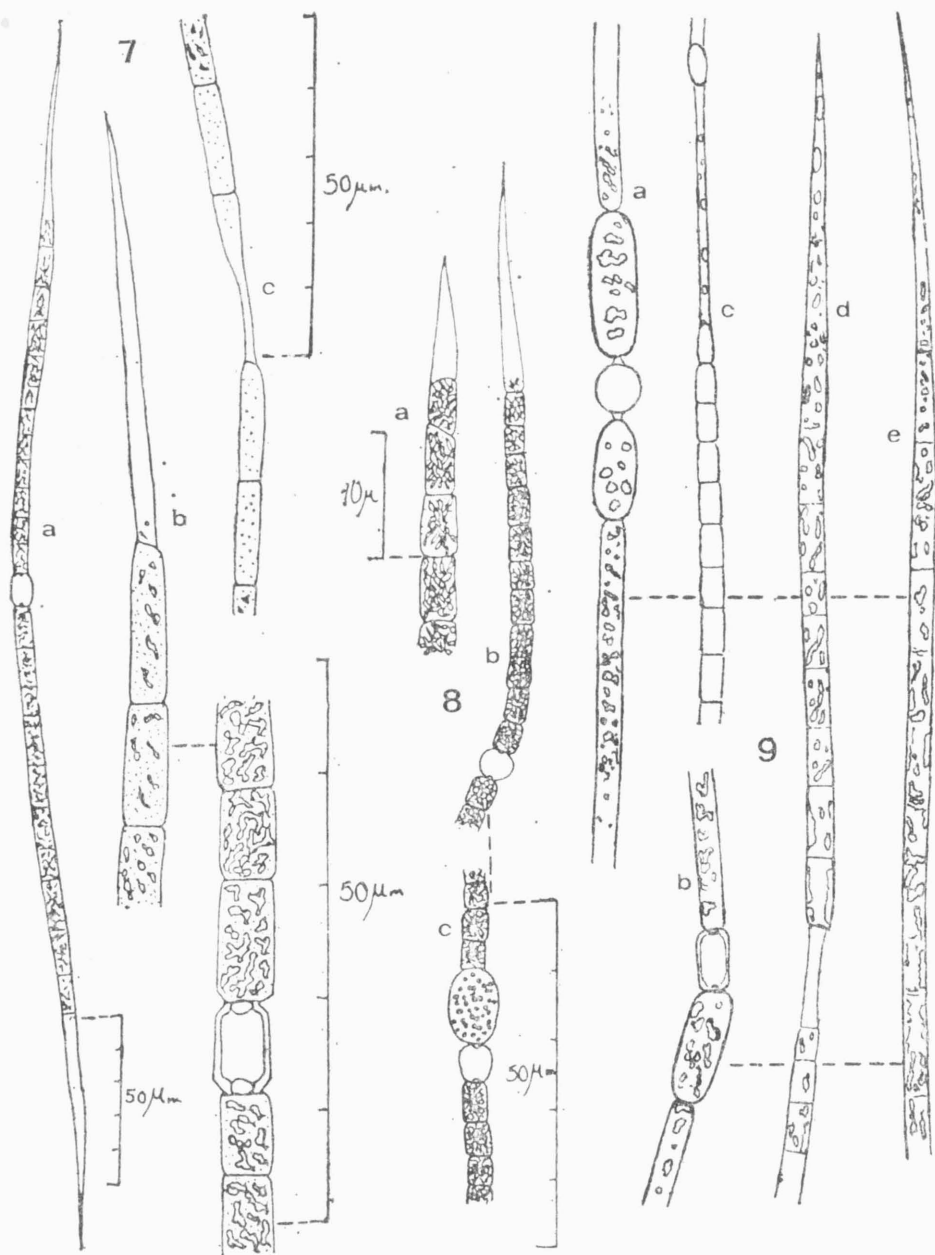
Syn.: *Anabaena aphanizomenoides* FORTI Atti Mem. Acad. agric. Sci., Lett. Arti Comm. (Verona), ser. 4, 12 : 126, fig. 2, 1912; (basonym). — *Aphanizomenon sphaericum* KISELEV Not. syst. Sect. crypt. Inst. bot. (Moskva) 10 : 36—38, 1955.

