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## Phytoplankton Composition and Morphology in Lake Valencia, Venezuela

*key words:* Lake Valencia, tropical phytoplankton, phytoplankton morphology, phytoplankton composition

### Abstract

Phytoplankton of Lake Valencia, Venezuela, were examined at weekly intervals over a period of two years. Eighty-two euplanktonic species were identified, including 35 Chlorophyta, 29 Cyanophyta, 9 Bacillariophyceae, 3 Chrysophyta, 2 Cryptophyta, 2 Euglenophyta, and 2 Dinophyceae. The biomass of the phytoplankton is heavily dominated by three groups: Cyanophyta, Chlorophyta, and Bacillariophyceae. The dimensions of all species were measured routinely, and the dimensions of the most common species were measured with sufficient frequency to permit separation of within- and among-dates variance components. For the 82 species, the mean greatest axial linear dimension (GALD) is 13  $\mu\text{m}$ , and the mean second greatest axial linear dimension (SGALD) is 5.3  $\mu\text{m}$  for individual cells. The plankton units, which may consist of individual cells, colonies, or coenobia, according to the species, have average values of GALD and SGALD about three times as great as for individual cells. The data indicate convergence toward a rather narrow range of average plankton unit dimensions in all taxa. Degree of variability of dimensions on specific dates is also surprisingly similar across different taxa. The mean coefficient of variation for axial dimensions on particular dates is typically between 15% and 20%. Variation across dates as determined by analysis of variance is surprisingly low. The component of variance attributable to dates gives a coefficient of variation of less than 15% for all major taxonomic groups. The phytoplankton of individual populations may be more conservative in their morphology than has previously been realized, even though considerable variations may occur between populations in different lakes or in laboratory culture.

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## 1. Introduction

As part of a comprehensive study of Lake Valencia, Venezuela, we have sampled and examined the phytoplankton at one-week intervals for more than two years. Although the primary emphasis of the phytoplankton studies is ecological, we have maintained careful records of species composition and have accumulated basic descriptive information on as many taxa as possible. Our purpose in doing this is to contribute to an understanding of the species composition of phytoplankton in tropical lakes (LEWIS and WEIBZAHN 1976, LEWIS 1978a). Although tropical lakes have been sampled by algal taxonomists for many years, such samples have typically been based on a single visit to a waterbody and have often emphasized net plankton or selected taxa rather than whole plankton, thus giving little impression of the overall species composition. In this case we deal with all euplanktonic taxa in the phytoplankton community of Lake Valencia, including those which may be quite rare at certain times of the year. In addition, we have had the opportunity to observe seasonal changes in the dimensions and morphology of important species and have documented these wherever possible.

Lake Valencia is a graben lake located in the Aragua Valley of Venezuela, 15 km south of the Caribbean Sea (Fig. 1). It was visited by VON HUMBOLDT (1820), who noted that the lake was not discharging water through the outlet, nor has it discharged

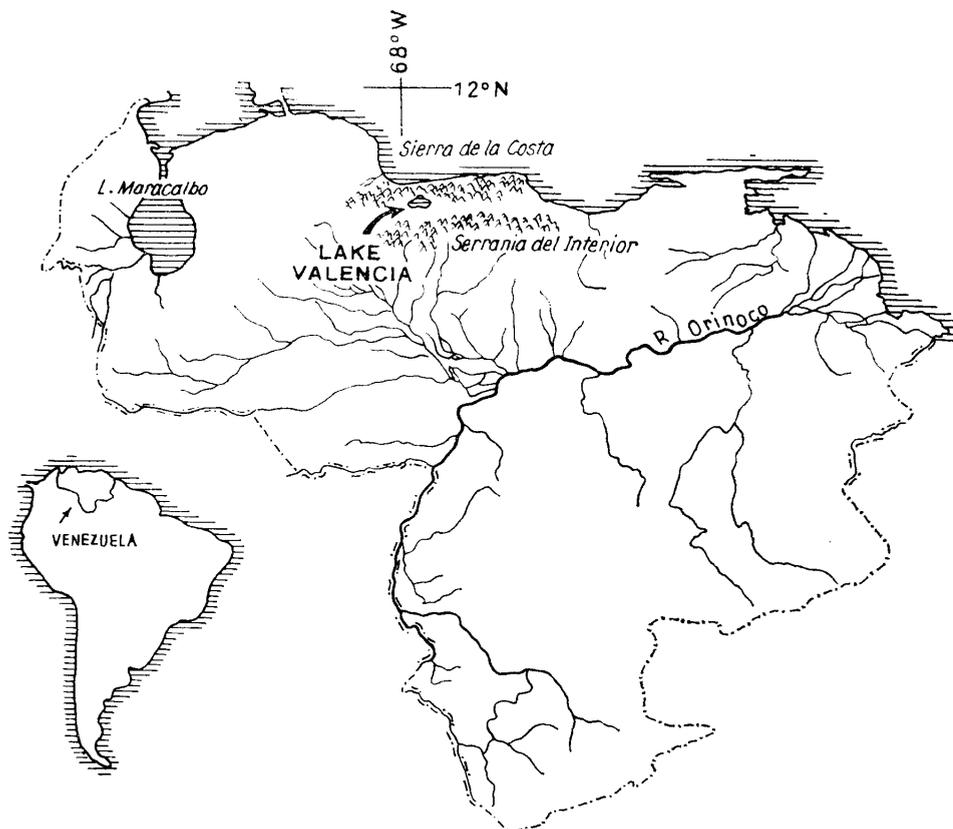


Figure 1. Map showing the location of Lake Valencia, Venezuela.

any water since that time. Historical accounts indicate that the last discharge of water from the lake occurred in 1727 (see review by SCHUBERT 1979). At the present time, the lake surface has an elevation of 404 m, which is approximately 23 m below the discharge level. The desiccation of the lake has resulted in an increase of dissolved solids to about 1400 mg/l.

The level of Lake Valencia has fluctuated a great deal over the past 10,000 years in connection with climatic variations (LEWIS and WEIBEZAHN 1981). The present decline in lake level is due to climatic change toward drier conditions, augmented by human use of water in the watershed. It is unlikely, however, that the solids content of Lake Valencia has been less than 150 mg/l over the last 10,000 years (LEWIS and WEIBEZAHN 1981).

The dominance order for cations by weight in Lake Valencia is  $\text{Na}^+ > \text{Mg}^{++} > \text{K}^+ > \text{Ca}^{++}$ . For anions, the order is  $\text{SO}_4^- > \text{HCO}_3^- > \text{Cl}^-$ . The lake is eutrophic (ca. 3 g C/m<sup>2</sup>/day net production, annual average). The levels of  $\text{PO}_4\text{-P}$  in the growth zone fall between 1 and 15  $\mu\text{g/l}$  (average, 10  $\mu\text{g}$ ) and the amounts of  $\text{NO}_3\text{-N}$  fall between 1 and 100  $\mu\text{g/l}$ . The present maximum depth of the lake is 39 m and the mean depth is 19 m. Substantial standing crops of algae are typical of the upper water column throughout most of the year. The principal factors limiting primary production appear to be light and, at certain times of year, inorganic nitrogen. Deep circulation of the lake occurs at the time of seasonal thermal uniformity (December through March). At all times of year the water is alkaline (pH 8.5 to 9.5.)

Lake Valencia sustains large herbivore populations which feed on all major groups of algae (INFANTE 1978). Because of the very high algal biomass levels of Lake Valencia, however, it seems highly improbable that these herbivores remove a significant proportion of the total production of the phytoplankton community, although measurements of grazing rates are not yet complete.

In our annotations of the phytoplankton species we have included wherever possible statistical information on the degree of variation in morphology. In addition to the routine weekly samples, samples for three different times were examined intensively for collection of statistical information on measurements: 22 February 1977, 12 July 1977, and 6 December 1977 (0–5 m water layer). For each of these dates, mean and variance of axial measurements and other morphological traits such as number of heterocysts were obtained for each species on 60 randomly-selected individuals in a counting chamber. The results show the degree of variation between seasons. February is late in the seasonal circulation period, July is in the middle of the stratification season, and December is very early in the seasonal circulation (Table 1).

Table 1. Conditions in the euphotic zone of Lake Valencia (0–5 m) on the three dates used in determinations of phytoplankton morphological statistics

Date	$\text{PO}_4\text{-P}$ $\mu\text{g/l}$	$\text{NO}_3\text{-N}$ $\mu\text{g/l}$	$\text{NH}_4\text{-N}$ $\mu\text{g/l}$	Mixing depth (m)	Secchi depth (m)
22 Feb 1977	5	4	7	38	2.1
12 July 1977	4	8	32	20	2.3
6 Dec 1977	13	140	15	38	1.9

## 2. Methods

Measurements of phytoplankton species were taken according to a standardized plan that has been used elsewhere in ecological analysis (LEWIS 1976, 1979). According to this plan, the longest geometric axis is identified. This is referred to as the GALD measurement (Greatest Axial Linear Dimension). For example, the GALD measurement for an elongate cylindrical species would be the length of the cylinder. For spherical species, GALD would be merely the diameter, and for a spheroid it would be the longest axis of rotation. The interpretation is simple enough for colonies or cells which have regular geometric shape. For those which do not have a symmetrical shape, GALD should be interpreted as the longest linear dimension, even if this dimension cannot pass through an axis of symmetry. For example, for an irregular colony, it would simply be the longest line segment connecting any two surfaces of the colony. In addition, we have also tabulated for most species the SGALD, which is the second greatest axial linear dimension. For an elongate cylindrical form, this would be the diameter of the cylinder, and for a sphere, it would also be the diameter. For forms which taper, SGALD is assumed to be measured at the broadest point. SGALD is of special interest because it appears to be closely related to the suitability of phytoplankton organisms as food for herbivores (LEWIS 1979).

The GALD and SGALD measurements were made on both cells and plankton units. A plankton unit is an association of cells typical of a given species. The size of the plankton unit must be determined by statistical methods; for each species there will be a mean plankton unit size and a variance around this mean. The dimensions of the plankton unit are assumed to include any space enclosed by the unit. For example, the GALD of a spiral filament is the length of the spiral axis, and the SGALD is the amplitude of the spiral. Spines are counted toward the GALD and SGALD for plankton units, but not for cells.

