The basic limnology of a low altitude tropical crater lake: Cerro Chato, Costa Rica

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Abstract: Cerro Chato Lake was visited in April, May, and June 1992. The lake is located within an intermediate-altitude crater in Costa Rica, Central America. It has steep sides and reaches a maximum depth of 18.8 m. The lake has no surface outlet, nevertheless, its water has a low concentration of solutes, possibly because of rain fall and underground seepage. Water column stratification was observed in all visits with a clinograde oxygen curve and anoxic conditions below 15 m. The Phytoplankton was composed mainly of small chlorophytes and other algae, with a total of 43 species. The diversity was low due to strong dominance of *Arthrodesmus bifidus*, and the Zooplankton, dominated by *Tropocyclops prasinus prasinus*, included four species of Cladocera. Large filter feeders were not observed which may partially explain dominance of small algae.

Key words: Crater lakes, limnology, tropics, plankton, Costa Rica,

Cerro Chato is a volcanic cone in Costa Rica, located between the Cordillera Volcánica de Guanacaste and the Cordillera Volcánica Central. Its activity ended abruptly some 3550 years ago with an explosion (Borgia *et al.* 1988), leaving a deep, steep-walled depression at its summit which filled with rain water. There are several crater lakes in Costa Rica, Chato Lake is the lowest in elevation (1020 m). The steep walls that rise 50 to 100 m above the lake surface form a rather small drainage basin, with no surface outlet. Its surface area, based on aerial photographs (photo 202 Arenal L-B-R-63, IGN, ICE), is ca. 4.8 ha. According to the topographic map (Fortuna 3247 II), the drainage basin area is about 22 ha (corresponding to the crater rim). The shape of the lake is nearly rectangular (Fig. 1) with low shore development (S.D.= 1.04). The main axis is oriented NNW-SSE, with a maximum length of 305 m, and a maximum breadth of 200 m.

Other crater lakes have been studied in Costa Rica. Hargraves & Víquez (1981) published an account of the planktonic algae at Botos lake, within the caldera complex of Poas Volcano.

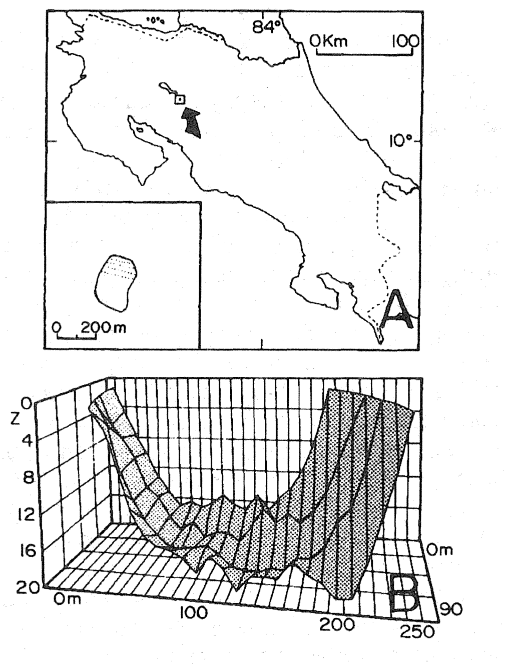


Fig. 1.A) location of the lake and B) three dimensional bottom contour of four paralell transects separated ca 30 m from each other. Front scale is approximate.

They found that a dinoflagellate *(Peridinium volzii)* dominated the entire community. Barva Volcano's lake was visited twice by Umaña (1988, 1990). The planktonic flora was completely different from that of Botos's. It was dominated by two small-celled algae, *Cosmarium* sp. and a microflagellate. Umaña (1988) also found evidence of stratification in the cold waters (15°C) of Barva lake. More recently, Horn and Haberyan (1993) published the results of a broad survey of physical and chemical properties of 30 Costa Rican lakes, including Botos and Barva. They found that both lakes had low conductivities and alkalinities, however they differed markedly in other respects such as transparency, temperature, pH, hardness, and the mayor anions and cations. Botos, at a lower altitude (2600 m vs. 2840 for Barva) was not as cold (13.8 vs. 11.7 °C), but more acidic (pH 4.39 vs. 7.45) and far more transparent (Secchi= 6.3 vs. 1.2 m) than Barva.