Description: Trichomes solitary, straight or slightly curved, up to 2000  $\mu\text{m}$  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,  $2-15 \times 3-5.5 \mu\text{m}$ , at the ends only  $1.4-3.5 \mu\text{m}$  wide and rarely lacking gas vacuoles. Heterocysts intercalary, spherical to slightly oval,  $4-7.5 \times 4.5-7 \mu\text{m}$ . Spores spherical (rarely slightly elongated — widely oval), solitary or in series up to 3, joined to one or both sides of the heterocysts,  $(6)8-14 \mu\text{m}$  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,  $4.5-7 \times 2.5-4.5 \mu\text{m}$ . Heterocystae solitariae, intercalares, sphaericae vel ellipsoideae, sporae ellipsoideae to cylindricae, heterocystas contingentae,  $9-14 \mu\text{m}$  longae,  $4-7 \mu\text{m}$  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,  $4.5-7 \times 2.5$  to  $4.5 \mu\text{m}$ , to the end conical, lacking gas vacuoles and sometimes vacuolised. Heterocysts intercalary, solitary, spherical to oval, somewhat wider than the vegetative cells ( $4-5 \mu\text{m}$ ). Spores oval to cylindrical, solitary, joined to one or both sides of the heterocysts,  $9-14 \times 4-7 \mu\text{m}$ .

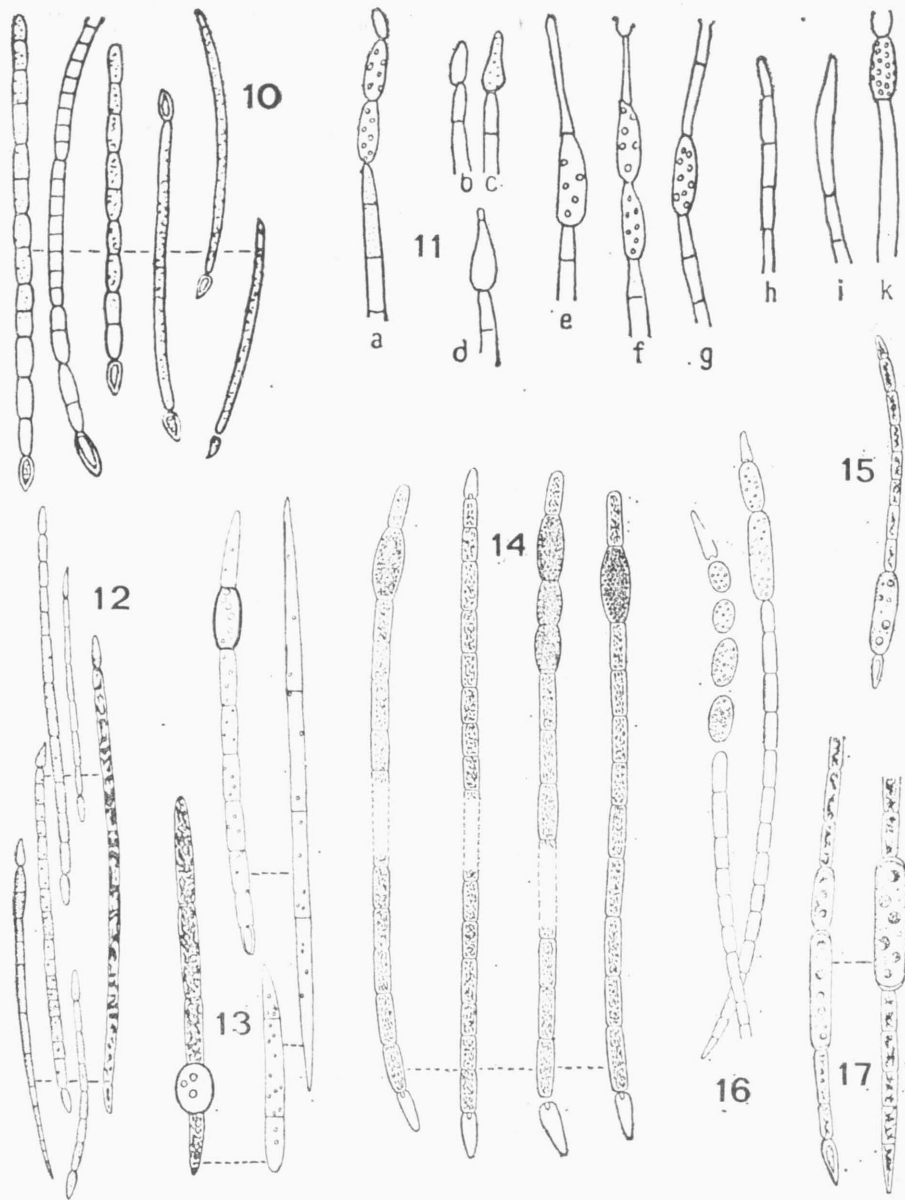
Distribution (Fig. 24): Planktonic in water reservoirs (tanks, fishponds) in tropical countries (S. Asia): India (Madras), Malaysia.