## 3. Annotated List of Species

### *I. Cyanophyta*

Bluegreen algae present special difficulties in taxonomy because of their great plasticity in form and the lack of structural features that would aid in identification. We have had little difficulty in identifying distinctive morphotypes among the bluegreen algae of Lake Valencia, but two problems remain: (1) are the distinct morphotypes really species, and (2) is it possible to identify the species?

Since there is a general confusion about the distinctions between species among the bluegreen algae, we can scarcely hope to resolve with complete confidence the problem of species separation. To some degree, however, this is only secondarily relevant to our main interest, which is the identification and enumeration of ecologically distinct types in the phytoplankton. In practice, we have retained species separations between any two forms which do not show evidence of intermediate morphologies that would suggest that they belong to a common stock. While this does not preclude the possibility that two such distinct forms may be in fact the same species, this method maintains good agreement with traditional species separations and also serves our own purpose of separating the significantly different morphologies, which may be associated with different adaptations to environment.

In making the assignment of species names, we have frequently been forced to choose between old classical works such as that of GEITLER (1925) as presented in its original form or by HUBER-PESTALOZZI (1938) and more modern works which take into account not only new systematic information but also new knowledge about the plasticity of form in the bluegreen algae. We were not able to accept the radical revision of the coccoid Myxophyceae by DROUET and DAILY (1956) simply because it would hide far too much significant biological diversity in form, which is not conclu-

sively proven to be intraspecific to the extent indicated by these authors. We have thus been guided in most cases by HUBER-PESTALOZZI and more conservative later authors, particularly KOMAREK (1958, 1976), and BOURRELLY (1970) for generic distinctions. Unless a particular monograph is referenced, the reader can assume that identifications of bluegreens were made from HUBER-PESTALOZZI (1938) as modified by KOMAREK (1958, 1976).

Table 2 summarizes the statistical data on Lake Valencia Cyanophyta.

Table 2. Dimensions and morphological statistics for bluegreen species from Lake Valencia; coefficient of variation for some species:  $(s/\bar{x}) \cdot 100$

Name	Cells		Plankton Units	
	GALD	SGALD	GALD	SGALD
1. <i>Microcystis aeruginosa</i>	6.0	6.0	201	153
2. <i>M. holsatica</i>	1.0	1.0	40	30
3. <i>Aphanocapsa delicatissima</i>	0.7	0.7	11	9
4. <i>A. elachista</i>	1.5	1.5	20	15
5. <i>Aphanothece nidulans</i>	2.0	1.0	20	25
6. <i>Chroococcus dispersus</i>	2.7 (15)	2.3 (14)	48 (16)	29 (15)
7. <i>C. sp. 1</i>	2.4	2.0	19	19
8. <i>C. limneticus</i>	5.0	4.5	25	25
9. <i>Synechocystis aquatilis</i>	5.5 (25)	5.0 (19)	5.5 (25)	5.0 (19)
10. <i>S. sp. 1</i>	2.8 (13)	2.5 (15)	2.8 (13)	2.5 (15)
11. <i>Gomphosphaeria naegeliana</i>	2.7	1.7	20	14
12. <i>Merismopedia elegans</i>	1.4	1.0	7.0	6
13. <i>Coelosphaerium minutissimum</i>	0.9	0.9	9.0	9.0
14. <i>Eucapsa alpina</i>	2.0	2.0	17	17
15. <i>Dactylococcopsis fascicularis</i>	43 (29)	0.7 (0)	43 (79)	0.7 (0)
16. <i>Spirulina laxissima</i>	3.5	0.7 (11)	14 (22)	6.0 (19)
17. <i>Cylindrospermopsis stagnale</i>	10	2.4 (19)	95 (37)	2.4 (19)
18. <i>Anabaenopsis circularis</i>	7.5	3.8 (6)	40 (8)	31 (25)
19. <i>Anabaena spiroides</i>	6.5	6.5	50	40
20. <i>A. volzii</i>	5.0	3.2 (18)	105 (70)	3.2 (18)
21. <i>Lyngbya limnetica</i>	2.5	0.7 (8)	68 (25)	0.7 (8)
22. <i>L. contorta</i>	2.5	0.7 (0)	27 (33)	20 (15)
23. <i>Oscillatoria limnetica</i>	7.0	0.9 (24)	30 (39)	0.9 (24)
24. <i>O. quadripunctulata</i>	3.9	1.7 (0)	278 (16)	1.7 (0)
25. <i>O. amphigranulata</i>	2.5	1.8	25	1.8
26. <i>Pseudanabaena sp. 1</i>	4.5	1.8	25 (0)	1.8
27. <i>Raphidiopsis sp. 1</i>	11 (29)	0.7 (2)	48 (26)	0.7 (2)
28. <i>R. curvata</i>	6.0	2.2	91 (27)	20 (34)
29. <i>R. mediterranea</i>	12 (5)	1.9 (11)	140 (6)	1.9 (11)

1. *Microcystis aeruginosa* KÜTZ. This species appears as an irregular colony held together with an extremely hyaline matrix material. The cells are irregularly arranged and have vacuoles. Cells are almost perfectly spherical in shape. The colonies develop very strong buoyancy under certain conditions, especially near the onset of seasonal mixing (November-December), and at such times appear in large numbers at the surface of the lake if the weather is calm (cf. REYNOLDS and WALSBY 1975). Despite the occasional prominence of this species, its importance in terms of annual biomass per unit surface area of lake is relatively low.

2. *Microcystis holsatica* LEMM. This species is much less common than *M. aeruginosa*

in Lake Valencia. No gas vacuoles are evident. The colonies tend to be somewhat flattened, and the gelatinous matrix is indistinct.

3. *Aphanocapsa delicatissima* W. and G. S. WEST. This species has cells consistently less than 0.8  $\mu\text{m}$  in diameter. The cells are spaced two or three diameters apart in an irregular manner and the colony shows a definite tendency to be spherical. The cells show no tendency to pair and no gas vacuoles are present.

4. *Aphanocapsa elachista* W. and G. S. WEST. Cells of this species show some tendency to pair. Small colonies tend to be spherical but larger colonies may be irregular in shape. The cells are dispersed by three or four diameters from each other in a gelatinous matrix. This species is easily distinguished from *Aphanocapsa delicatissima* by the larger size of cells, the marked tendency of cells to pair, and the much less dense packing of the cells.

5. *Aphanothece nidulans* P. RICHT. Cells of this species are oblong and uniformly twice as long as broad. The cells are dispersed in the matrix at a distance of about two cell lengths from each other. Colony size is typically quite small.

6. *Chroococcus dispersus* (KEISSL.) LEMM. The cells of this species are united in irregular colonies of moderate size. The cells lack gas vacuoles, show very little tendency to pair, and are almost round (Fig. 2 D).

7. *Chroococcus* species 1. This species is typified by moderate colony size (10–30 cells). The cells show a definite tendency to pair, although not all cells are paired. The cells are definitely smaller than those of *C. dispersus*. All cells have vacuoles. This species does not easily fit the description of any species in the literature. Due to the presence of gas vacuoles and small size of the cells it is closest to *Chroococcus planctonicus* BETHGE., but has a considerably smaller colony size, lacks the tabular colony form, and is typified by smaller cells than *C. planctonicus*.

8. *Chroococcus limneticus* LEMM. This species typically has 8 or 16 cells. Although most variants of this species described from the temperate zone have larger cells (KOMAREK 1958), the *subsalsa* LEMM. variant described by HUBER-PESTALOZZI (1938) is very close to the form observed in Lake Valencia.

9. *Synechocystis aquatilis* SAUV. *Synechocystis* species have proven to be very prominent in saline tropical waters (e.g., ILTIS 1972), hence it is not surprising that *Synechocystis* is a very important component of the algal flora in Lake Valencia. The cells of this species contain pseudovacuoles, and always appear as groups of two or singly, never as colonies (Fig. 2 A). The appearance of the species is very similar to that given by COMPERE (1970) for some freshwater habitats in Lake Chad. KOMAREK (1976) has recently clarified the taxonomy of this genus; it is clear from his review that *S. aquatilis* is quite variable in size but that the Lake Valencia population is near the middle of the known size spectrum.

Table 3 summarizes the variability in dimensions on a particular date and between seasons. The measurements are quite constant, especially across seasons.

10. *Synechocystis* sp. 1. (Fig. 2 B). Certain individuals of *Synechocystis* are very similar to *S. aquatilis* but are always less than 4  $\mu\text{m}$  in diameter. The cells frequently occur as joined pairs. The similarity in form would suggest that this is identical to *S. aquatilis* and the revision by KOMAREK (1976) would clearly place these cells as *S. aquatilis*. However, a persistent dichotomy of sizes (Table 3) causes us to retain the separation between these smaller cells of *Synechocystis* and *S. aquatilis*. As KOMAREK (1976) has indicated, species separations are very tenuous, as they can at present be based only on cell size. At present it is essentially impossible to tell if the smaller cells are a distinct species or not.

