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Studies on Planktonic Blue-green Algae 8. *Anabaena* species with twisted trichomes in Japan

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Abstract One new and eleven previously known species of the genus *Anabaena* with twisted trichomes *Anabaena circinalis*, *A. crassa*, *A. flos-aquae*, *A. lemmermannii*, *A. mendotae*, *A. minispora* sp. nov., *A. mucosa*, *A. oumiana*, *A. pseudocompacta*, *A. reniformis*, *A. spiroides*, and *A. ucrainica*, have been reported to exist in many water bodies from Hokkaido, down to Tottori and Hyogo Prefectures in western Honshu, with descriptions and illustrations.

Key words: *Anabaena*, plankton, blue-green algae, Cyanophyta, taxonomy.

Though many authors have reported finding *A. spiroides* and its variety *crassa* in different locations throughout Japan, in many cases they have not mentioned anything about akinete morphology (Umezaki & Watanabe, 1994). Many authors of those reports must have used such taxonomic names as a general term for the *Anabaena* forming spiral trichomes. Through his studies of planktonic blue-green algae in Japan, the present author has become acquainted with different types of *Anabaena* in cell, akinete and coil morphology among the coiling species. In this paper the author describes and compares the coiling species.

In their "Illustrations of the Japanese Fresh-water Algae", Hirose and Hirano (1977) recorded 28 taxonomic names in the genus *Anabaena* from Japan. This includes four planktonic species with twisted trichomes: *A. circinalis*, *A. crassa* (as *A. spiroides* var. *crassa*), *A. mendotae* (as *A. spiroides* var. *treleasii*), and *A. spiroides*. Niiyama (1992) studied planktonic *Anabaena* of Japan with culture materials of TAC (Tsukuba Algal Collection), National Science Museum as well with her original isolates which were also added to the TAC. She reported seven *Anabaena* species and added two species with twisted trichomes, *A. lemmermannii* and *A. reniformis* to the Japanese flora. Recently, the present author recorded *A. ucrainica* and a new species *A. oumiana* through a study of bloom-forming Cyanophytes in Lake Biwa, Shiga Prefecture (Watanabe, 1996). He also recorded *A. mucosa* (Watanabe, 1998) and a new species *A. pseudocompacta* (Watanabe, 1996a) from Lake Inba-numa in Chiba Prefecture.

In this paper the author proposes one new species of *Anabaena* which is characterized by its formation of wide coils and spherical, comparatively smaller akinetes.

Table 1. Specimens and cultures used in this study.

Specimen no. or Culture no.	Locality	Date of collect.	Collector	Species name
50102	L. Akan	1966–7–14	Watanabe	*A. mendotae*
50172	L. Akan	1966–8–4	Watanabe	*A. mendotae*, *A. circinalis*
51588	L. Kasumigaura	1978–7–25	Watanabe	*A. flos-aquae*
52803	L. Koyama-ike	1984–9–7	Watanabe	*A. spiroides*
52807	L. Suigetsu	1984–9–8	Watanabe	*A. flos-aquae*
52823	L. Kutsuzawa	1984–9–12	Watanabe	*A. crassa*
53621	L. Tega-numa	1989–9–12	M. F. Watanabe	*A. pseudocompacta*
53626	L. Toro-ko	1990–8–28	Watanabe	*A. mucosa*
53658	L. Biwa-ko	1994–8–22	Ichise	*A. oumiana*
53679	L. Sagami-ko	1990–8–4	Park	*A. ucrainica*
53685 (A-20)	Sikata-futago pond	1990–9–16	Kato (Niiyama cult.)	*A. reniformis*
53716	L. Inba-numa	1995–10–14	Watanabe	*A. minispora* nov. sp.
53750	L. Koya-ike	1996–7–26	Kimura	*A. reniformis*
53844	L. Sagami-ko	1997–10–16	Watanabe	*A. mucosa*
————	L. Hime-numa	1969–8–18	Ioriya & Haga	*A. mucosa*
————	L. Sagami-ko	1990–7–16	Tanaka	*A. ucrainica*
————	L. Kasumigaura	1991–6–25	Watanabe	*A. flos-aquae*
————	L. Higurasi-ike	1992–9–19	Saito	*A. mucosa*
TAC436	L. Akan	1990–8	Watanabe (Niiyama cult.)	*A. crassa*
TAC437	L. Akan	1990–8	Watanabe (Niiyama cult.)	*A. lemmermannii*

Materials and Methods

The sources of the materials used in this study are shown in Table 1. A large part of the observations and measurements were done with natural samples, however cultured materials were also supplementally used, especially for observations of akinetes. The specimens were deposited in the herbarium of the National Science Museum in Tokyo (TNS) and the cultures were maintained in the stock room of the Botany Department in the National Science Museum in Tsukuba (TAC, Tsukuba Algal Collection).

Observations and Discussion

1. Description of species

In this paper three species with irregularly twisted trichomes and eight species

with more or less regularly coiled trichomes are reported. The latter group are divided further into two subgroups, one of which forms spherical akinetes and the other elongated ones. In the following description the species in each subgroup are arranged from smallest to largest in cell size. Distribution in Japan is based on specimens examined during this study and by selected references from " Enumeration of the Cyanophyta of Japan" by Umezaki & Watanabe (1994).