*Cylindrospermopsis raciborskii* (WOLOSZ.) 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* (WOLOSZ.) SEENAYYA et SUBBA RAJU. 10 — after WOLOSZYŃSKA 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 Kazakhstan, USSR); 16 — after PRESCOTT et ANDREWS from KONDRATEVA 1968 (sub "*Anabaenopsis seriala*" and "*A. wustericum*", from the USA); 17 — after OBUCHOVA from KONDRATEVA 1968 (sub "*Anabaenopsis maksimilianii*" from Kazakhstan, USSR).

the position of spores joined to the heterocysts or of intercalary 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

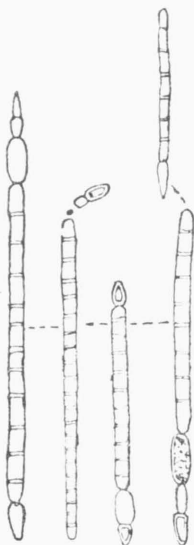


Fig. 18. — *Cylindrospermum doryphorum* BRUHL et BISWAS. After BRUHL et BISWAS from DESIKACHARY 1959 (from India).

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. kogonii*, *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

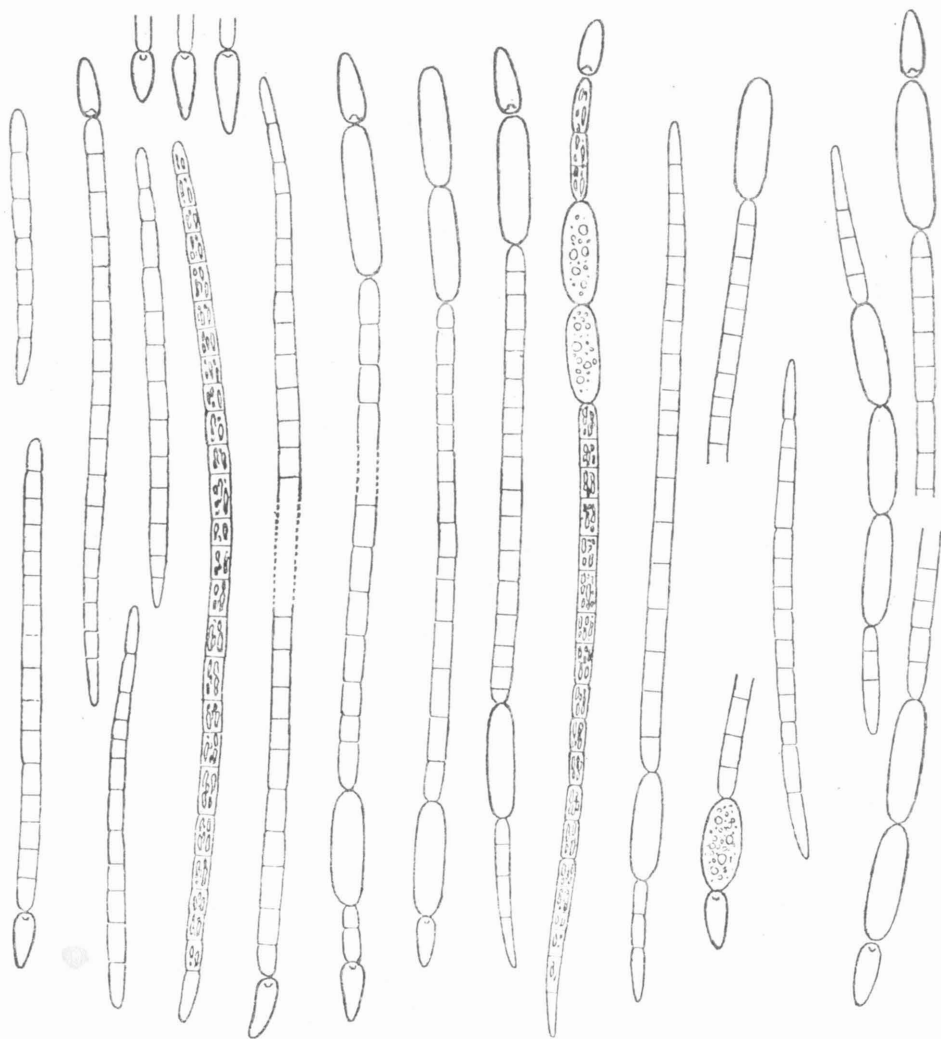


Fig. 19. — *Cylindrospermopsis raciborskii* (WOŁOZ.) SEENAYYA et SUBBA RAJU. Orig. KOMÁREK (from Hungary).

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.