11. *Gomphosphaeria naegeliana* (UNGER) LEMM. The cells of this species are oblong. Colonies typically consist of 50 to 100 cells. The central portion of the colony is much less densely filled with cells than the periphery. The cells appear to contain pseudo-

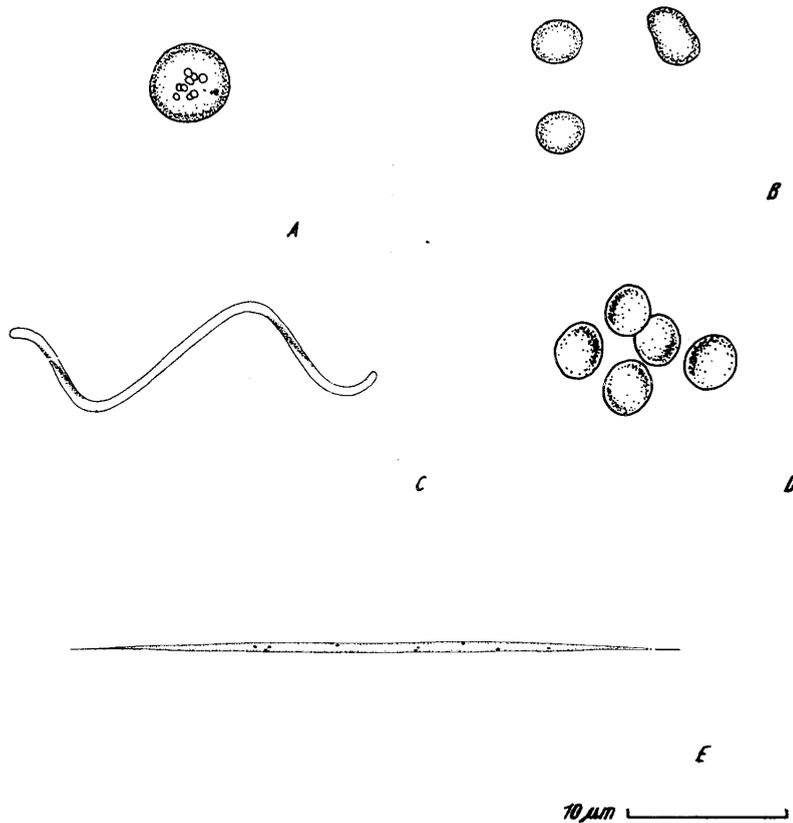


Figure 2. Some common bluegreen species of Lake Valencia, Venezuela. (A) *Synechocystis aquatilis*. (B) *Synechocystis* sp. 1. (C) *Spirulina laxissima*. (D) *Chroococcus dispersus*. (E) *Dactylocoopsis fascicularis*.

Table 3. Statistics on two important coccoid bluegreens from Lake Valencia showing the extent of morphological variation.  $s$  = standard deviation,  $\bar{x}$  = mean

Species	Long Axis ( $\mu\text{m}$ )						Short Axis ( $\mu\text{m}$ )					
	Feb.		July		Dec.		Feb.		July		Dec.	
	$\bar{x}$	$s$	$\bar{x}$	$s$	$\bar{x}$	$s$	$\bar{x}$	$s$	$\bar{x}$	$s$	$\bar{x}$	$s$
<i>Synechocystis aquatilis</i>	5.2	.67	5.4	1.8	5.9	1.7	4.8	.54	4.4	1.1	5.9	1.2
<i>Synechocystis</i> sp. 1	2.9	.40	2.5	.34	3.0	.34	2.6	.40	2.1	.34	2.7	.34

vacuoles. The appearance of the colonies is almost identical to that shown by KOMAREK (1958).

12. *Merismopedia elegans* A. BR. Colonies of this species are variable in size, but in Lake Valencia typically contain 16–32 cells. The cells lack gas vacuoles and are oblong.

13. *Coelosphaerium minutissimum* LEMM. The cells of this species are very similar in appearance to those of *Microcystis holsatica*, but the colony shows a definite open space in the center and an aggregation of cells around the periphery of the colony.

14. *Eucapsa alpina* CLEM. and SHANTZ. Although this species is known from clear

mountain lakes, it has been found in Africa, as noted by BOURRELLY (1970). The cells are arranged in tetrads and the tetrads are layered. The species is very rare in Lake Valencia and is reported here primarily because of distributional record.

15. *Dactylococcopsis fascicularis* LEMM. (Fig. 2E). This species is very widespread in tropical lakes (RUTTNER 1952, LEWIS and WEIBEZAHN 1976, LEWIS 1978a). In Valencia we have never seen the species in colonial form. When RUTTNER and GEITLER encountered these small, spindle-shaped solitary cells in many of the lakes visited by the Sunda Expedition, they identified them as identical to *D. fascicularis* despite their solitary growth habit. We see no reason to depart from this decision. The cells take either a straight or a spiral form. Usually the intracellular space of the cells is uniform as seen under a light microscope, but sometimes small granular inclusions are present in the protoplasm. It is conceivable that these are pseudovacuoles but it was not possible for us to verify this. It is probable that this species is one of the most widespread in tropical plankton, but may often be confused with *Ankistrodesmus* (*Monoraphidium*). Staining and examination with fluorescence microscopy indicate that it is definitely of the Cyanophyta, however. The solitary form is given by HUBER-PESTALOZZI (1938) as fa. *solitaria* GEITL. Table 4 shows that the mean dimensions of the species are very

Table 4. Statistics on three important bluegreens from Lake Valencia. *s* = standard deviation,  $\bar{x}$  = mean

Species	Length ( $\mu\text{m}$ )				Width (Middle, $\mu\text{m}$ )				Amplitude ( $\mu\text{m}$ )			
	Feb.		July		Feb.		July		Feb.		July	
	$\bar{x}$	<i>s</i>	$\bar{x}$	<i>s</i>	$\bar{x}$	<i>s</i>	$\bar{x}$	<i>s</i>	$\bar{x}$	<i>s</i>	$\bar{x}$	<i>s</i>
<i>Spirulina laxissima</i>	14.1	3.6	14.1	2.6	.75	.17	.67	—	5.9	1.1	6.0	1.2
<i>Dactylococcopsis fascicularis</i> (spiral)	20.1	4.2	20.8	6.1	.72	.12	.67	0.0	6.8	1.0	7.8	1.9
<i>Dactylococcopsis fascicularis</i> (straight)	45.6	13.4	39.5	11.4	.67	0.0	.67	0.0	—	—	—	—

constant across seasons, but that significant size variation is characteristic for a given date.

16. *Spirulina laxissima* G. S. WEST. This filamentous species typically does not reach very great lengths in Lake Valencia; it is often restricted to only a few cells. The divisions between the cells are very difficult to see under some conditions but at other times become more apparent (Fig. 2C). Dimensions are remarkably constant (Table 4).

17. *Cylindrospermopsis stagnale* (WOLOSZ.) SEENAYYA et SUBBA RAJU. This species is common in tropical freshwaters. It has also been named *Anabaenopsis raciborskii* WOLOSZ. and *Cylindrospermum stagnale* (KÜTZ.) BORN ET FLAHL. A connection between *Anabaenopsis* and *Cylindrospermum* is described by STARMACH (1962), who presents evidence that *Anabaenopsis raciborskii* is merely a developmental stage of *Cylindrospermum stagnale*. JEEJI-BAI et al. (1977) have pointed out that the formation of heterocysts is different from what is expected of the genus *Anabaenopsis*, yet certain features, such as gas vacuoles, also distinguish it from *Cylindrospermum* (HORECKA and KOMAREK 1979). In the Lake Valencia species, the akinetes are most definitely located adjacent to the heterocysts. Trichomes may have one heterocyst, two heterocysts, or no heterocysts (Fig. 3). Divisions between the cells are frequently very difficult to see. The cells often have vacuoles, but sometimes have no vacuoles at all. The cells vary greatly in width according to time of year. In fact the dimensions all vary

more than most of the Valencia species (Table 5). Even the heterocyst varies in shape. At some times of the year it is longer and more pointed than at others. The heterocyst is always terminal. Resting cells are 3–4  $\mu\text{m}$  wide and 11–13  $\mu\text{m}$  long. The trichome tapers markedly at the end and at some times of the year is more blunt than at others.

In view of the cogent arguments advanced by HOREKA and KOMAREK (1979), we assign the species to the genus *Cylindrospermopsis*, thus recognizing its differences from both *Cylindrospermum* and *Anabaenopsis*.

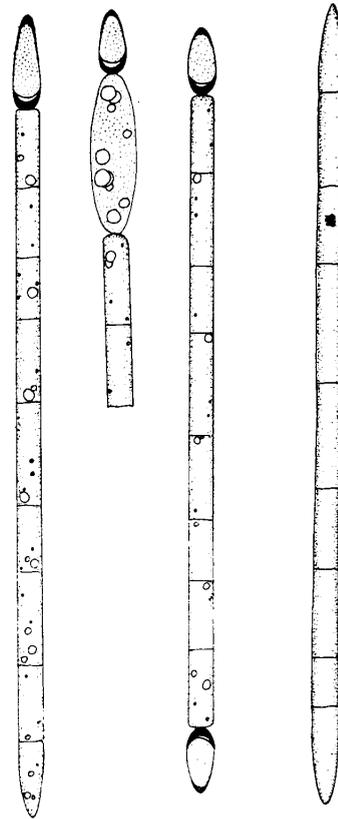


Figure 3. *Cylindrospermopsis stagnale*, an important species in Lake Valencia.

10  $\mu\text{m}$  

Table 5. Statistics on the most important *Lyngbya* and *Oscillatoria* species and on *Cylindrospermum stagnale* in Lake Valencia.  $s$  = standard deviation,  $\bar{x}$  = mean

Species	Length ( $\mu\text{m}$ )						Width ( $\mu\text{m}$ )					
	Feb.		July		Dec.		Feb.		July		Dec.	
	$\bar{x}$	$s$	$\bar{x}$	$s$	$\bar{x}$	$s$	$\bar{x}$	$s$	$\bar{x}$	$s$	$\bar{x}$	$s$
<i>Lyngbya limnetica</i>	57.0	16.8	74.4	14.1	73.7	20.1	.77	.11	.67	.00	.69	.06
<i>Oscillatoria limnetica</i>	26.1	10.1	32.8	12.8	30.1	12.1	.91	.20	.88	.23	1.0	.24
<i>Cylindrospermopsis stagnale</i>	113.2	49.5	77.3	16.5	93.8	42.0	3.14	.25	1.98	.40	2.23	.60

18. *Anabaenopsis circularis* (G. S. WEST) WOL. and MILLER. The trichomes of this species are curved and typically have terminal heterocysts. Intercalary heterocysts are also present. Cells range in shape from almost spherical to three times as long as broad. Heterocysts are about the same or slightly wider than the trichome (4  $\mu\text{m}$ ) and slightly longer than broad (5.0–7.0  $\mu\text{m}$ ). Some variation in the shape of the heterocysts occurs. For example, on a single trichome we observed that one heterocyst was

5.5  $\mu\text{m}$  long and the other 6.7  $\mu\text{m}$  long, although both heterocysts were of the same width. Resting cells (6.5  $\times$  11  $\mu\text{m}$ ) were seen occasionally.

