VI.1b. Algae: General floristic study

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The first studies on the algal flora of Lake Titicaca were carried out by Frenguelli (1939) on diatoms of the littoral zone and by Tutin (1940) on the algae collected during the Percy Sladen Expedition of 1937. Later, various authors made partial observations on the phytoplankton, particularly Thomasson, 1956; Gilson, 1964; Ueno, 1967; Hegewald *et al.*, 1976; Reyssac and Dao, 1977. In 1977, Richerson *et al.* provided a list of 33 taxa with information on their abundance. Later came the studies of Acosta and Ponce (1979) and Lazzaro (1981), followed by the inventories of Iltis (1984) who listed 58 taxa in the lake and 69 in the lakes of the mountain range located above Lake Titicaca (diatoms were not included in this study). In 1985, Theriot *et al.* described a new centric diatom from the Peruvian side of Lago Mayor. In 1987, the Latin American Organization of Fisheries Development published an illustrated inventory of 62 phytoplankton species of the lake (Liberman and Miranda, 1987) in addition to a repertoire of 168 taxa found in the lake by various authors; in the same year Carney *et al.* (1987) published a list of 172 taxa, and made comparisons with other tropical and temperate lakes. Finally, for this book, we make an inventory complementary to that of 1984, and Servant-Vildary (Chapter VI 1a) provides a list of the diatoms present. The combined total of 259 taxa is based on the samples collected between 1985 and 1989 in the Bolivian part of the lake.

Composition of the flora

For this analysis of the characteristics of the flora, only three of the published species lists (Frenguelli, 1939; Tutin, 1940; Carney *et al.*, 1987) are included plus those of Servant-Vildary (Chapter VI 1a) and Iltis (1991) because of their relative completeness (Fig. 1 and Table 1).

What stands out from these data is that three groups comprise about 90% of the flora: cyanophytes, chlorophytes and diatoms. The euglenophytes, pyrrhophytes, xanthophytes and chrysophytes supply in all the lists only a limited number of taxa. The percentages observed are quite consistent given

C. Dejoux and A. Iltis (eds.), Lake Titicaca, 176–181.

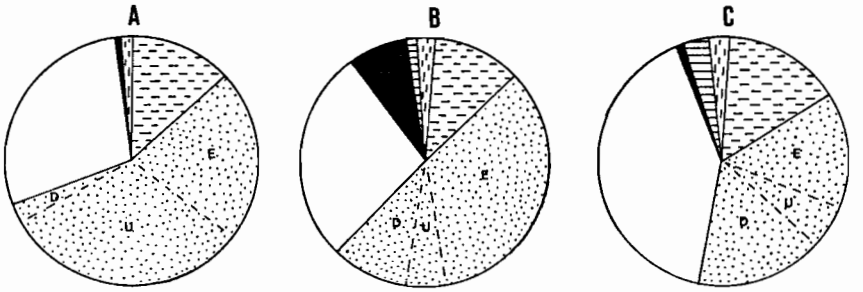

Figure 1. Graphical representation of the proportions of different algal groups in the algal flora of Lake Titicaca. A: after Frenguelli (1939) and Tutin (1940); B: after Carney *et al.* (1987); C: after Servant-Vildary and Iltis. Horizontal dashes, cyanophytes; Dots, chlorophytes (E, euchlorophytes; U, Ulotrichales; D, desmids); Blank, bacillariophytes (diatoms); Black, pyrrhophytes; Horizontal lines, euglenophytes; Vertical dashes, xanthophytes and chrysophytes.

the diversity of authors, times and sampling locations. The cyanophytes constitute approximately 10–12% of the flora, diatoms 27–39% and chlorophytes 43–57%. In this last group, there is a high proportion of euchlorophytes, the Chlorococcales generally comprising the most abundant group at the species level: 48% in the most recent list, and 58% in the list of Carney *et al.* Only the inventory of Tutin (1940) gives a relatively low proportion for this group, the filamentous algae (Ulotrichales, Chaetophorales, Oedogoniales, Zygnemataceae) being analyzed in more detail by this author. The desmids represent about 10–20 % of the total taxa of the flora.

Within the diatoms, the Centrales:Pennales ratio is 0.05 in the list of Frenguelli (*op. cit.*), 0.19 in that of Carney *et al.* (*op. cit.*), and 0.08 in that of Servant-Vildary (*op. cit.*).

Table 1. Number of taxa and proportions of the major groups of algae in the flora of Lake Titicaca.