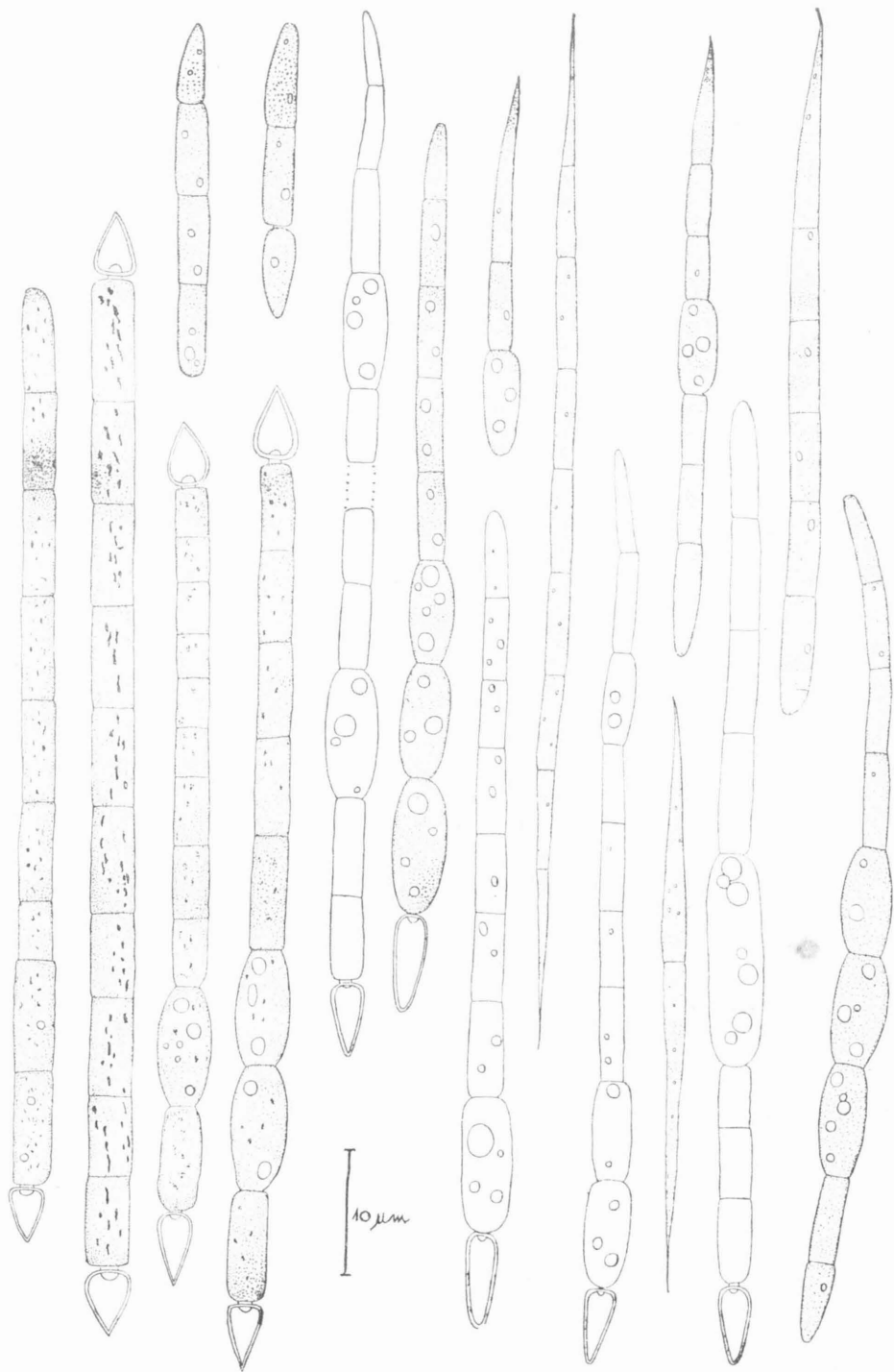


Fig. 20. — *Cylindrospermopsis raciborskii* (Wolosz.) SEENAYYA et SUBBA RAJU. Orig. HORECKÁ (from SW. Slovakia, Czechoslovakia).

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

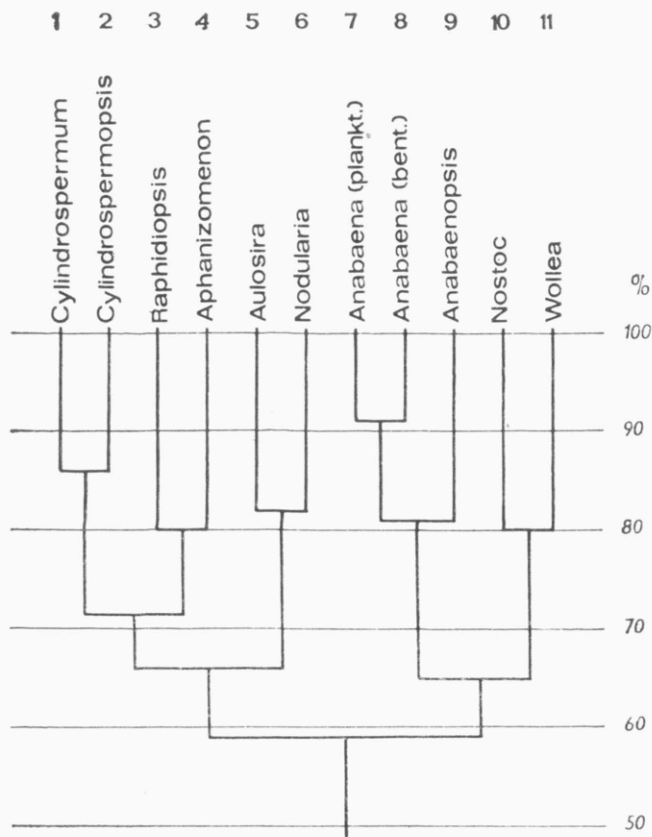


Fig. 21. — Phenogram derived from the numerical