*Anabaenopsis* is common in tropical lakes but is difficult to identify because of the confused state of the taxonomy (HUBER-PESTALOZZI 1938, KOMAREK 1958). For

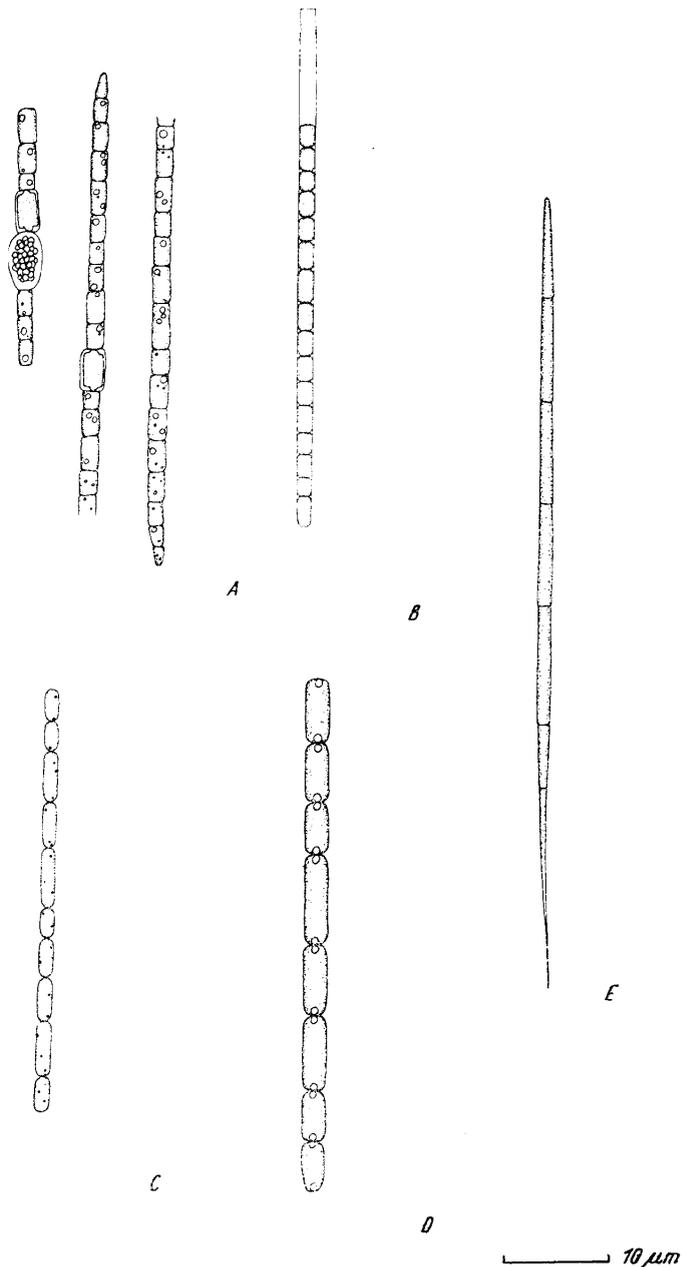


Figure 4. Some important filamentous bluegreen species from Lake Valencia. (A) *Anabaena volzii*. (B) *Lyngbya limnetica*. (C) *Oscillatoria limnetica*. (D) *O. amphigranulata*. (E) *Raphidiopsis* sp. 1.

example, in this case the species is identical to some *Anabaenopsis arnoldii* forms. Possibly there is no valid distinction between these species (KOMAREK 1958). We believe that *A. circularis* is slightly more appropriate because the mature cells in the trichomes are considerably longer than broad and quite narrow. Although *A. arnoldii* has been described from tropical Africa and Asia, such narrow trichomes have never been observed. Specimens from Lake Valencia are even narrower than those of *A. circularis* but are very close to the reported lower limit of the trichome widths for this species as reported from tropical localities (HUBER-PESTALOZZI 1938).

19. *Anabaena spiroides* KLEB. This species has a coiled trichome but is less regular in coiling than *Anabaenopsis circularis*. The cells are spherical following division. No significant elongation of cells occurs. The heterocyst is slightly larger than the cells of the trichome (8–9  $\mu\text{m}$ ) and is almost perfectly spherical. The species is very close to some variants of *A. flos-aquae*, but the heterocyst is consistently larger than one would expect for *A. flos-aquae*.

No resting cells were observed for this species in the Lake Valencia sample. The species is not very abundant in Lake Valencia, however, and resting cells might be overlooked for this reason.

20. *Anabaena volzii* LEMM. This is morphologically a highly variable species of *Anabaena*, but is easily identified by the strongly tapering trichome (Fig. 4A). It is very important in Lake Valencia. It has also been reported elsewhere from Venezuela (DE REYES 1972). The heterocysts are always intercalary, and can be almost perfectly spherical or more nearly cylindrical. We established that the remarkably great variation in shape of heterocyst is in fact intraspecific because we have seen both spherical and cylindrical heterocysts on the same trichome. Heterocysts vary in width from 3–6  $\mu\text{m}$  and in length from 4–7  $\mu\text{m}$ . Typically the heterocysts have the same width as the cells adjacent to them or are slightly narrower. The cells of the trichome vary in width from a maximum towards the middle of the trichome to a minimum toward the ends (Table 6). The width of the terminal cells may be as little as 1.5  $\mu\text{m}$ . The terminal

Table 6. Statistics for *Anabaena volzii* in Lake Valencia.  $s$  = standard deviation,  $\bar{x}$  = mean

Dimension	February		July		December	
	$\bar{x}$	$s$	$\bar{x}$	$s$	$\bar{x}$	$s$
Length ( $\mu\text{m}$ )	127.3	72.0	137.4	55.0	49.6	56.0
Width (middle, $\mu\text{m}$ )	4.0	.54	2.4	.54	3.2	.58
Width (terminal, $\mu\text{m}$ )	2.5	.56	1.5	.32	2.1	.47
Heterocyst (number/ Trichomes)	1.6	.94	1.0	.34	.26	.33

cells are pointed and much longer than broad, but the cells in the middle of the trichome or on the same filament may be the same length as breadth. Cells toward the middle of the trichome tend to be cuboidal or cylindrical in shape.

Resting cells were occasionally observed for *A. volzii* in Lake Valencia. The resting cells, like the heterocysts, vary greatly in shape. They may be almost spherical or quite cylindrical. The latter shape is expected from collections in other localities (STARMACI 1966). Typically they are about twice the width of the trichome (6–8  $\mu\text{m}$ ). The resting cells in some specimens are as long as 14  $\mu\text{m}$ ; the resting cell shown in Fig. 4 is actually toward the smaller end of the size spectrum. Trichomes of *Anabaena volzii* frequently contain vacuoles.

21. *Lyngbya limnetica* LEMM. This species is abundant in Lake Valencia and is

widespread and extremely important throughout the tropics of all three continents (LEWIS and WEIBZAHN 1976, LEWIS 1978a). In Lake Valencia it shows considerable variation in form. The length of the cells ranges from little greater than the width to 2 or 3 times as great as the width, the latter being the most common. A definite sheath is apparent at one end of the trichome, but not at the other end in many cases. The sheath projects beyond one end of the trichome for a considerable distance, typically the length of 3 or 4 cells (Fig. 4B).

22. *Lyngbya contorta* LEMM. This is a coiled species very similar in appearance to *Lyngbya limnetica*. Conceivably it is simply a morphotype of *L. limnetica*, but it has traditionally been treated as a distinct species. The convolutions are quite regular (mean wavelength, 11  $\mu\text{m}$ ). Cells are always longer than broad, typically by a factor of about three. A sheath is evident at one end in a manner very reminiscent of *L. limnetica*.

23. *Oscillatoria limnetica* LEMM. This *Oscillatoria* is a very close morphological counterpart to *Lyngbya limnetica*. It completely lacks a sheath, of course, and the cells may contain small vacuoles, which are not found in *Lyngbya*. The cells are typically considerably longer than broad, although the length to width ratio varies (Fig. 4C). Average filament length is quite steady across seasons (Table 5). Occasionally the filaments are slightly curved, but never tightly coiled. The cells touch each other but are not closely joined as in most *Oscillatoria* species.

24. *Oscillatoria quadripunctulata* BRUH. and BISWAS. The trichome of this species is quite narrow, but wider than *O. limnetica*. The cells are 2–2.5 times as long as broad. The species is distinctive because of a terminal vacuole at the ends of each cell, which gives a paired vacuole appearance to the filament. The vacuoles are quite small and must be examined at very high magnification to appear clearly. The species is very close to *O. redekei* VAN GOOR, but typically there are no constrictions whatever between the cells in the trichome. An almost identical form from African lakes was also identified by COMPERE (1970) as *O. quadripunctulata*.

25. *Oscillatoria amphigranulata* VAN GOOR. This species has a straight trichome. The divisions between cells are distinct, but the constriction between cells is not so great as for *O. limnetica* (Fig. 4D). Frequently cells have paired vacuoles near the junction with an adjacent cell. This does not always occur, however. Some filaments lack vacuoles.

26. *Pseudanabaena* sp. 1. The trichome of this species is always wider than 1.5  $\mu\text{m}$ , which separates it from *Oscillatoria limnetica*. The cells are 2–3 times as long as wide. Occasionally vacuoles appear inside the cells. The cells are terminally constricted but not so much as *O. limnetica*.

27. *Raphidiopsis* sp. 1. This species is a narrow filament that is pointed on one end (Fig. 4E). It is not uncommon for filaments to appear which are pointed at both ends and occasionally filaments appear which are rounded at both ends. The cells are much longer than broad, are broadly joined to each other but can show some evidence of constriction at the junctions. The filament is always straight. No heterocysts or resting cells have been seen. Although this species probably belongs with the genus *Raphidiopsis*, it is clearly not closely allied with any of the species of *Raphidiopsis* which have been described. The filament is far too narrow, the cells have far too low a width: length ratio, and the filament is not curved as it typically is in the species of *Raphidiopsis* which have been described. We therefore believe that this is an undescribed species. It is moderately common in the Lake Valencia plankton.