In this paper the characteristics of the lake at Cerro Chato were examined and compared with the results reported above for lakes Botos and Barva.

MATERIAL AND METHODS

The lake was visited three times in 1992 (8 April, 28 May and 29,30 June). Depth profiles were measured for four parallel transects across the lake, separated by roughly 30 m. We used a diver's fixed needle depth meter (DACOR) attached to a line. It was lowered every ten meters along the transect and the depth in feet was recorded. Depth was later expressed in meters using the appropiate factor according to lake altitude (NAVI 1989).

On each visit Secchi depth was recorded and oxygen and temperature profiles where measured with a YSI meter (Model 57). Additionally, on one occasion (June) a 24 h cycle was followed at six sampling stations along a transect accross the lake, to determine whether the stratification observed during the day was eroded away at night. pH was also measured with a Helige color comparator (Hach) and conductivity with a YSI meter (Model 33 T-S-C). Estimations of nitrate, nitrite, amonium, orthophosphate and silica were made at the surface and at selected depths (0, 1, 6, 10, and 17m) following commonly accepted methods (Strickland and Parsons 1972).

Samples for chlorophyll and phytoplankton were taken using a Niskin water sampler (General Oceanics) from selected depths in May and June 1992. Chlorophyll was measured with the trichromatic formulas by SCOR/UNESCO (Strickland and Parsons 1972). Phytoplankton samples consisted of 140 ml of whole lake water, fixed with acetic Lugol's solution. Samples were allowed to settle for two days and later were concentrated by siphoning off the supernatant and by centrifugation (Umaña 1985). Counts were made with a Palmer-Maloney counting chamber with a 40x objective. A maximum of 100 individuals of the most abundant species were counted (cf. Lewis 1978). A total of 5 transects in the mid portion of the chamber were scanned for the most rare species. Zooplankton vertical hauls were performed on 8 April and 28 May, 1992 using a weighted 80 µm mesh size Wisconsin plankton net with opening diameter of 11.7 cm from the depth of 18 m.

RESULTS

Maximum lake depth was 18.8 m, yielding a high relative depth (z_r) of 7.6. The lake has steep sides (Fig. 1) and the transects revealed a very irregular bottom surface. The water had a deep green color and a mean Secchi depth of 1.5 m, with a maximum of 2.0 m in April.

The lake was thermally stratified. The temperature of the lake fluctuated between a minimum of 20°C in the hypolimnion and a maximum of 23.7°C at the surface. Surface temperature varied little in a single day (23.1-23.7°C). The thermocline was always located between 5 and 8 m of depth. Fluctuations of the thermocline along a transect in a 24 hour cycle (Fig. 2) suggest the presence of internal oscillations of the thermocline.

Depth profiles of dissolved oxygen showed a clinograde curve, with a small but persistent peak at the thermocline (6 to 7 m deep) that was observed in May and June throughout the lake. Occasionally other increases in oxygen ocurred at the surface (Fig. 3). The mid water peak was more pronounced following heavy rains in the 24 hour cycle. The deepest layer remained anoxic at all times.

The water of the lake was quite dilute, with conductivities between 10 and 12 $\mu S\ cm^{-1}$. Hardness was also very low (17 mg $CaCO_3\ l^{-1}$).