evaluation of similarity between nostocacean genera (= OTU); 45 features were used.

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.

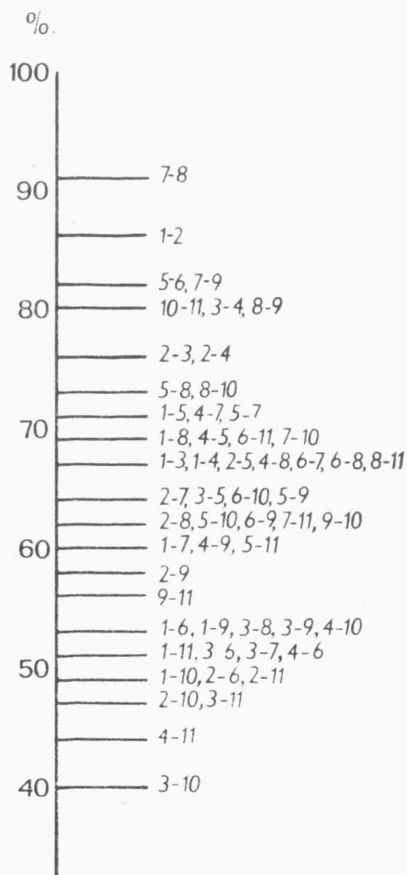


Fig. 22. — Coefficients of similarity between the single genera of *Nostocaceae* (the numbers correspond with the phenogram in the Fig. 21).