28. *Raphidiopsis curvata* FRITSCH. This species is typically bent and consists of a filament of 8 or 10 cells, the cells are 2–4 times longer than broad and show no evidence of constriction at the junction between cells. The wavelength of the s-curve averages 42  $\mu\text{m}$ . Pseudovacuaes are frequently visible in the cell. No resting cells are recorded for this species in Lake Valencia.

29. *Raphidiopsis mediterranea* SKUJA. The trichome of this species is also pointed at both ends. The junctions between cells show slight evidence of constriction. Pseudovacuaes appear in the cells on some occasions. No resting cells have been seen. Part of the trichome can be slightly bent.

## II. Euglenophyta

The euglenophytes play a minor role in the phytoplankton of Lake Valencia (Table 7). Although this is probably true of tropical lakes in general (LEWIS 1978a), frequently various species of *Trachelomonas* are found in freshwater plankton of the tropics. In Lake Valencia, all euglenophyte species are rare.

Table 7. Morphological characteristics of species belonging to the Euglenophyta, Chrysophyceae, Cryptophyceae, and Dinophyceae from Lake Valencia

Name	Cells		Plankton Units	
	GALD	SGALD	GALD	SGALD
Euglenophyta				
1. <i>Phacus</i> sp. 1	27	14	27	14
2. <i>Trachelomonas</i> sp. 1	7	7	7	7
Bacillariophyceae				
1. <i>Melosira granulata</i>	17	5	85	5
2. <i>Cyclotella meneghiniana</i>	17 (22)	12 (6)	17 (22)	12 (6)
3. <i>Fragilaria construens</i>	7	5	7	5
4. <i>Synedra acus</i>	75	4	75	4
5. <i>Nitzschia palea</i>	26 (20)	2.7 (23)	26 (20)	2.7 (23)
6. <i>N. amphibia</i>	18	4	18	4
7. <i>N. kützingiana</i>	13 (16)	2.2 (11)	13 (16)	2.2 (11)
8. <i>N. gracilis</i>	101 (8)	4.9 (5)	101 (8)	4.9 (5)
9. <i>Thalassiosira guillardii</i>	7	3.0	7	3.0
Chrysophyceae				
1. <i>Dinobryon petiolatum</i>	55	5	100	20
2. <i>D. sociale</i>	20	4	50	15
3. Unknown sp. 1	20	12	20	12
Cryptophyceae				
1. <i>Cryptomonas caudata</i>	6.6 (4)	4.0	6.6 (4)	4.0
2. <i>C. erosa</i>	10 (11)	5.9 (13)	10 (11)	5.9 (13)
Dinophyceae				
1. <i>Peridinium inconspicuum</i>	21	19	21	19
2. <i>Gymnodinium bogoriense</i>	17	14	17	14

1. *Phacus* sp. 1. This species was observed in the plankton late in 1976 in small numbers but did not reappear between 1976 and 1978. It is dorsoventrally flattened and has 5 sinistral ridges. The posterior end of the cell is drawn to a point such that the main body of the cell is only about 15  $\mu\text{m}$  long, whereas the tail piece is about 12  $\mu\text{m}$  long. A considerable effort was made to key this species but it could not be successfully identified. It is probably undescribed.

2. *Trachelomonas* sp. 1. This species also appeared briefly late in 1976 and early in 1977 but not after that time. The cell is almost perfectly spherical. The anterior pore is surrounded by two smooth knobs, and the test is otherwise unornamented. The species is similar to but not identical to *T. volvocina*.

## III. Chlorophyta

The chlorophytes are typically the most diverse group of phytoplankton algae in tropical lakes of moderate to low salinity (LEWIS 1978a), despite the fact that they may be secondary in biomass to both bluegreen algae and diatoms. Extremely saline lakes, on the other hand, have almost no chlorophytes (LITIS 1972). Lake Valencia appears to occupy an intermediate ground, as its chlorophyte diversity (Table 8) is below that which one would predict for a lake of the same type with lower salinity, but still is not completely dominated by bluegreens. Artificial eutrophication of Valencia may have increased bluegreen dominance at the expense of chlorophytes. In many cases, specific monographs are mentioned as sources for identification of Chlorophyta, but where no modern relevant monograph is mentioned, it can be assumed that we have used BOURRELLY (1972) for generic distinctions and LEMMERMANN *et al.* (1915).

Table 8. Measurements for the Chlorophyta of Lake Valencia

Name	Cells		Plankton Units	
	GALD	SGALD	GALD	SGALD
1. <i>Chlamydomonas</i> sp. 1	5.5	5.5	5.5	5.5
2. <i>Tetraedron minimum</i>	8.3 (11)	8.0 (11)	8.3 (11)	8.0 (11)
3. <i>T. tumidulum</i>	12	12	12	12
4. <i>Schroederia setigera</i>	60.3 (.8)	2.1 (11)	60.3 (.8)	2.1 (11)
5. <i>S. spiralis</i>	55	2.7	55	2.7
6. <i>Sphaerocystis schroeteri</i>	2.7	2.7	12	11
7. <i>S.</i> sp. 1	6.0	6.0	25	23
8. <i>Chlorella vulgaris</i>	4.0 (17)	3.5 (11)	4.0 (17)	3.5 (11)
9. <i>Oocystis solitaria</i>	40	22	40	22
10. <i>O. lacustris</i>	8.3 (25)	4.7 (23)	8.3 (25)	4.7 (23)
11. <i>O. marssonii</i>	7.8 (21)	4.8 (25)	7.8 (21)	4.8 (25)
12. <i>Chodatella subsalsa</i>	10	7	17	14
13. <i>Franceia javanica</i>	4.5	4.0	8.5	8.0 (0)
14. <i>Treubaria triappendiculata</i>	9.0	9.0	31	31
15. <i>Kirchneriella obesa</i>	7.1 (11)	6.0 (11)	7.1 (11)	6.0 (11)
16. <i>K. contorta</i>	5.0	1.5	20 (0)	18
17. <i>Monoraphidium contortum</i>	9.2 (22)	1.3 (20)	9.2 (22)	1.3 (20)
18. <i>M. griffithii</i>	20 (12)	1.8 (13)	20 (12)	1.8 (13)
19. <i>Golenkinia radiata</i>	13	13	38	38
20. <i>Coccomyxa</i> sp. 1	2.3 (20)	2.1 (19)	2.3 (20)	2.1 (19)
21. <i>Micractinium pusillum</i>	4.5	4.5	49	49
22. <i>Dictyosphaerium pulchellum</i>	6.0	6.0	36	42
23. <i>Coelastrum reticulatum</i>	6	6	16 (18)	16 (18)
24. <i>C. cambricum</i>	8	8	22	18
25. <i>Crucigeniella apiculata</i>	6.5	4.5	13	9
26. <i>Scenedesmus acuminatus</i>	17	3.5	10	15
27. <i>S. ecornis</i>	5.4 (21)	2.2 (24)	5.4 (21)	4.9 (26)
28. <i>S. intermedius</i>	6.5	3.0	22	14
29. <i>S. quadricauda</i>	5.4 (0)	2.4 (0)	5.4 (0)	5.0 (0)
30. <i>S. spinosus</i>	6.6 (6)	2.6 (11)	6.6 (6)	5.7 (8)
31. <i>S.</i> sp. 1	6.4 (7)	1.8 (13)	9.7 (5)	6.4 (7)
32. <i>Closterium</i> sp. 1	68	11	68	11
33. <i>Cosmarium wembaerense</i>	6.9 (34)	11.8 (26)	12.8 (34)	11.8 (26)
34. <i>C.</i> sp. 1	9.0	14.4 (36)	18.0 (47)	14.4 (36)
35. <i>Staurastrum luetkemuelleri</i>	16	48	32	48

1. *Chlamydomonas* sp. 1. Only one species from Volvocales appeared in Lake Valencia and even this species was quite rare. The species belongs to the subgenus *Euchlamydomonas*. Beyond this, it cannot be identified because of the unavailability of living material from which the contractile vacuoles could be observed. The species measures 5–6  $\mu\text{m}$  in diameter and the cells are spherical. The flagella are only slightly longer than the cells. The chloroplast occupies the basal two thirds of the cell and is very slightly cup shaped. There is a single pyrenoid body.

2. *Tetraedron minimum* (A. BRAUN) HANSGIRG. *Tetraedron* appears only sporadically in Lake Valencia; the most common species is *T. minimum* (Fig. 5A). The cell wall is very slightly roughened and slightly knobbed at the apices.

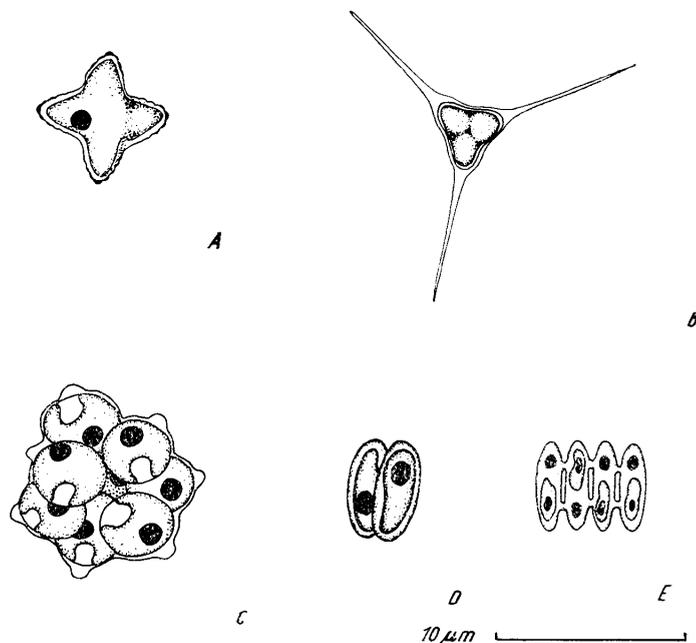


Figure 5. Some important greens from Lake Valencia. (A) *Tetraedron minimum*. (B) *Treubaria triappendiculata*. (C) *Coelastrum cambricum*. (D) *Scenedesmus ecornis*. (E) *Scenedesmus* sp. 1.