Irregularly twisted forms

Anabaena flos-aquae Brébisson ex Bornet & Flahault Figs. 1–3.

Trichomes free-floating, irregularly twisted, forming floccose colonies, sometimes forming somewhat irregular coils, without a mucilaginous sheath. Cells spherical or barrel-shaped, 5–6 μm broad. Heterocytes spherical, 5–6.5 μm broad. Akinetes remote from heterocytes, cylindrical, with rounded ends, slightly curved, 9 μm broad, 18 μm long.

Distribution: Sarobetsu, Lake Akan, Lake Abasiri, Kiritappu, Sapporo (Hokkaido); Tsugaru-12-ko, Hirosaki (Aomori Pref.); Oze (Gunma Pref.); Lake Kasumigaura (Ibaraki Pref.); Lake Inba-numa (Chiba Pref.); Lake Suwa, Kuwabara (Nagano Pref.); Lake Mikata (Fukui Pref.); Lake Biwa (Shiga Pref.); Lake Koya-ike (Osaka Pref.).

Anabaena mendotae Trelease Figs. 4–5.

Syn. *Anabaena spiroides* var. *treleasei* Born. & Flah.

Trichomes free-floating, irregularly twisted, forming floccose colonies, sometimes forming somewhat irregular coils, without a mucilaginous sheath. Cells barrel-shaped or cylindrical, 3–5 μm broad, 4–12 μm long. Heterocytes barrel-shaped to ellipsoidal 4–8 μm broad, 5.2–10 μm long. Akinetes cylindrical, with rounded ends, 4.5–8.5 μm broad, 15–40 μm long.

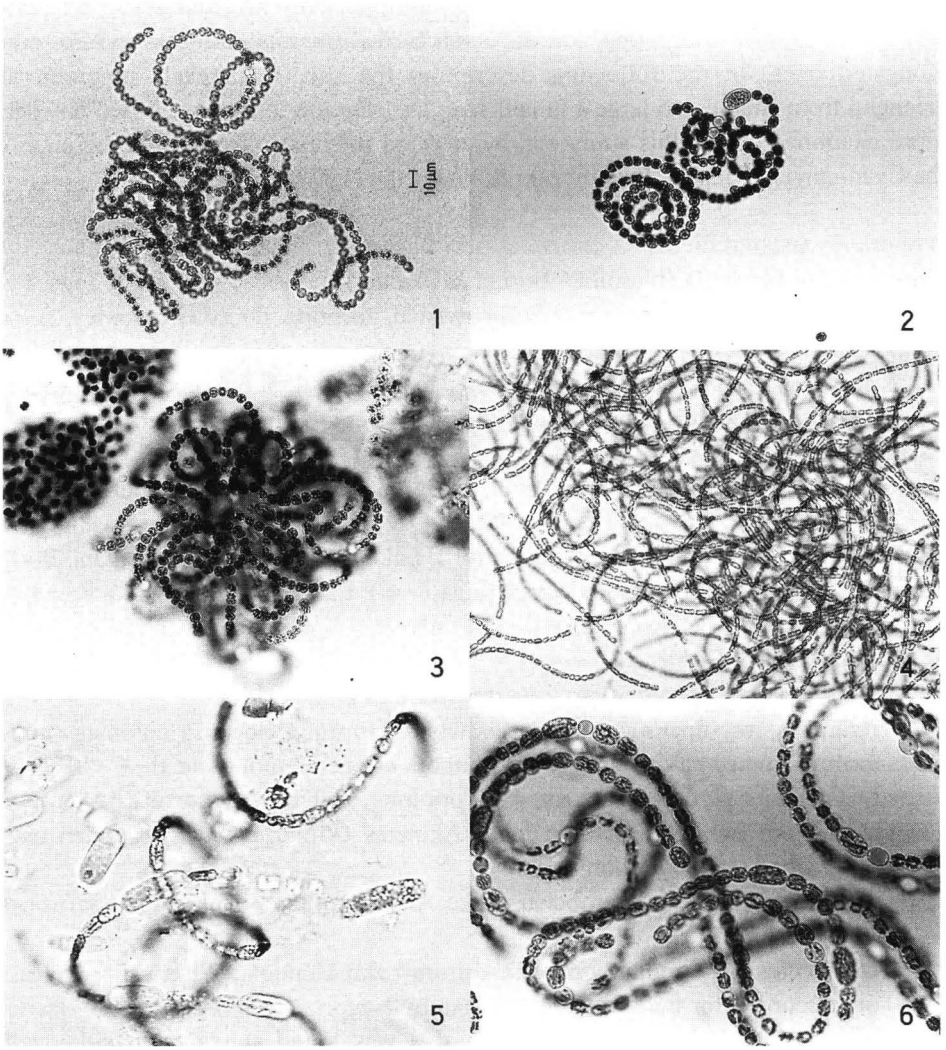
Distribution: Nemuro, Sarobetsu, Lake Akan, Sapporo (Hokkaido); Sarusawa-ike pond (Nara Pref.).