*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 kogonii* OBUCH. in OBUCHOVA et KOSENKO Bot. Mat. Gerb. Inst. Bot. Acad. Nauk Kaz. SSR, 2 : 81, Pl. 2 : 1—4, 8, 1964. — *Anabaenopsis maksimiliani* OBUCH. in OBUCHOVA et

Table 2

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

|                    |                                                            |                                             |                                    |                   |              |
|--------------------|------------------------------------------------------------|---------------------------------------------|------------------------------------|-------------------|--------------|
| Spores — shape     |                                                            | ellipsoidal                                 | long ellipsoidal<br>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<br>and streams        | planktonic in Nile                 | planktonic        |              |
| Locality           | Java, Indonesia                                            | (Kazakhstan,<br>Turkmenia, Ukraine)<br>USSR | Egypt                              | Kansas lakes, USA |              |
| Note               | spiroid trichomes<br>belong probably to<br>another species |                                             |                                    |                   |              |

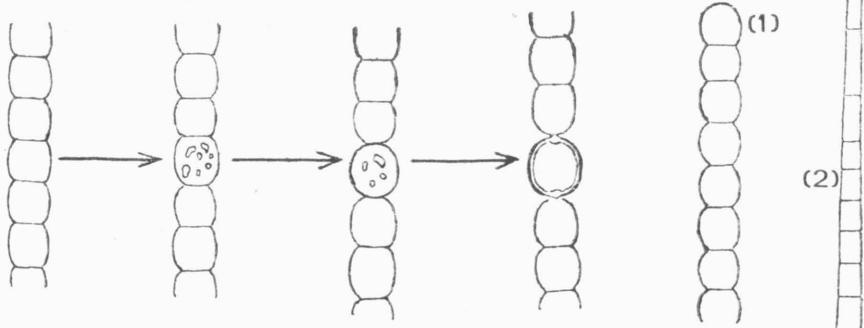
Table 2, contd.

| <i>A. maksimilianii</i><br>OBUCHOVA 1964<br>— diacr. features | <i>A. wuistericum</i><br>OBUCHOVA 1964<br>— diacr. features | <i>A. raciborskii</i><br>sec. HILL 1970                 | <i>A. raciborskii</i><br>(orig. HORECKÁ)                | <i>A. raciborskii</i><br>(orig. KOMÁREK)            | Resulting data                                                             |
|---------------------------------------------------------------|-------------------------------------------------------------|---------------------------------------------------------|---------------------------------------------------------|-----------------------------------------------------|----------------------------------------------------------------------------|
|                                                               |                                                             | solitary,<br>± straight                                 | solitary, straight<br>or slightly curved                | solitary, straight<br>or slightly curved            | solitary, straight<br>or slightly curved                                   |
|                                                               |                                                             |                                                         | slightly<br>attenuated                                  | slightly<br>attenuated                              | slightly<br>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<br>rounded                          | conical,<br>pointed-rounded                             | conical,<br>rounded                                 | ± conical,<br>pointed-rounded                                              |
|                                                               |                                                             | 6.9—14 × (1.8)2 to<br>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) ×<br>× (1.8)2—3(4)                                         |
|                                                               |                                                             | terminal,<br>spear-point like                           | terminal,<br>conical                                    | terminal,<br>conical                                | terminal, long-conical<br>or long ovoid                                    |
| 1—2, separated<br>from Htc. by veget.<br>cells                | 1—2, joined to<br>Htc.                                      | 1—5, joined to Htc. or<br>separated by few veget. cells | 1—2, joined to Htc. or<br>separated by few veget. cells | 1—3, joined to Htc. or<br>with 1—2(3) intere. cells | 1—3(5), joined to term.<br>Htc. or separated by<br>1—3 (more) veget. cells |