3. *Tetraedron tumidulum* (REINSCH) HANSGIRG. This species appears regularly but never in great abundance in Lake Valencia.

4. *Schroederia setigera* (SCHROED.) LEMM. Total length of this species in Lake Valencia is somewhat less than reported by some other authors for the temperate zone (e.g., HORTOBAGYI 1969). The spines occupy about 75% of the length of the cell and the central part about 25%. The two spines are not always exactly equal in length, but they are always straight. The cell has one pyrenoid body.

5. *Schroederia spiralis* (PRINTZ) KORSCHIK. The spines of this species are most often curved in opposite directions. Zoosporulation has been observed in Valencia. Most often the number of zoospores forming is about five.

6. *Sphaerocystis schroeteri* CHODAT. The cells of this species in Lake Valencia are arranged in a tetrahedral formation within a mucilaginous matrix that is extremely hyaline. Two tetrads may also appear together, one over the other.

7. *Sphaerocystis* sp. 1. This species has larger cells than *S. schroeteri* in Lake Valencia. The colony typically consists of an 8-cell unit. Occasionally several 8-cell units are

attached to each other. The cells stain very darkly with Lugol's iodine, which is quite unusual among chlorophytes. The gelatinous matrix also stains red, although not so darkly as the cells. Pyrenoid bodies are either indistinct or absent. This species is not particularly common in Lake Valencia.

8. *Chlorella vulgaris* BELJERINCK. Small isolated cells of the genus *Chlorella* appear sporadically in the lake in low to moderate numbers, although they never become a major element of the phytoplankton. This species has a thin cell wall, a pyrenoid body, and a cup-shaped or girdle-shaped chloroplast (FOTT & NOVAKOVA 1969).

9. *Oocystis solitaria* WITROCK. The cells of this species typically are solitary or occur in pairs. The cell walls are thick and have a pronounced apical knob. The cells which have many chloroplasts, were identified according to the key in REHAKOVA (1969), as were other *Oocystis* species.

10. *Oocystis lacustris* CHODAT. This species typically has a single chloroplast and is considerably smaller than *O. solitaria*; the cells are ellipsoidal. The cells often show evidence of an apical knob, but it is not always pronounced.

11. *Oocystis marssonii* LEMM. This species has two or four chloroplasts. The cells have polar nodules.

12. *Chodatella subsalsa* LEMM. We follow here the distinctions drawn by FOTT (1948) in distinguishing *Chodatella* from *Lagerheimia*. *Chodatella subsalsa* in Lake Valencia lacks tubercles at the base of the spines and in all observed cases has three spines at each end of the cell. Although FOTT reports a single parietal chloroplast, and the same is shown by HORTOBAGYI (1969), we on occasion observed multiple chloroplasts (up to 12) in a single cell. On other occasions, only one chloroplast was observed. Consequently this may be a new species, but we take the conservative view that it may simply be a variation in the morphology of this poorly studied species. The spines are 6–8  $\mu\text{m}$  long and bear an angle of approximately 45 degrees to the long axis of the cell.

13. *Franceia javanica* (BERNARD) HORTOB. This species, which is quite unfamiliar in the temperate zone, appears steadily but never in great abundance in Lake Valencia. Cells are more rounded than the more common species of *Franceia* and have a prominent pyrenoid body and single chloroplast. In the Lake Valencia specimens, spines 3–5  $\mu\text{m}$  long are situated over the entire surface of the cell. The species is almost exactly as described by HORTOBAGYI (1969). We cannot rule out the possibility that this is in fact a stage of *Scenedesmus* (TRAINOR *et al.* 1976).

14. *Treubaria triappendiculata* (BERNARD) WILLE. This species occurs routinely but at low abundance in Lake Valencia. Spines are drawn to a sharp point and are 14–17  $\mu\text{m}$  long (Fig. 5B).

15. *Kirchneriella obesa* (W. WEST) SCHMIDLE. A single parietal chloroplast occupies half or more of the cell. The pyrenoid body is not distinct but may be present. Although the cells are supposed to occur in colonies typically, only unicells are observed in samples from Lake Valencia. Since the cells are in all respects extremely similar to specimens of *K. obesa* reported from around the world, however, we have little doubt of the identity of the species. It is possible that the gelatinous matrices are extremely delicate in this population and that handling the specimens disrupts the colonial organization.

16. *Kirchneriella contorta* (SCHMIDLE) BOHLIN. This species occurs routinely in colonies. Colonies tend to be small, averaging 6–8 cells each. The individual cells are rounded on the ends. There is virtually no difference between this and *K. elongata* (G. M. SMITH), but SMITH (1920) distinguishes the two on the basis of diameter, which we have followed here.

17. *Monoraphidium contortum* (THURET in BRÉB.) LEGN. This is a solitary species, thus, following LEGNEROVA (1969), we have assigned it to the genus *Monoraphidium*.

A similar species is described from Lake Tanganyika by VAN MEEL (1954) as *Ankistrodesmus convolutus* CORDA; we believe that the difference between this and *M. contortum* is strictly nomenclatural.

18. *Monoraphidium griffithii* (BERKEL.) LEGN. This is a solitary species consisting of straight or nearly straight cells with attenuate ends. The cells are similar to *M. setiforme* (NYG.) LEGN., but lack the extremely attenuate apices of this species. The chloroplast is parietal and extends to the end of the cells but does not quite fill the terminal portions in most cells.

19. *Golenkinia radiata* CHOD. This species is not very common in Lake Valencia. Spines average 25  $\mu\text{m}$  in length. The cell is surrounded by mucoid sheath several  $\mu\text{m}$  thick.

20. *Coccomyxa* sp. 1. *Coccomyxa* is a sporadic element of the phytoplankton in Lake Valencia. The cells are slightly elongate.

21. *Micractinium pusillum* FRESENIUS. This species is rare but persistent in Lake Valencia. Typically the coenobia consist of four cells. Length of the attached spines averages 20  $\mu\text{m}$ . Each cell has approximately 5 spines.

22. *Dictyosphaerium pulchellum* WOOD. Colonies of this species in Lake Valencia are typically small (4–8 cells). The cells are spherical and contain a large pyrenoid body in a central location. The cells are typically spaced by a distance of 3–4 diameters.

23. *Coelastrum reticulatum* (DANG.) SENN. The colonies of this species are typically small. The surface of the colony is marked by small bumps. According to the work by SODOMKOVA (1970), the species keys to *C. reticulatum*. The colonies were occasionally infected with *Stylosphaeridium* cf. *stipitatum* (BACHM.) GEITLER and GIMESI. This parasitic chlorophyte is attached by a stipe to the *Coelastrum* colony. At the far end of the stipe is a cell measuring  $.5 \times 1 \mu\text{m}$ .

24. *Coelastrum cambricum* ARCHER. The cells of this species in Lake Valencia are spherical or almost spherical and relatively smooth (Fig. 5C). They resemble var. *intermedium* BOHLIN. Colonies typically consist of 8 cells, but cells frequently appear singly.

25. *Crucigeniella apiculata* (LEMM.) KOMAREK. Here we are following KOMAREK's work (1974) on the crucigenioid algae. In Lake Valencia this species almost always comes in groups of four cells. The species is not common in Lake Valencia.

26. *Scenedesmus acuminatus* (LAGERH.) CHOD. In this case, as with the other *Scenedesmus*, we are following as closely as possible UHERKOVICH (1966). Cells of this species in Lake Valencia typically occur in groups of 2 or 4. They are also seen singly, but these may actually be disrupted colonies.

27. *Scenedesmus ecornis* (RALFS) CHOD. This species typically occurs in coenobia of 2 or 4 cells (Fig. 5D).

28. *Scenedesmus intermedius* CHOD. Coenobia of this species consist of 4 cells. Terminal cells each bear 2 spines, which are extremely delicate. Spines are 5–6  $\mu\text{m}$  long. Cells are slightly offset from each other.

29. *Scenedesmus quadricauda* (TURP.) BRÉB. *S. quadricauda* in Lake Valencia typically occurs as 2 cells rather than 4. The spines are delicate and short (2.5–3.0  $\mu\text{m}$ ).

30. *Scenedesmus spinosus* CHOD. Coenobia typically consist of 2 cells rather than 4. The form is similar to var. *crassispinosus* HORTOB., with relatively thick, short spines (ca. 2  $\mu\text{m}$ ).

31. *Scenedesmus* sp. 1. This species could not be found in the literature and is probably new to science. It consists always of four cells which stand apart from each other but are joined at either end by a thin bridge of material (Fig. 5E). An identical species was observed in Lake Lanao, Philippines (LEWIS 1978a). Occasionally very faint, stout and short spines (<1  $\mu\text{m}$ ) are observed. These resemble spines of *S. denticulatus*.

32. *Closterium* sp. 1. The desmids of Lake Valencia were recently studied by FÖRSTER (1972). Although Lake Valencia is not rich in desmids, FÖRSTER lists about 15 species. Since the lake has become considerably more saline, the composition and importance of desmids may now be reduced from the former condition. Also, we made no attempt to search for desmid forms in the littoral zone where they may be more common. All the desmids we observed were small, euplanktonic forms. The *Closterium* species which we observed in Lake Valencia is not the same as the *Closterium* species observed by FÖRSTER. We did not have sufficient material to give a firm identification. It is similar in form to *C. venus* KÜTZING.

33. *Cosmarium wembaerense* SCHMIDLE. This species was identified in Lake Valencia by FÖRSTER and was a common desmid in the plankton zone of the lake over the period of our study. It is also widely known from the temperate zone.

34. *Cosmarium* sp. 1. This second species of *Cosmarium* was not sufficiently common to be identified. It is not identical with any of the species described by FÖRSTER from Lake Valencia.

35. *Staurastrumluetkemulleri* DONAT. This is the most common desmid in Lake Valencia, and was observed in some quantity by FÖRSTER. Cells vary a great deal in form, as indicated by FÖRSTER.

