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Recent limnological changes in a saline lake of the Bolivian Altiplano, Lake Poopo

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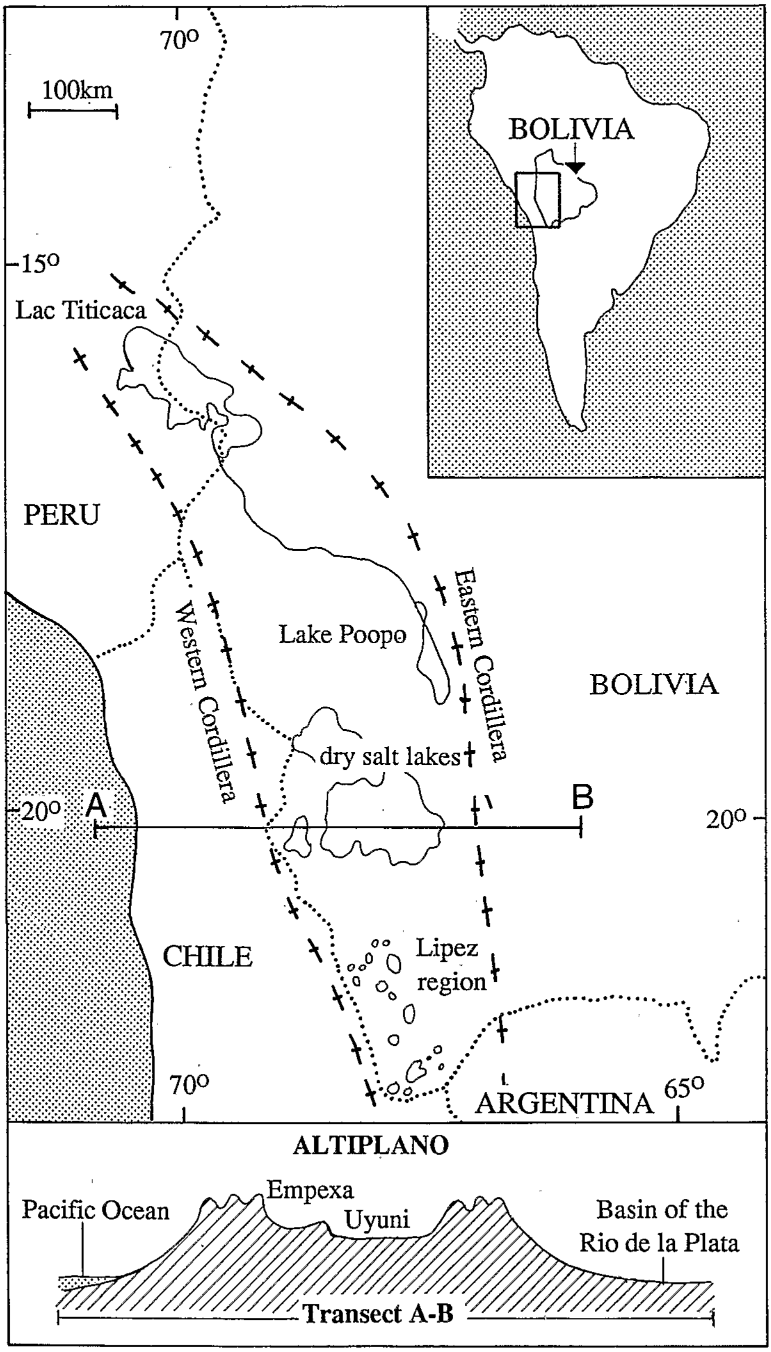
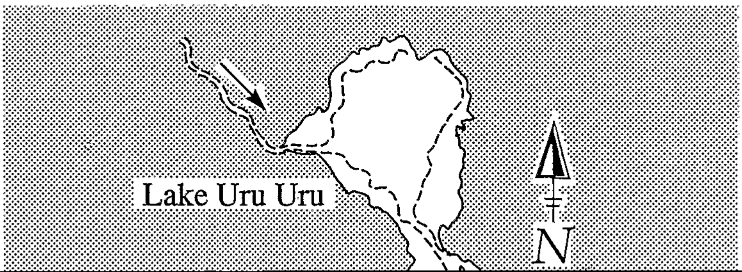


Fig. 1. Map of the area. (After Ballivian and Risacher, 1981).

some 350 km. The average gradient of this river is very slight (0.03 per cent) since the altitude of Titicaca is 3,810 m and that of Poopo ~3,690 m, that is, only about 120 m lower.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An important flora of aquatic macrophytes (Allen, 1940; Tutin, 1940) occurred on the bottom sediments of part of the lake basin (68 per cent around the surface). The bottom of the central part, aligned north-south (32 per cent of the area), comprised compact grey sediment and lacked vegetation. Where macrophytes existed, *Ruppia* and *Chara* constituted most of them (Collot, 1982). This situation still existed at the end of 1982: a salinity of 7.5 g L^{-1} was observed at the level of Pazna in the north of the lake and of 75 g L^{-1} near Huari in the south (unpublished information).