This species was originally described from Lake Mendota, Wisconsin (Trelease, 1889) and recorded for the first time in Japan by Negoro (as *Anabaena spiroides* var. *treleasei*, 1937) at Lake Akan, where the alga was found abudantly together with *Ceratium* sp. and *Asteronella* sp. The alga is distributed widely in Hokkaido and flourish in the northern part of Japan.

Anabaena lemmermannii P. Richter Fig. 6.

Niiyama, Jpn. J. Phycol. (Sorui), **44**: 2, f. 9, 10.

Trichomes free-floating, irregularly twisted, forming floccose colonies. Cells spherical, hemispherical, ellipsoidal, 4–6 μm broad, 2.5–7 μm long. Heterocytes almost spherical, 5–6 μm broad, 5–7.5 μm long. Akinetes cylindrical, with rounded ends, more or less curved, attaching at one or both sides of the heterocytes, one to three in series, 8.5–11.5 μm broad, 13.5–24 μm long.



Figs. 1–6. 1, *A. flos-aquae* (L. Suigetsu); 2, *A. flos-aquae* (L. Kasumigaura); 3, *A. flos-aquae* (L. Suwa); 4, 5, *A. mendotae* (L. Akan); 6, *A. lemmermannii* (L. Akan); 1–5, ×200, 6, ×400.

A record of this species in Japan is based only on cultured materials (TAC 437, 438) isolated from a plankton sample which was collected in Lake Akan by the present author in August 1990 (Niiyama, l.c.).

Coiled forms

'species with spherical akinete'

Anabaena reniformis Lemmermann emend. Aptekarj Figs. 7, 8, 26

Niiyama, Jpn. J. Phycol. (Sorui), **44**: 2, f. 14. 1996.

Trichomes free-floating, regularly twisted, solitary or densely aggregated. Cells spherical to slightly elongated, 4.1–5.1 μm broad, 2.7–5.4 μm long. Heterocytes spherical to slightly elongated, 4.6–5.7 μm broad, 5.1–6.9 μm long. Akinetes spherical, attaching usually at the both sides of heterocytes, 8.2–11 μm broad. Coils regularly twisted, closely contracted, 15.5–17.9(–21.7) μm broad, 4.1–6.1 μm apart.

Distribution: Lake Koya-ike (Osaka Pref.); Shikata-futago pond (Hyogo Pref.).

This alga was described for the first time by Lemmermann (1898) in Germany without an observation of akinetes. Aptekarj found the alga in some locations around Dniepurpetrovsk, Ukraine and emended the species by adding morphological observations of akinetes in 1927. The time alga was found in Japan was in a plankton sample collected at Shikata-futago pond in September 1990. Dr. Yuko Niiyama isolated the alga and soon added two cultures to TAC. She made precise observations and reported the alga (Niiyama, l.c.). Recently the alga was found again in a water-bloom sample from Lake Koya-ike, which is located about 50 kilometers east of Shikata-futago pond and several kilometers west of Itami Air port in Osaka Prefecture. Professor Yukio Kimura of Mukogawa Women's University sent the specimen to the present author for identification. According to Prof. Kimura the habitat of the alga is highly eutrophicated and the alga is found to be the main component of water-bloom together with *Anabaena flos-aquae*, *Arthrospira maxima* and some *Microcystis* species.