	FRENGUELLI, 1939 TUTIN, 1940		CARNEY, RICHERSON, ELORANTA, 1987		SERVANT-VILDARY ILTIS (in press)	
	N taxa	%	N taxa	%	N taxa	%
Cyanophyceae	17	12.5	19	11.0	26	10.0
Chlorophyceae	78	57.3	86	50.0	112	43.3
– Euchlorophyceae	31	22.8	60	34.9	58	22.4
– Ulotrichophyceae	43	31.6	8	4.6	9	3.5
– Desmidiae	4	2.9	18	10.5	45	17.4
Euglenophytes	0	0.0	2	1.2	9	3.5
Pyrrophytes	1	0.8	14	8.1	7	2.7
Xant. + Chrys.	2	1.5	4	2.3	4	1.5
Diatoms	38	27.9	47	27.4	101	39.0
	136	100	172	100	259	100

Considering the tropical location of Lake Titicaca, the proportion of pantropical and subtropical taxa in relation to cosmopolitan forms is low; it is not higher than 5% in the above inventories, even though there is some imprecision due to the fact that certain sterile forms, principally filamentous ones, could only be identified to genus level. The same is the case for the American forms which represent a maximum of 4.5% of the taxa listed.

Considering the desmids as good indicators of geographical distributions, the empirical indices proposed by Bourrelly (1957) presenting percentages, first of *Pleurotaenium* species plus filamentous desmids divided by the total of desmids, and second of *Pleurotaenium* and *Euastrum* species plus filamentous desmids divided by total desmids, are calculated here for the two most recent lists. These percentages are 5.5 and 11.1% for Carney *et al.* (*op. cit.*) and 25.5 and 31.9% for Iltis. The higher proportions in the latter list are due to the presence of eleven taxa of filamentous desmids; the lower values of Carney *et al.* may be due to the fact that they concentrated on the deeper-water plankton. These indices are not calculated for the study of Tutin (*op. cit.*) because this author indicated that his analysis of desmids was not complete.

Comparison with other floras

There is little known about the algal flora of lakes and other inland waters in South America, so it is at present difficult to confidently determine similarities and differences between them. Carney *et al.* (*op. cit.*) used a method developed by Lewis (1978) to determine affinities between floras. This method provides an estimate of percent similarity between two lists based on the genera in common. In this way the generic list of algae for Lake Titicaca were compared with the lists of 35 other lakes throughout the world. Carney *et al.* found that the Lake Titicaca flora was somewhat different from those of 18 other tropical lakes (on average 53% of genera in common) and even more distinct from those of 13 temperate lakes (only 50% of genera in common). By contrast, there was a much greater affinity with floras of four lakes of the Andes mountains (on average 67.5% genera in common).

The comparisons made here are between the recent Lake Titicaca lists and, on the one hand, tropical waters such as the Bolivian Amazon (Therezien, 1985, 1986a, 1986b, 1987, 1989), and, on the other hand, mountain lakes, some Peruvian located at 3600 m a.s.l. in the department of Cuzco (Hegewald *et al.*, 1980), some alpine in the Vanoise region of France (Martinot and Rivet, 1985), some Bolivian (lakes of Hichu Kkota between 4300 and 4900 m) in the Eastern Cordillera (Iltis, 1984). The percentages of the major algal groups have been calculated without taking into account the diatoms (Table 2 and Fig. 2).