The second configuration relates to the situation after 1985. The exceptionally large increase in the level of Lake Titicaca in 1985 resulted [illegible]

Characeae seem largely dominant except in the north-west at the new inlet of the River Desaguadero where *Ruppia* still covers large areas.

ble 1. Extreme values observed for temperature, conductivity (25°C), salinity (by refractometer), pH, and transparency :cchi disc) at Lake Poopo. Values relate to surface waters and to five series of observations between March 1987 and April 39.

Date	Number of stations	Temperature (°C)	Conductivity (µS at 25°C)	Salinity (g L^{-1})	pH	Transparency (Secchi disc, m)
rch 1987	8 (west)	15.0–17.6	10,000–12,500	8–10	—	0.80–1.20
cember 1987	9 (east)	16.3–18.8	—	8–10	—	0.33–1.20
rch 1988	9 (west)	14.7–16.4	13,000–14,300	9–11	8.17–8.43	0.90–3.00
cember 1988	9 (east)	14.5–16.8	12,20014,000	8–11	8.47–9.05	0.60–2.50
ril 1989	6 (west)	13.3–14.4	12,000–13,000	9–10	8.75–8.86	0.50–3.50

Changes in the phytoplankton

The status of the phytoplankton is very different in the two configurations of the lake. Information is available on when the lake lacked an outlet from the work of Servant-Vildary (1978) who studied diatoms collected from superficial sediments and from some unpublished work of my own undertaken in 1982. This information indicates that the diatoms, salinity was about ten times lower (7.5 g L^{-1}), the algal biomass was much higher (21.5 g m^{-3}). It comprised 64 per cent diatoms, 34 per cent pyrrophytes and 2 per cent cyanophytes.

Information on the situation when the lake had an outlet was obtained between 1987 and 1989 during five expeditions to different parts

With regard to the spatio-temporal distribution of the biomass, because of the timing of sample collections it is not possible to discern seasonal variations. No differences have been observed between samples collected at the end of the dry season (December) and those collected at the end of the wet season (March–April); presumably, those differences encountered were not related to a seasonal cycle. More frequent observations would be needed for adequate resolution of this question.

With regard to spatial variation, the following points may be made. The greatest biomass occurred near the lake's shores, with *Peridiniopsis cristatum* var. *boliviense* dominant. The central zone, with a smaller biomass, was characterised by an abundance of *Dictyosphaerium pulchellum*. The central zone had a low transparency throughout. Presumably, suspended matter was the principal cause of the water's turbidity. Elsewhere, turbidity was highest near the inlet of the Desaguadero. It was high too in the central region lacking macrophytes where, during strong winds, disturbed sediments remained in suspension.

Discussion

Because salt lakes are most often found in hydrologically endoreic or [illegible] interannual variations in physicochemical features, especially salinity. Biological changes which follow are often of considerable amplitude. However, changes of this sort over extended periods have been seldom studied. An exception is provided by studies of the Great Salt Lake in Utah, USA (Jensen and Arnow, 1972; Greer, 1977; Arnow, 1978; and Stephens, 1990). These studies cover environmental changes from 1847 until 1987.

In the case of Lake Poopo and its evolution over the last 12 years, apart from the observations on the phytoplankton reported in this paper, there exist only isolated observations on variations in other biological components. A few analyses of the benthic fauna made between 1987 and 1989 (Iltis *et al.*, 1990) suggest that this fauna adapted only slowly to the southern part was too saline before 1985. After 1985, when salinity was uniformly low throughout the basin, fishing was equally good in both parts. In this regard, the evolution of populations as a response to salinity variations remains little known and unpredictable: information on the response of organisms to changes in salinity in athalassic waters of South America does not exist, unlike, for example, the situation with regard to aquatic species in Australia (Hart *et al.*, 1991). Even so, observations on these components of the biota show that variation displayed by them follows salinity variation after an important delay.

Finally, in the present state of our knowledge of Lake Poopo, the phytoplankton appears to respond most rapidly to changed physico-chemical conditions and is therefore the best biological indicator of these conditions, especially salinity, in the lake at any given time. According to observations made on African carbonate lakes, an inverse relationship exists between the number of algal species and salinity (Iltis, 1973a). Elsewhere, a general relationship between the number of species and salinity is indicated by Hammer (1986) and, in modified form, by Williams *et al.* (1990) for Australian lakes. A positive correlation has been observed between algal biomass and salinity in the salt lakes of Chad and variations in the proportions of different algal groups in the biomass have been related to fluctuations in the concentration of dissolved salts (Iltis, 1973b).

It is evident that each geographical athalassic assemblage has its own characteristics, and so conclusions obtained from studies of one of them cannot be applied directly to a group of saline lakes in another region. Further studies to complement those on Lake Poopo are necessary and these should particularly address conditions in the period between the two configurations of the lake. It should then be possible to provide a predictive model on the qualitative and quantitative composition of the plankton in relation to the concentration of dissolved salts and lake level. Such a model would complement that on the energy flux outlined by Hurlbert *et al.* (1986) for the Altiplano lakes of South America. However, access to study Lake Poopo is relatively difficult and one can anticipate that good limnological knowledge will not be acquired for several years.

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