Anabaena oumiana M. Watanabe Figs. 9, 10, 27

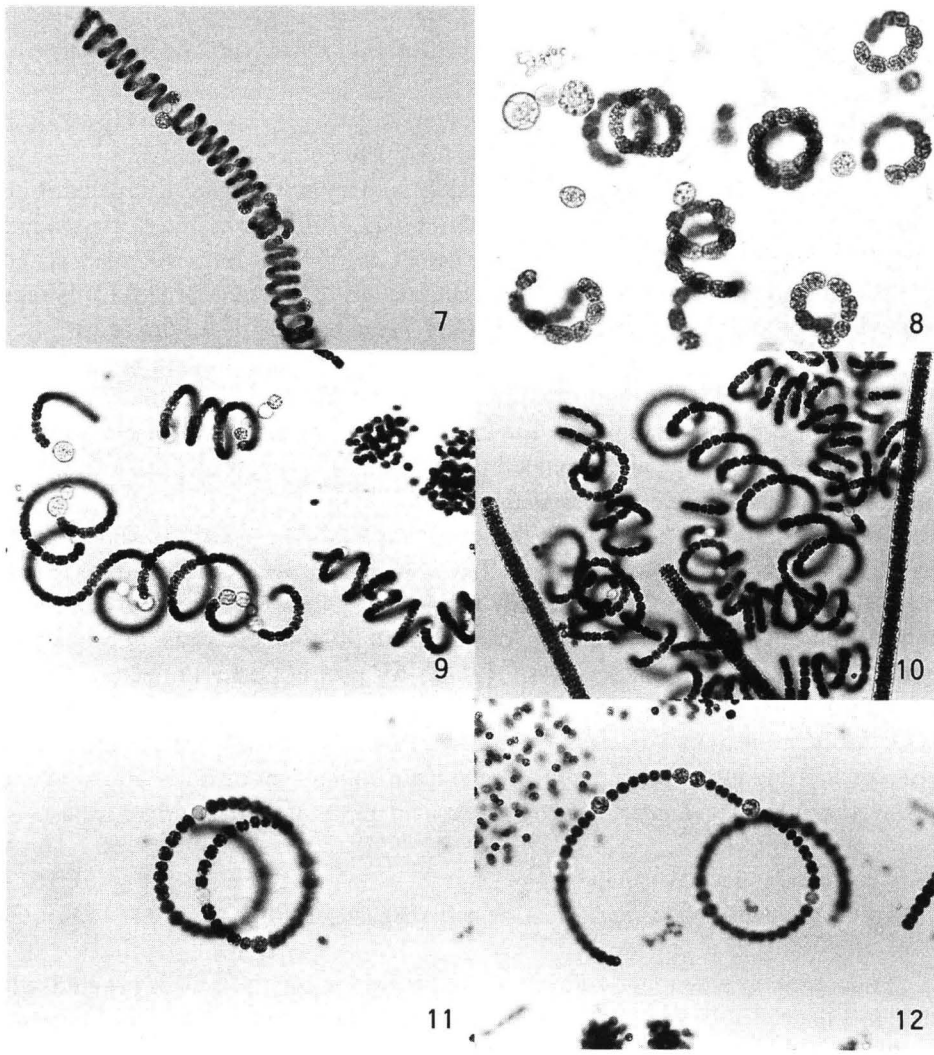
Watanabe, Bull. Natn. Sci. Mus., Ser. B (Botany) 22: 3, f. 5–7, 14, 15, 19, 21, 1996.

Trichomes free-floating, solitary, more or less regularly coiled, covered with thick mucilage. Coils 28–46 μm broad,10–20 μm apart. Cells spherical or barrel-shaped, 6.0–7.1 μm broad, 3.0–6.5 μm long. Heterocytes spherical, 6.8–8.5 μm broad, 6.4–8.0 μm long. Akinetes spherical, 10–12 μm broad, solitary or in pairs, attaching at one or both sides of the heterocytes.

Distribution: Lake Biwa (Shiga Pref.).

Anabaena minispora M. Watanabe sp. nov. Figs. 11, 12, 28

Trichomata libere natantia, solitaria, irregulariter circinata, vaginis crassis mucosis circumcincta. Spirae 80–100 μm in diametro, circiter 40 μm distantes. Cellulae vacuolis gaseosis includentes, sphaeroideae vel cupiformes, 6.8–7.8 μm latae, 4–7 μm longae. Heterocytae sphaericae, circiter 9 μm latae. Akineta sphaerica, 10–12 μm lata, ab heterocytis remota, solitaria vel 2, 3 seralia.



Figs. 7–12. 7, 8, *A. reniformis* (L. Koya-ike, culture Ko-19); 9, 10, *A. oumiana* (L. Biwa); 11, 12, *A. minispora* (L. Inba-numa); 7–12, ×200.

Iconotypus: Figulae 11, 12, 28.

Locus typicus: in lacu Inbanuma, Chiba, Japoniae.

Trichomes free-floating, solitary, irregularly coiled, covered with thick mucilage. Coils 80–100 μm broad, about 40 μm apart. Cells spherical or barrel-shaped, 6.8–7.8 μm broad, 4–7 μm long. Heterocytes spherical, about 9 μm broad. Akinetes spherical, 10–12 μm broad, distant from heterocytes, one or 2, 3 in series.

Distribution: Lake Inba-numa (Chiba Pref.).

Anabaena ucrainica (Schkorbatow) M. Watanabe Figs. 13, 14, 29.

Watanabe, Bull. Natn. Sci. Mus. Ser. B (Botany) 22: 3, f. 8, 16–18, 1996.

Syn. *Anabaena spiroides* var. *ucrainica* Schkorbatow

Trichomes free-floating, solitary, forming regular coils, with a thick mucilaginous sheath. Coils about 45–75 μm broad, 25–70 μm apart. Cells spherical or barrel-shaped, 7–11 μm broad, 3.5–9.9 μm long. Heterocytes spherical, 9–13 μm broad, 7–11 μm long. Akinetes spherical, 13–23 μm broad, 14–19 μm long, remote from the heterocytes.

Distribution: Lake Sagami-ko (Kanagawa Pref.); Lake Biwa (Shiga Pref.).

Anabaena mucosa Komárková-Legnerová & Eloranta Figs. 15, 16, 30.

Trichomes free-floating, solitary, forming more or less irregular coils, with thick mucilaginous sheath. Coils 82–126 μm broad, 45–65 μm apart. Cells spherical or barrel-shaped, 9–11.3 μm broad, 4–10 μm long. Heterocytes spherical, 10–12.3 μm broad, 9.5–12 μm long. Akinetes spherical, 16.3–20.4 μm broad, 17.6–21.3 μm long, remote from the heterocytes.