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

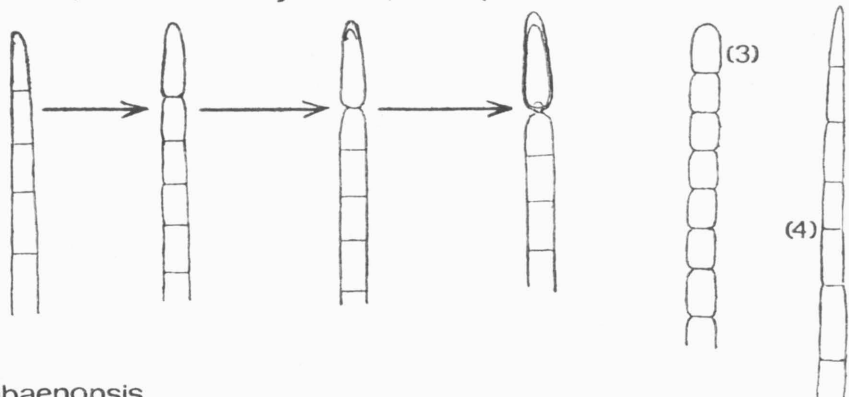
Type

# Anabaena (1) / Aphanizomenon (2)



Type

# Cylindrospermum (3) / Cylindrospermopsis (4)



Type

# Anabaenopsis

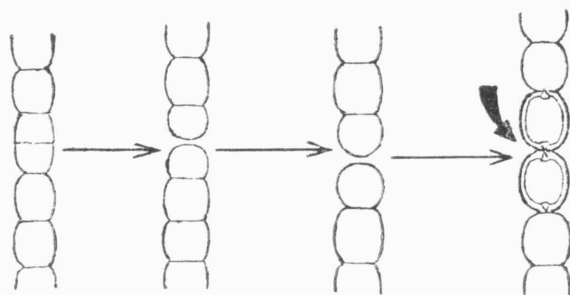


Fig. 23. — Scheme of development of heterocysts, and the ends of trichomes in selected nostocacean genera; the thick arrow indicates the site of trichome disintegration.

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)  $\mu\text{m}$  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,  $2.5-16 \times (1.8)2-4 \mu\text{m}$ . 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,  $(3.4)4.6-12(14) \times (1.8)2-3(4) \mu\text{m}$ . Spores cylindrical