#### IV. Bacillariophyceae

Diatoms from surface and deep sediments of Lake Valencia have been identified and described by BRADBURY (1980). Some of the frustules present in surface sediments are derived from the littoral zone and do not appear in the plankton, and some of the diatom species present over the past 10,000 years in Lake Valencia are not represented at the present time due to changes in lake chemistry. For the most part, however, the lake has been for the last 8,000 years dominated by some combination of *Cyclotella*, *Nitzschia*, and *Melosira*. Identifications were made from HUBER-PESTALOZZI and HUSTEDT (1942) except as indicated and were verified by J. P. BRADBURY (pers. comm.).

In tropical lakes of moderate to large size, diatoms very frequently share biomass dominance with the blue-green algae (LEWIS 1978a). Lake Valencia follows this pattern except that the proportionate importance of blue-greens relative to diatoms seems to have been exaggerated by the salinity and highly eutrophic state of the lake. Nevertheless, diatom biomass is extremely high at certain times of the year, especially the beginning of the growing season following the establishment of stratification. As is typical of tropical planktonic diatom assemblages, diversity is considerably lower than for the blue-greens or chlorophytes. Although one occasionally sees frustules or dying cells brought from the littoral zone, true planktonic populations are limited to a handful of species (Table 7).

1. *Melosira granulata* (EHR.) RALFS. This species appears seasonally in Lake Valencia at the time of deep mixing. Its annual cycle is similar to that of *Melosira* in temperate lakes in which viable cells are brought from the sediment surface into the water column at the time of deep mixing (LUND 1965). A similar seasonal cycle is known from other tropical lakes for various species of *Melosira* (LEWIS 1978b). The duration and importance of the *Melosira* peak appears to be declining at the present, however, in relation to its past importance, probably because of the increasing salinity of the lake. The modal number of cells per filament is between 4 to 6.

2. *Cyclotella meneghiniana* KÜTZ. Striae extend about one-third the distance to the center of the cell (Fig. 6A). The species appears sporadically.

3. *Fragilaria construens* (EHR.) GRUN. *F. construens* appears sporadically in Lake

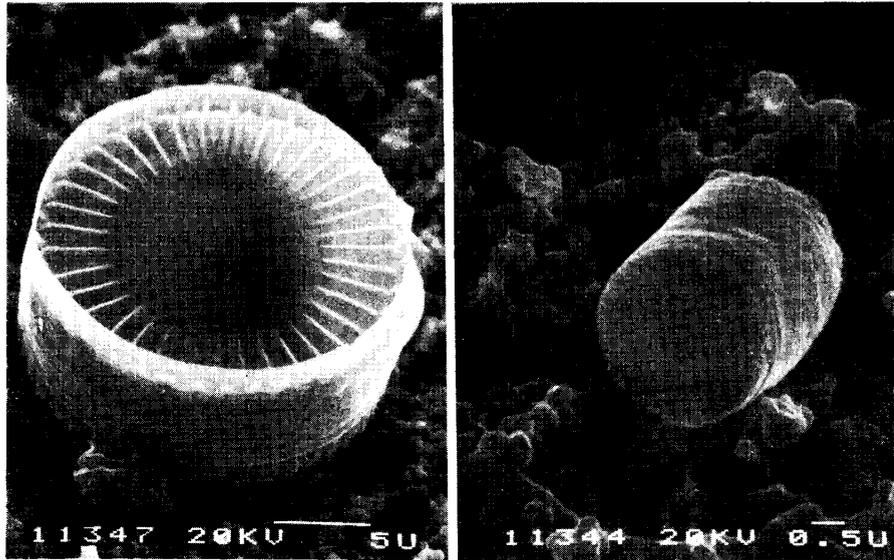


Figure 6. Scanning electron micrographs of two important diatom species from Lake Valencia. (A) *Cyclotella meneghiniana*. (B) *Thalassiosira guillardii*.

Valencia. BRADBURY (1980) also reports *F. brevistriata* GRUN. from sediments in the littoral zone, but this species was not observed in mid-lake.

4. *Synedra acus* KÜTZ. This species never reaches high densities. The length to width ratio of *S. acus* in Lake Valencia and its rarity suggest that it cannot really sustain itself in open water but is probably tied principally to the littoral zone.

5. *Nitzschia palea* (KÜTZ.) W. SMITH. This is the most common species in the phytoplankton of Lake Valencia, and reaches quite impressive densities each year. The species is typical of highly eutrophic waters worldwide, hence it is not surprising to find it in Lake Valencia. Cell breadth varies seasonally (Table 9), but length varies little across seasons.

6. *Nitzschia amphibia* GRUN. This species, which is distinguished from *N. palea* by its much coarser transapical stripes and keel punctae, is present in very small quantities in the phytoplankton at the present time. It is found in substantial quantities in the sediments, however (BRADBURY 1980), indicating possible change in the dominance of *Nitzschia* species over the recent past.

7. *Nitzschia kutzingiana* HILSE. This species is very similar to *N. palea*, but is considerably smaller.

Table 9. Statistics on *Nitzschia palea*, the most important diatom in Lake Valencia.  $s$  = standard deviation,  $\bar{x}$  = mean

Dimension	February		July		December	
	$\bar{x}$	$s$	$\bar{x}$	$s$	$\bar{x}$	$s$
Length ( $\mu\text{m}$ )	24.8	5.9	25.5	3.4	27.5	6.2
Width (middle, $\mu\text{m}$ )	1.7	.50	3.5	.98	2.8	.37
Width (terminal, $\mu\text{m}$ )	.76	.18	1.2	.29	1.1	.42
Depth ( $\mu\text{m}$ )	5.7	1.5	5.8	1.2	—	—

8. *Nitzschia gracilis* HANTZSCH. *N. gracilis* is much larger than the other *Nitzschia* species of Lake Valencia and shows enormous variation in length (50–110  $\mu\text{m}$ ).

9. *Thalassiosira guillardii* HASLE. This very delicate diatom is occasionally observed in great abundance in Lake Valencia (Fig. 6B). Frustules of this diatom are not found in the sediments, probably because they are extremely delicate and may dissolve or be destroyed by sediment preparation methods. Since the genus is principally marine, the present importance of the species in Lake Valencia may be due to recent increases in salinity, although these have by no means yet approached marine salinities. Our identification of this species is provisional, based on the opinions of Dr. G. A. FRYXELL (personal communication) and the work of HASLE (1978).

#### V. *Chrysophyceae*

The Chrysophyceae are not so prominent an element of the lacustrine plankton in the tropics as they are in lakes of higher latitude (LEWIS 1978a). Lake Valencia, like many other tropical lakes, has a few species of chrysophytes which appear sporadically but never reach large abundance. Neither the richness nor biomass contribution of the Chrysophyceae is very important in the ecology of the lake.

1. *Dinobryon petiolatum* WILLÉN. This unusual *Dinobryon* species, identified from WILLÉN (1963), has a very elongate stipe. Up to now, it has been known only from a few locations in Europe, where it principally occurs in brackish water environments. The most abundant of the *Dinobryon* species in Lake Valencia is almost certainly identical with *D. petiolatum* from Europe. Undoubtedly the high salinity of the lake favors this species in South America for the same reasons it does in Europe. Colonies in open water are small, usually incorporating only a few cells.

2. *Dinobryon sociale* EHR. A second *Dinobryon* species which occurs in Lake Valencia appears to be *D. sociale*, although the identification from HUBER-PESTALOZZI (1941) is somewhat uncertain. *D. sociale* is extremely widespread and quite variable in morphology. Few specimens were available for identification due to the rarity of the species in Lake Valencia. From the specimens which are available, it appears that the Lake Valencia form is var. *americanum* (BRUENNTH) BACHM. The cells are shorter than one would normally expect for this species, but resemble closely some individuals found by BROOK (1954) in Scotland. This may conceivably be a new and undescribed species, but for present purposes we assign it to *D. sociale*. The stalk is 10–20% the length of the lorica.

3. Unknown chrysophyte 1. This unknown species has a lorica and almost certainly belongs to the family Dinobryaceae. It was not possible to identify the specimens even to genus, although they would appear to belong to the genus *Stylobryon*. The Lake Valencia specimens do not fit the description of any described *Stylobryon* species, however. It thus seems likely that this chrysophyte is new to science. The entire lorica is 18–22  $\mu\text{m}$  long, of which 5  $\mu\text{m}$  is accounted for by a delicate stalk. The remainder of the lorica is composed of a cylinder approximately 10  $\mu\text{m}$  in diameter and relatively uniform in width from top to bottom except for a definite flare to a diameter of about 12  $\mu\text{m}$  at the top. The species is not particularly common in Lake Valencia.

#### VI. *Cryptophyceae*

The cryptophytes are almost universally present in tropical lakes (LEWIS and WEIBEZAHN 1976, LEWIS 1978a), but seldom reach high abundances. *Cryptomonas* and *Rhodomonas* are the two most ubiquitous genera. Lake Valencia has only *Cryptomonas*. Identifications are from HUBER-PESTALOZZI (1950).

1. *Cryptomonas caudata* SCHILLER. This species, which is distinctive because of the sharp tailpiece of the cell, is widely distributed.

2. *Cryptomonas erosa* EHRENBERG. This species is also widely distributed. In Lake Valencia, as in other localities, its morphology varies. Some specimens, which have been called var. *reflexa* MARSSON, have a reflexed tail, while others do not. The species has been reported from saline water in Europe (HUBER-PESTALOZZI 1950), but is found in soft waters as well.

### VII. Dinophyceae

The Dinophyceae have a status similar to the cryptomonads in the plankton of most tropical lakes: they are almost always present, but usually in low numbers. This is true of Lake Valencia. Identifications are from HUBER-PESTALOZZI (1950).

1. *Peridinium inconspicuum* LEMM. This species is rather rare but appears steadily in Lake Valencia. It belongs to the *conjunctum* subgroup of this species. Specimens usually have about 6 spines located near the bottom of the cell. Similar morphotypes are reported from numerous locations in the tropics as well as Europe (HUBER-PESTALOZZI 1950).