Distribution: Lake Hime-numa, Lake Toro-ko (Hokkaido); Lake Higurashi-ike (Aomori Pref.); Lake Sagami-ko (Kanagawa Pref.).

The Japanese alga differs in several morphological points from the original one which was described from Finland (Komárková-Legnerová & Eloranta, 1992). The former is a little larger in dimensions of cells and heterocytes, and a little smaller in those of akinetes than the latter.

'species with elongate akinetes'

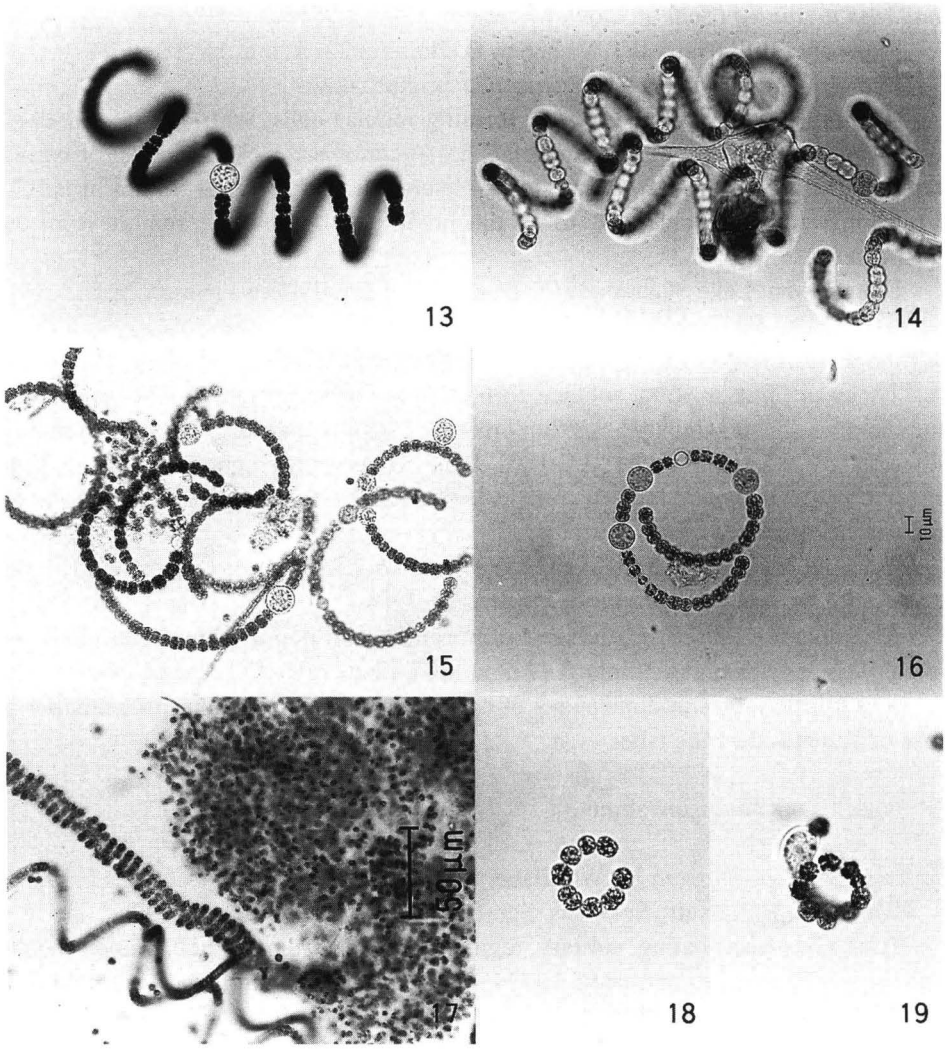
Anabaena pseudocompacta M. Watanabe Figs. 17–19, 31.

Watanabe, Bull. Natn. Sci. Mus. Ser. B (Botany) 22: 93, f. 1–11, 1996.

Trichomes free-floating, solitary, regularly coiled, without mucilaginous sheath. Coils generally closely contracted, 18–24 μm broad, 50–250 μm long. Cells spherical or barrel-shaped, 5.2–7 μm broad, 3–6.8 μm long. Heterocytes spherical, 5.5–7.5 μm broad. Akinetes ellipsoidal, sometimes slightly curved or asymmetrically curved (nearly straight at the inner side), 7.5–11.3 μm broad, 16.8–21.3 μm long, 1.8–2.6 times longer than broad, remote from the heterocytes.

Distribution: Lake Kasumigaura (Ibaraki Pref.); Lake Inba-numa, Lake Teganuma (Chiba Pref.).

This alga from Lake Kasumigaura was first recorded as *Anabaena spiroides* (M. Watanabe & Chihara, 1980) and described as a new species, *A. pseudocompacta*, by the present author lately (Watanabe, 1996). *A. pseudocompacta* resenbles *A. compacta* Nygaard superficially, however the former is larger in cell dimensions and in akinete form. Length/width ratios of the akinetes are 1.8–2.6 and 1.2–1.4 respectively.