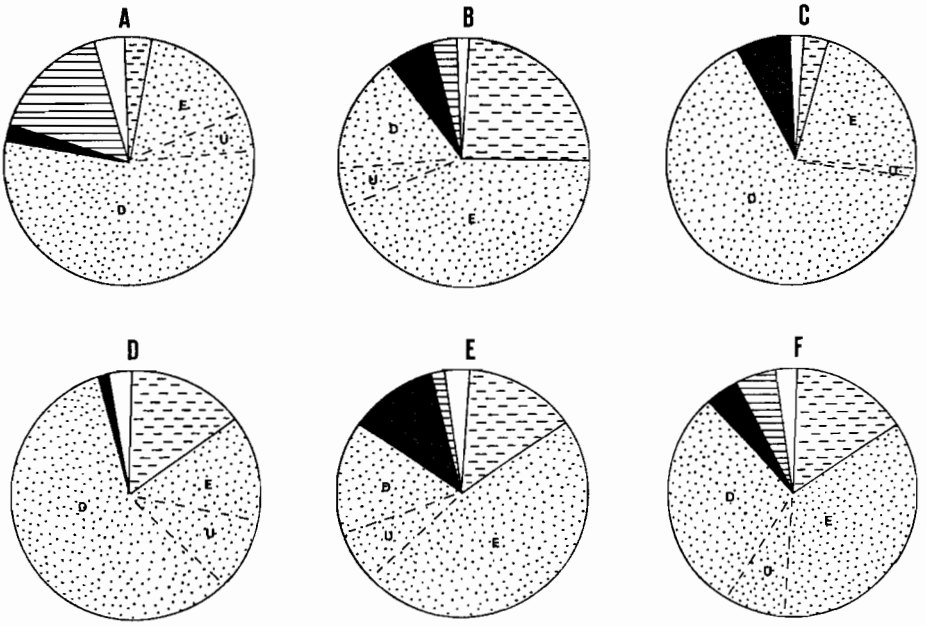

Figure 2. Graphical representations of proportions of major algal groups (excluding diatoms) from lists of algal floras. A: in Bolivian Amazon (Therezien), B: in Peruvian lakes (Hegewald *et al.*), C: in alpine lakes of the Vanoise (Martinot and Rivet), D: in high-altitude lakes of the La Paz, Bolivia, region (Iltis), E and F: Lake Titicaca (Carney *et al.*) and (Iltis), respectively. Horizontal dashes, cyanophytes; Dots, chlorophytes (E, euchlorophytes; U, Ulotrichales; D, desmids); Black, pyrrhophytes; Horizontal lines, euglenophytes; Blank, xanthophytes and chrysophytes.

The percentage of cyanophycean taxa is higher in the Andean lakes of Peru (close to 25%) and Bolivia (14 to 16%) than in north temperate alpine lakes or in waters of the Bolivian Amazon (3 to 4%). The chlorophytes are always present in high proportions, the largest component being the Euchlorophyceae in Lake Titicaca and the lakes studied in Peru, and the desmids in high-altitude Andean and alpine lakes, and in warmer waters of the Bolivian Amazon. The pyrrhophytes, euglenophytes, chrysophytes and xanthophytes are always found in relatively low abundances, though the proportion of pyrrhophytes is generally somewhat higher in mountain lakes, and euglenophytes are somewhat higher in lowland tropical waters. The taxa which have been classified until now as characteristic of the tropics reach 7% in the Bolivian Amazon, only slightly above 4% in Lake Titicaca, and they are absent in the mountain lakes of the Andes and other regions. Bourrelly's (1957) indices of tropicality have quite variable values: zero in lakes of Peru, 4 and 12% in alpine lakes, 7.5 and 12.5% in high-elevation lakes, 13 and 23% in the plains of Bolivia, and for Titicaca 5 and 11% (1987 list) and 27 and 31% (1991 list). The percentage of genera in common with

Table 2. Proportions of major algal groups in the flora of Lake Titicaca and, by comparison, with other recently studied systems. Diatoms are not included in this analysis.

	Bolivian Amazone (Thérézien)	Peruvian lakes (Hegewald *et al.*)	Alpine lakes (Martinot and Rivet)	Andean lakes (Iltis)	Lake Titicaca (Carney *et al.*)	Lake Titicaca (Iltis)
Number of taxa	642	65	199	69	125	158
Relative composition in %						
Cyanophyceae	3.1	24.6	3.5	14.3	15.2	16.4
Chlorophyceae	76.0	64.6	87.4	81.4	68.8	70.9
Euchlorophyceae	15.6	44.6	21.6	13.1	48.0	36.7
Ulotrichophyceae	5.3	4.6	0.5	10.1	6.4	5.7
Desmidiae	55.1	15.4	65.3	58.2	14.4	28.5
Pyrrhophytes	1.5	6.2	7.5	1.4	11.2	4.5
Euglenophytes	15.4	3.1	0.0	0.0	1.6	5.7
% Xant. Chrys.	4.0	1.5	1.6	2.9	3.2	2.5
% of pantropical forms	6.7	0.0	0.0	0.0	2.4	4.4
Pleurot.+desm.filam. Total desm.	13.3	0	3.8	7.5	5.5	26.7
Pleurot.+Euastr.+D.filam. Total desm.	23.4	0	12.3	12.5	11.1	31.1
% of genus common with Lake Titicaca						
Cyanophyceae	26.3	62.5	11.1	50.0	–	–
Chlorophyceae	42.6	29.9	31.0	35.9	–	–
Total (except diatoms)	36.1	36.1	24.2	33.3	–	–

the most recent algal list for Lake Titicaca is highest for the mountain lakes of Peru and Bolivia, slightly lower for the Bolivian Amazon, and relatively low for temperate alpine lakes.