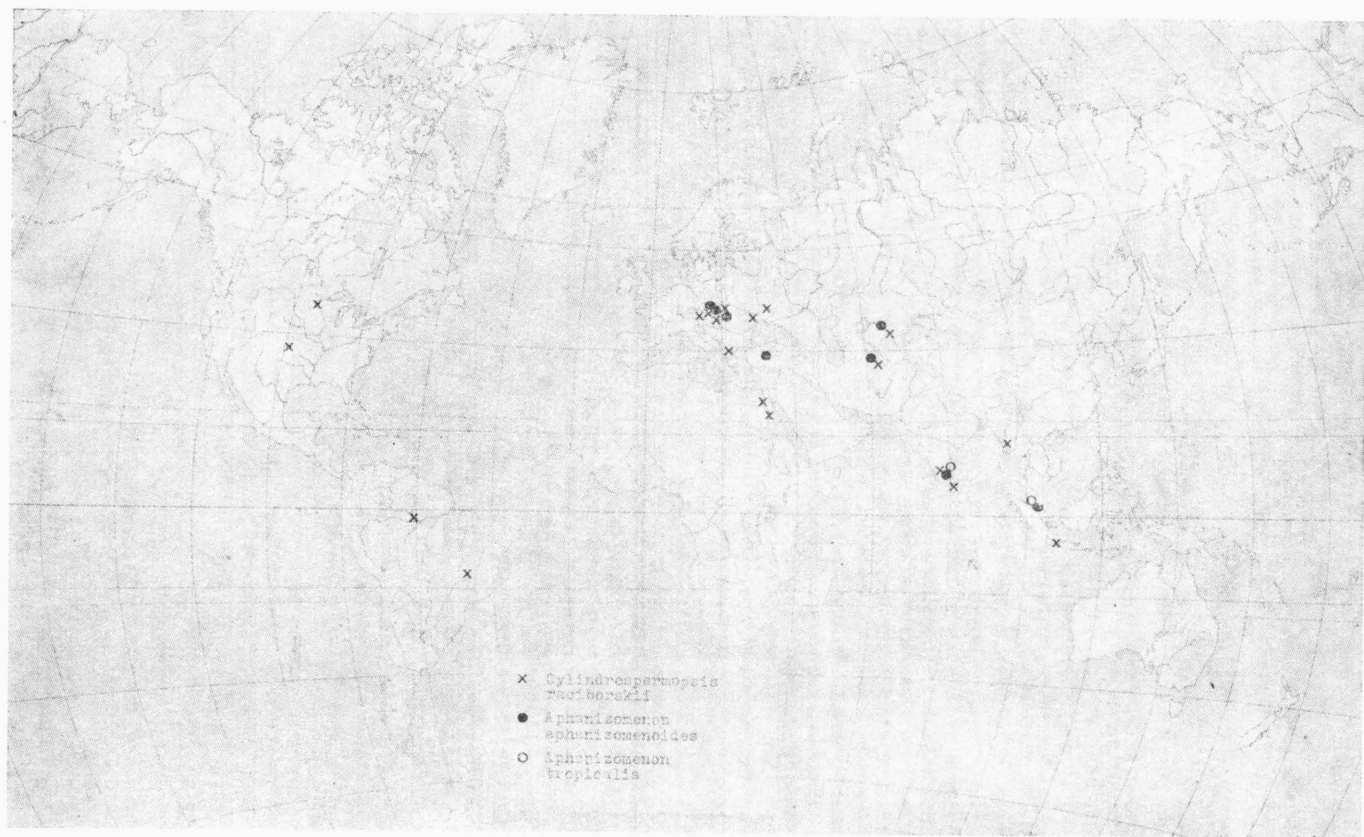


Fig. 24. — Geographical distribution of *Cyindrospermopsis raciborskii*, *Aphanizomenon aphanizomenoides* and *Aphanizomenon tropicale*.

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,  $(4.5)7–18(22) \times (2.4)3–5(5.5) \mu\text{m}$ .

Distribution (Fig. 24): Planktonic in stagnant and floating waters, mainly in tropical countries, rarely in the temperate zone: Austria, Brasil (Lago Paranoá, near Manaus — CRONBERG 1978 in litt.), Burma, Ceylon (CRONBERG in litt.), Czechoslovakia, Egypt (Nile); Greece, Hungary, India, Indonesia (Java), USA (Kansas, Minnesota), USSR (Kazakhstan, 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  $4 \mu\text{m}$ ) he proposes the name *Anabaenopsis woloszynskae*. Of *Anabaenopsis raciborskii*, some subspecific taxa have also been described. Var. *longiscellula* SZALAI 1942 has cells up to  $20.2 \mu\text{m}$  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  $3.5–4 \mu\text{m}$  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 *Anabaenopsis raciborskii* from the river Tisza (Hungary) in 1975, and accepted two varieties: var. *longiscellula* SZALAI 1942 (differential features: cells  $16.2–20 \times 4–5 \mu\text{m}$ , trichomes slightly constricted at cross walls, heterocysts ovoid,  $3.2$  to  $3.7 \mu\text{m}$  long), and var. *seriata* (PRESC.) HAMAR 1977 (syn. *A. seriata* PRESC. 1955; differential features: heterocysts elongated cone-shaped,  $4.5–8 \times 3 \mu\text{m}$ , spores up to 5 in series).

## SOUHRN

Během l. 1976–1978 byly nalezeny na území Československa (jz. Slovensko, pískovna Boříčky 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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Profesor botaniky na vídeňské universitě. Narodil se v Bratislavě, vystudoval teologii a přírodní vědy. Zprvu působil jako knihovník dvorní knihovny ve Vídni. V té době vydává v Bratislavě zpracování květeny Bratislavy a okolí v díle „*Flora Posoniensis*“ (1830). O tři roky později vychází ve Vídni jeho „*Prodomus Florae Norfolkicae*“ a navazují další botanické práce. Již jako kustod dvorního přírodovědného kabinetu vydává v letech 1836–1841 ob-  
sáhlé dílo „*Genera plantarum*“, na které navazuje jako pokračování „*Mantissa botanica*“ (1842–1850) a „*Iconographia generum plantarum*“ (1838). Spolu s Benthamem, Fenzlem a Schotttem připravil „*Enumeratio plantarum... Novae Hollandiae*“ (1837). Od r. 1840 působil jako profesor botaniky na univer-  
sitě ve Vídni a ředitel tamější botanické zahrady. Jako učebnici botaniky na-  
psal společně s Ungerem „*Grundzüge der Botanik*“ (1843), z níž čerpal J. Sv. Presl množství údajů pro svou všeobecnou botaniku „*Počátkové rostlinosloví*“.