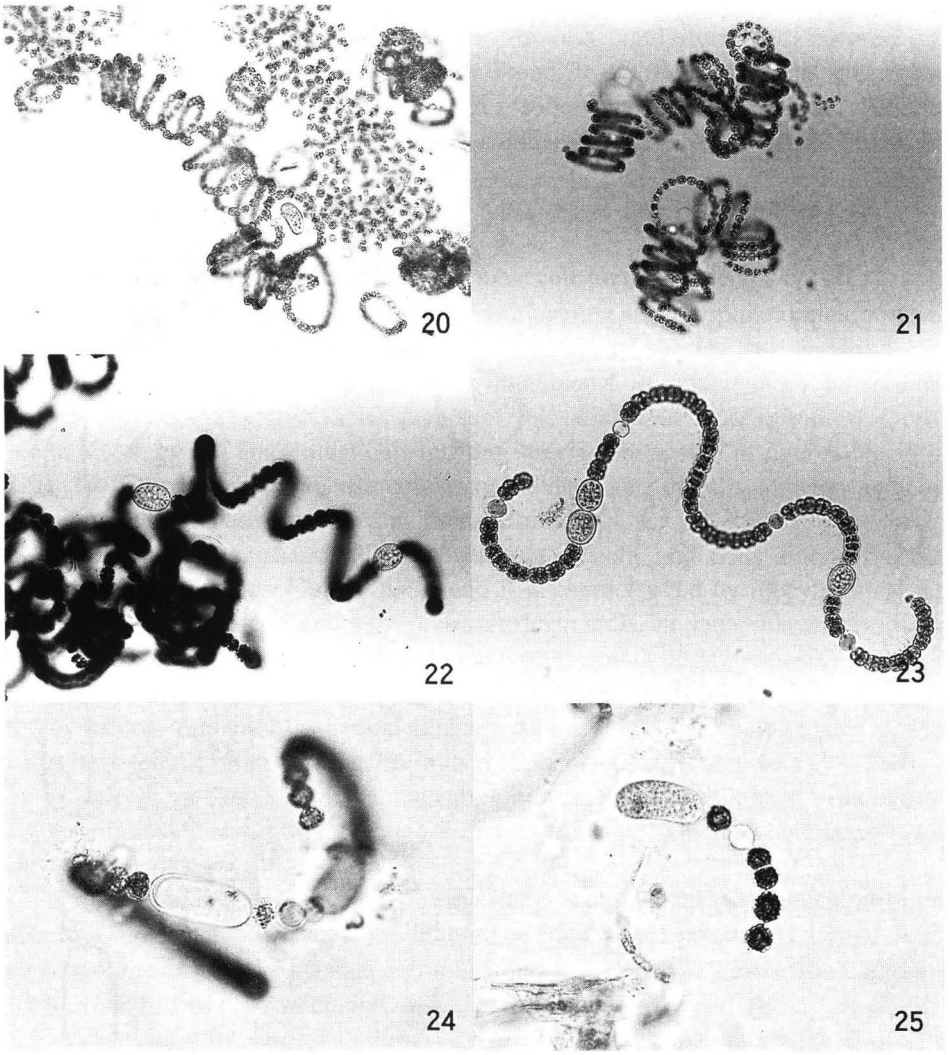


Figs. 13–19. 13, 14, *A. ucrainica* (L. Sagami); 15, *A. mucosa* (L. Toro); 16, *A. mucosa* (L. Himenuma); 17–19, *A. pseudocompacta* (L. Tega-numa); 13–17, ×200, 18,19, ×400.

Anabaena spiroides Klebahn Figs. 20, 21, 32.

Trichomes free-floating, solitary, more or less regularly coiled, without mucilaginous sheath. Coils 27–37 μm broad, 7–10 μm apart. Cells spherical or barrel-shaped, 4.9–6.3 μm broad, 3.0–7.6 μm long. Heterocytes nearly spherical, 6.3–7.1 μm broad, slightly shorter than broad. Akinete ellipsoidal, usually curved, 9.1–10.1 μm broad, 21–24 μm long.

Distribution: Lake Koyama-ike (Tottori Pref.).