Combining these analyses, we find that the Lake Titicaca algal flora is most similar to that of Peruvian lakes of similar altitude (3600 metres). The flora of high-altitude Bolivian lakes is distinguished by a higher percentage of desmids, as in the Amazon, and in alpine lakes, where, in addition, the percentage of cyanophytes is particularly low.

Conclusions

Although the study of the Lake Titicaca algal flora cannot in its present state be considered exhaustive, it is possible to determine some major characteristics from the work completed to date.

Firstly, the number of algal species appears to be relatively limited. Even though the pelagic zones appear to have been investigated more than the shallower littoral areas (Totora wetlands, for example) and the periphyton, none of the inventories to date exceed 260 species. This is a relatively small

number of taxa for such an extensive ecosystem which includes a great variety of habitats.

Secondly, there is a clear predominance of chlorophytes, with the Chlorococcales generally being the best represented order in the samples. This latter feature distinguishes the flora of Titicaca, on the one hand from the floras of tropical regions, where desmids constitute the most important group, and on the other hand from the floras of Bolivian Andean lakes between 4300–4900 metres (Iltis, 1984) and of alpine lakes (Martinot and Rivet, 1985) where desmids also predominate.

One should also appreciate the cosmopolitan character of the algal flora: the percent of tropical forms is only slightly less than 5%. The number of species which can be considered endemic are quite low. The only ones found so far have been: four species of diatoms (Frenguelli, 1939), seven species described by Tutin (1940) which have not been found by others, one species of *Peridiniopsis* (Iltis and Coute, 1984) and a species of *Cyclotella* (Theriot *et al.*, 1985). The endorheic basin of the Altiplano and the unique ecological conditions of Lake Titicaca thus do not appear to manifest in a strongly endemic algal flora, as is the case for certain animal groups.

Finally, the comparisons made above with floras from various regions (temperate as well as tropical, mountains as well as lowland plains) lead us to conclude that Lake Titicaca contains an algal flora which has few similarities with most lowland or mountain lakes of temperate regions; it has a greater affinity with floras of tropical South America, for example the Bolivian Amazon. Carney *et al.* (*op. cit.*), following their analysis of genus-level similarity between Lake Titicaca and four smaller lakes in Peru and Ecuador (Hegewald *et al.*, 1978, 1980; Steinitz-Kannan *et al.*, 1982), suggest the possible existence of a biogeographical region in the central Andes. The characterization and geographical delineation of such a zone will require additional algal inventories in the lakes prospected up to now, and detailed studies in many other Andean lakes of which we have as yet very little or no knowledge.

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C. DEJOUX and A. ILTIS / Editors

Lake Titicaca

A Synthesis of Limnological Knowledge

Kluwer Academic Publishers

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KLUWER ACADEMIC PUBLISHERS

DORDRECHT / BOSTON / LONDON

Library of Congress Cataloging-in-Publication Data

Lake Titicaca : a synthesis of limnological knowledge / edited by C.
Dejoux and A. Iltis.
p. cm. -- (Monographiae biologicae ; v. 68)
Includes indexes.
ISBN 0-7923-1663-0 (HB : alk. paper)
1. Limnology--Titicaca Lake (Peru and Bolivia) 2. Aquatic
resources--Titicaca Lake (Peru and Bolivia) I. Dejoux, Claude.
II. Iltis, A. III. Series.
QP1.P37 vol. 68
[QH128]
574 s--dc20
[574.5'26322'098412] 92-7958

ISBN 0-7923-1663-0

Published by Kluwer Academic Publishers,
P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

Kluwer Academic Publishers incorporates
the publishing programmes of
D. Reidel, Martinus Nijhoff, Dr W. Junk and MTP Press.

Sold and distributed in the U.S.A. and Canada
by Kluwer Academic Publishers,
101 Philip Drive, Norwell, MA 02061, U.S.A.

In all other countries, sold and distributed
by Kluwer Academic Publishers Group,
P.O. Box 322, 3300 AH Dordrecht, The Netherlands.

Printed on acid-free paper

Printed in the Netherlands