2. *Gymnodinium bogoriense* KLEBS. This tropical form is known from Southeast Asia. It is extremely small and almost round. Because of the poorly defined taxonomic status of the small tropical *Gymnodinium* species, this identification is only tentative.

### 4. Phytoplankton Composition and Morphology

Table 10 summarizes the composition of the Lake Valencia phytoplankton community and the measurements of cells and plankton units. The main diversity of species is accounted for by three taxa: bluegreens, greens, and diatoms. This is the usual situation in tropical lakes (LEWIS 1978a). The relative diversity of these three taxa also follows the normal pattern for tropical lakes: Chlorophyta > Cyanophyta > Bacillariophyceae. Lake Valencia does have a lower diversity of chlorophytes and a higher richness of bluegreens than would be expected in most lakes, however. The total species richness is about as expected on the basis of other tropical lake studies (LEWIS 1978a). The number of species could probably be doubled by inclusion of non-planktonic forms, intensive searching for very rare species, or special concentrating mecha-

Table 10. Averages of cell and plankton unit measurements for the phytoplankton taxa of Lake Valencia

Taxon	Number Species	Cells		Plankton Units	
		GALD $\mu\text{m}$	SGALD $\mu\text{m}$	GALD $\mu\text{m}$	SGALD $\mu\text{m}$
Cyanophyta	29	5.6	2.1	53	17
Euglenophyta	2	17	10	17	10
Chlorophyta	35	13	7.1	20	14
Cryptophyceae	2	8.3	4.9	8.3	5.0
Chrysophyceae	3	31	7.0	57	16
Bacillariophyceae	9	31	4.8	38	4.8
Dinophyceae	2	19	17	19	17
All taxa	82	13	5.3	35	14

nisms such as the use of nets to find large species. Such methods would misrepresent the actual composition of the euplanktonic plankton community, however.

The cells of the bluegreens are by far the smallest among the Lake Valencia taxa (Table 10). The cells of the diatoms, in contrast, are among the largest on the average among the major taxa. For plankton units, however, the small cell size of bluegreens is compensated by the fact that most taxa of bluegreens are characterized by colonies or filaments of some size, producing a functional ecological unit considerably larger than the individual cell. The opposite tendency is characteristic of the diatoms, whose plankton unit sizes are very little greater on average than their cell sizes. The green algae show an intermediate condition between the bluegreen and green algae in this respect. The other divisional taxa have too few species to show any pattern. The comparison of cell sizes and plankton unit sizes in Table 10 among the three major taxa suggests that an optimal range of colony size exists across taxa, and that the difference in cell sizes between taxa is accommodated by variation in the number of cells per colony to approximate this range of colony size. Of course there is considerable variation among species in a given group, but Table 10 is definitely indicative of evolutionary pressures toward a restricted range of colony sizes.

Table 11. Average variability of phytoplankton measurements for Lake Valencia, expressed as coefficient of variation ( $\%$ ). These averages are for only single randomly chosen fixed point in time, and thus exclude variance across seasons.

Taxon	Coefficient of Variation ( $s/\bar{x} \cdot 100$ )			
	Cells		Plankton Units	
	GALD	SGALD	GALD	SGALD
Cyanophyta	19	13	26	17
Chlorophyta	15	17	17	16
Bacillariophyceae	17	11	17	11
All Taxa	16	15	20	16

Table 11 summarizes the degree of variance in measurements of the three major taxa and of all taxa together. In order to facilitate comparison, variation is in all cases expressed as the coefficient of variation ( $s/\bar{x} \cdot 100$ ).

The numbers in Table 11 are derived only from those species for which measurements of variation were possible as indicated in the species lists. For the rarer species estimates of variability were not always possible, hence Table 11, unlike Table 10, is biased toward an inclusion of larger numbers of common species. Also, it should be noted that the variation reported in Table 11 is the average relative variation on specific dates. In most cases, variation was measured on three different dates, and Table 11 reports the average of the coefficient of variation for each of these three dates. There is another component of total variation not shown in Table 11, and this is the variation among dates which is discussed below.

Table 11 shows two noteworthy aspects of morphological variation. First, the relative variation in all measurements is surprisingly uniform across taxa. Almost all of the values are between  $10\%$  and  $20\%$ , and most are between  $10\%$  and  $15\%$ . Secondly, the values are quite low, indicating a surprisingly conservative morphology for the average phytoplankton species in Lake Valencia on a given date. This is perhaps unexpected, as those who measure phytoplankton for taxonomic purpose are aware of major variations in size of cells and of colonies. However, it must be remembered that much of the morphological variability of the species is due to the variation among different habitats. Here we see evidence of the conservative tendency of morphological features in a particular habitat.

Variability among dates can be estimated by application of a single classification analysis of variance with unequal sample sizes (e.g., SOKAL and ROHLF 1969, p. 211). This source of variance is segregated from other sources by subtraction:

$$s_A^2 = \frac{(MS_{\text{dates}} - MS_{\text{within}})}{n_0}$$

where  $s_A^2$  is the variance component due to dates only,  $MS_{\text{dates}}$  is the mean square among groups,  $MS_{\text{within}}$  is the mean square among measurements on a given date, and  $n_0$  is the adjusted value of  $n$  for unequal sample sizes. Since  $s_A^2$  is obtained by subtraction, it can occasionally be negative, even though the corresponding parameter,  $s_A^2$ , can only be positive. Negative values of  $s_A^2$  in effect indicate that  $s_A^2$  is very small, so that estimates of it can by chance fall below zero.

The value of  $s_A^2$  was computed for all species for which sets of measurements had been made on different dates. The values of  $s_A^2$  were then expressed in a relative sense as follows:

$$CV_A = (s_A / \bar{X}) \cdot 100$$

where  $CV_A$  is the coefficient of variation due to dates only and  $\bar{X}$  is the grand mean of measurements for the species on all dates. If  $s_A^2$  was negative,  $CV_A$  was considered to be negative. The means of  $CV_A$  for division level groups are shown in Table 12. If the mean proved to be negative, then it is reported as zero, as the true value of  $CV_A$  cannot be below zero.

Table 12 shows that the variance attributable to time is even smaller than the variance on a given date. Most variable is the SGALD of diatoms; this is probably attributable to progressive change in the size of frustules, which is well documented for diatoms. Whether this is an intrinsic limitation of the mode of asexual reproduction for diatoms, or is adaptive is difficult to say. Many of the species of other taxa show measurable variation among dates as well, but in a relative sense it is scarcely distinguishable from zero.

Table 12. Summary of average coefficients of variation (percent) for the component of variance in plankton unit dimensions due to different dates only  $((s_A / \bar{X}) \cdot 100$ ; see text).

	Bluegreens (10 species)	Greens (7 species)	Diatoms (2 species)	All taxa (19 species)
GALD	2.8	0.0*	0.0*	0.0*
SGALD	5.9	0.0*	11.2	2.6

\* Slightly negative values for sums of squares are shown as 0.0

## 5. Acknowledgements

This work was supported by National Science Foundation grants DEB 7604300 and DEB 7805324 to W. M. LEWIS, Jr. and grants from the Venezuelan CONICIT to A. INFANTE. The authors are grateful to JEANNE BEAUDRY and NATALIE KNOX for their careful phytoplankton measurements, and to Prof. P. BOURRELLY for some very useful advice on taxonomic problems.

## 6. Summary

The phytoplankton of Lake Valencia, Venezuela, were collected at weekly intervals over a two-year period. Whole samples were examined so that the apparent species composition would be as near as possible to the actual species composition of the lake. The phytoplankton were separated as carefully as possible into species groups. Measurements were made to establish the degree of variability on a given date and the degree of variability in morphology between dates. A total of 82 species was found, of which 35 belong to the Chlorophyta, 29 to the Cyanophyta, and 9 to the Bacillariophyceae. Small numbers of species were found in four other minor taxa. The phytoplankton show substantial compositional overlap with other tropical lakes that have been studied and to some degree with temperate lakes as well.

The bluegreens show by far the smallest average cell sizes among the three major taxa, but this is compensated by greater numbers of cells per plankton unit on the average among the bluegreens, which increases the axial dimensions of average bluegreen units to levels comparable to those of the greens and diatoms. The coefficients of variation for linear measurements of either cells or plankton units on specific dates were in almost all cases between 10% and 20%, indicating surprising morphological uniformity for individual phytoplankton species. Variability across different dates was even less, thus reinforcing the indication of high morphological stability in most of the phytoplankton species of Lake Valencia.

## Resumen

El fitoplancton del Lago de Valencia, Venezuela, fue colectado a intervalos semanales por un periodo de mas de dos años. Se examinaron las muestras completas de tal forma que la composición aparente de especies fuera lo mas similar posible a la composición real o actual de especies en el lago. El fitoplancton fue separado en grupos de especies, con el mayor cuidado posible. Se hicieron mediciones para establecer el grado de variabilidad morfológica para una determinada fecha y entre diferentes fechas. Se encontraron un total de 82 especies, de las cuales 35 corresponden a las Chlorophyta, 29 a las Cyanophyta y 9 a las Bacillariophyta. Se encontraron, además, pequeños números de especies correspondientes a cuatro taxa menores. El fitoplancton muestra una coincidencia sustancial de composición con otros lagos tropicales que han sido estudiados y también, en cierto grado, con lagos templados.

Las algas verde-azules muestran evidentemente el menor promedio de tamaño de células entre los tres taxa, pero esto está compensado por el mayor número de células de verde-azules, en promedio, por unidad de plancton, lo que hace aumentar la dimensión axial de unidades promedio de verde-azules a niveles comparables con aquellos de las algas verdes y diatomeas. Los coeficientes de variación de las medidas lineales de, ya células, o unidades de plancton, para fechas determinadas, fueron en casi todos los casos entre 10% y 20%, indicando una sorprendente uniformidad morfológica para especies individuales de fitoplancton. Variabilidad a través de diferentes fechas fue aun menor, reforzando así la indicación de una alta estabilidad morfológica en la mayor parte de las especies de fitoplancton del Lago de Valencia.

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