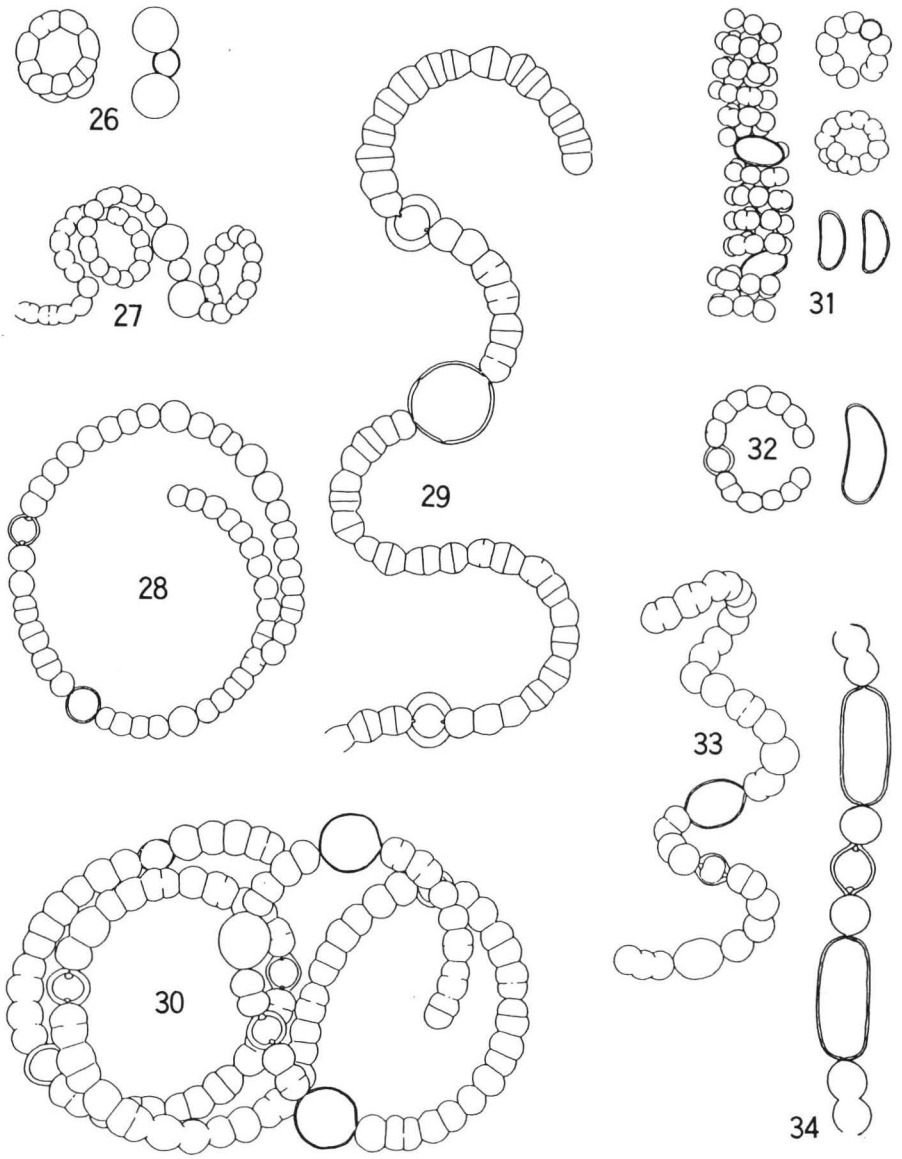
Figs. 20–25. 20, 21, *A. spiroides* (L. Koyama-ike); 22, *A. crassa* (L. Kutsuzawa); 23, *A. crassa* (L. Biwa); 24, 25, *A. circinalis* (L. Akan); 20–25, ×200.

Anabaena crassa (Lemmermann) Komárková-Legnerová & Cronberg

Figs. 22, 23, 33.

Syn. *Anabaena spiroides* var. *crassa* Lemmermann

Trichomes free-floating, solitary, regularly coiled. Coils 33–57 μm broad, 20–60 μm apart. Cells spherical or barrel-shaped, 8.1–12.2 μm broad, 4.9–9.6 μm long. Heterocytes spherical, 10–12.8 μm broad. Akinetes ellipsoidal, 12.5–17.7 μm broad, 15.5–23.4 μm long, remote from the heterocytes.



Figs. 26–34. 26, *A. reniformis*; 27, *A. oumiana*; 28, *A. minispora*; 29, *A. ucranica*; 30, *A. mucosa*; 31, *A. pseudocompacta*; 32, *A. spiroides*; 33, *A. crassa*; 34, *A. circinalis*; ×500.

Distribution: Lake Akan (Hokkaido); Lake Kasumigaura (Ibaraki Pref.); Lake Kutsuzawa-ko (Nagano Pref.); Lake Biwa-ko (Shiga Pref.).

Anabaena circinalis Rabenhorst ex Bornet & Flahault Figs. 24, 25, 34.

Trichomes free-floating, solitary, more or less regularly coiled, covered with thick mucilaginous sheath. Coils 47–99 μm broad, 36–73 μm apart. Cells spherical or barrel-shaped, 8–12 μm broad. Heterocytes spherical, 10–14 μm broad. Akinetes cylindrical, with rounded ends, sometimes slightly curved, 12–14(–20) μm broad, 25–30 μm long.

Distribution: Lake Akan (Hokkaido); Kiryu-gawa dam (Gunma Pref.).

2. Morphological relationships among nine coil-forming species

In order to help our understanding of coil forming species in planktonic *Anabaena*, the present author proposes two hypothetic lines of species: species developing spherical akinetes such as *A. reniformis*, *A. oumiana*, *A. ucrainica* and *A. mucosa* and those developing elongate akinetes such as *A. pseudocompacta*, *A. spiroides*, *A. crassa* and *A. circinalis*. These nine coil-forming species are shown in figures 26–34 together for comparison, and measurements of the diameters of cells, akinetes and coils of each population base are shown in Tables 2 and 3.

A. reniformis has the smallest dimensions of cells and coils among the nine species under discussion (Tables 2, 3), and it is characterized by its cylindrical tendency in cells, which consequently cause reniform cells. In such characteristics this species may not be adequate for comparison with the other eight species.

A. oumiana, as well as the above-mentioned alga and *A. ucrainica*, is characterized by its development of spherical akinetes at both sides of the heterocytes. However it is between the other two species in its dimensions of cells and coils.

A. minispora shows similar dimensions in cells and akinetes to *A. oumiana* but is discontinuously larger than the latter in coil diameter which is comparable with that of *A. mucosa*.

A. ucrainica is characterized by formation of quite regular coils which is comparable to *A. crassa*, and consequently both algae show stout appearance. Length/width ratios in akinetes are 0.9–1.2 in *A. ucrainica* and 1.2–1.4 in *A. crassa*. The coil diameter of *A. ucrainica* is between that of *A. oumiana* and *A. mucosa*.

A. mucosa is the largest in dimensions of cells and coils among the above five species with spherical akinetes.

A. pseudocompacta is the smallest in dimensions of cells and coils among the four species forming elongate akinetes (Table 3), and is superficially quite similar to *A. reniformis*, especially in a sterile state. It is interesting that the habitats of those algae are both highly eutrophicated water bodies. *A. pseudocompacta* is known in the Kanto area and *A. reniformis* in the Kansai area.

A. spiroides is one of the commonest names of the genus *Anabaena*, especially of the species forming spiral trichomes, and is believed to be widely distributed. However the present studies have so far indicated that this alga is, in fact, rather rare at least in Japan. Many of the algae which were recorded as *A. spiroides* were likely

Table 2. Comparison of the diameter of cells, akinetes and coils among ten populations forming spherical akinetes.

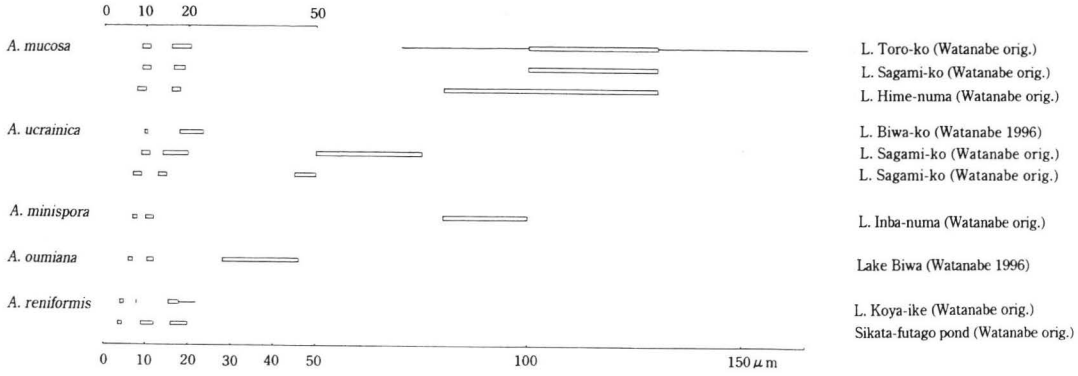
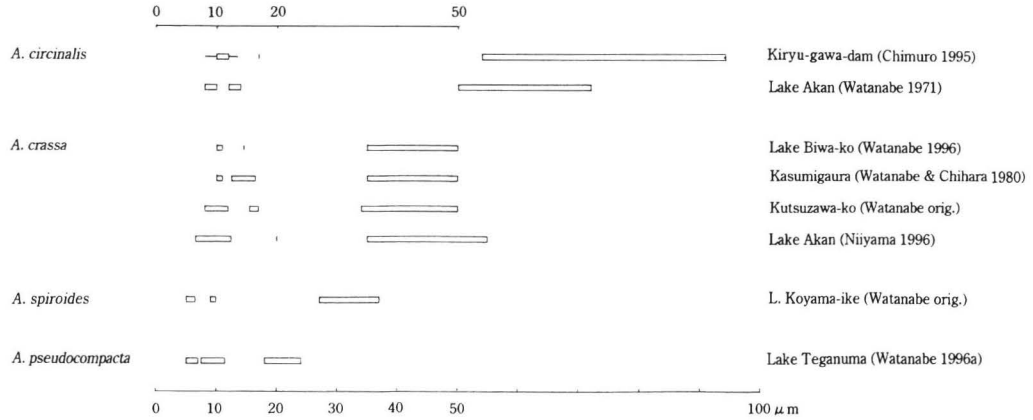


Table 3. Comparison of the diameter of cells, akinetes and coils among eight populations forming elongate akinetes.



other species.

A. crassa is commoner than the previous alga, though some of the records might be identified with *A. ucrainica*. This species resembles *A. circinalis* in cell dimensions but differs in akinete form and in coil diameter.

A. circinalis is distinguished by broader coil diameter and by more cylindrical tendency in akinetes from *A. crassa*.

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