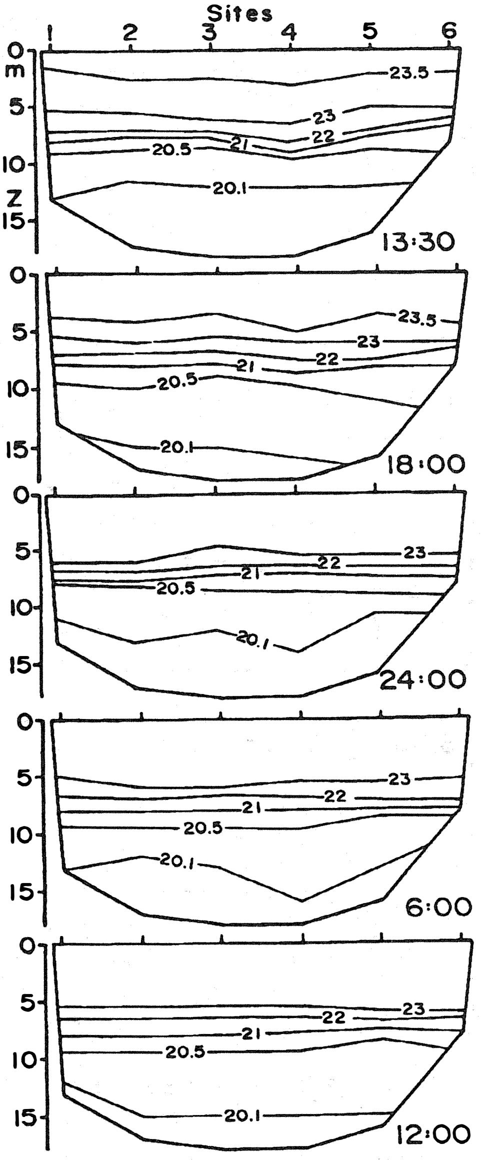


Fig. 2. Isotherms at six stations in a transect across Cerro Chato lake at different times of day (29,30 June 1992).

The lake is acidic, with a pH value ranging from 3.3 to 6.0 depending on depth and time of the day. Higher pH values tended to occur at about 6 m depth (Fig. 4). In June 1992 two pH profiles were measured at different times. A shift in the pH value at 6 m was observed. During the day pH increased up to 6.06 (15:30, 06.29.92), but it decreased during the night to 4.51 (06:00, 06.30.92).

Nitrate nitrogen was highly variable at the surface (4.75 to 5.6 $\mu g\ l^{-1}$). Nitrite was always near or below the detection point. Ammonium was also low in surface waters. Phosphate ranged from undetectable levels up to 18.58 $\mu g\ l^{-1}$ at the surface. Silica was also very variable, with values between 2.1 and 14.5 $mg\ l^{-1}$ at the surface.

A total of 43 species of phytoplankton were observed (Table 1) with representatives from Chlorophyta (20 spp.), Euglenophyta (1), Pyrrophyta (3), Cryptophyta (1), Chrysophyta (2), Bacillariophyta (9) and Cyanophyta (4). Species diversity was low, with values between H'=0.06 and 0.77, and J=0.03 and 0.26 (Table 1). Phytoplankton were dominated by small-sized desmids and Chlorococcal greens (*Arthrodesmus bifidus, Monorhaphidium* sp., small coccoid cells (cf. *Tetraedron)* and small spherical cells (Diameter= 6.2 µm).

Total cell counts in May at noon were significantly different among depths (X^2= 33.4, a<0.01) with fewer cells at midwater than at the surface and bottom waters (Fig. 5). In contrast, chlorophyll a was lowest at 1 m and reached its peak at 6 m, but otherwise it was relatively constant with depth (Fig. 5).

Zooplankton were dominated by the cyclopoid copepod *Tropocyclops prasinus prasinus* which accounted for 85% of all zooplankters observed. Several species of cladocerans were also observed: *Alonella dadayi, Bosminopsis dietersi, Bosmina hagmannii,* and *Daphnia laevis*. No rotifers were found, but this was probably attrinutable to the net mesh size.

DISCUSSION

The lake was stratified during all three visits, but our data are limited to the warmer, less windy period of the year. Although the thermocline persisted over the entire 24 hour period, a heavy rainstorm lowered surface temperature by almost 1°C. The lake could mix deeply during cold and windy periods, in spite of its somewhat sheltered location at the bottom of the crater. We did not cover both dry and wet seasons, but due to the variability of the weather and the strong winds in the region, the stratification of the lake may be eroded more than once a year, a fact that we will study more closely in the future.

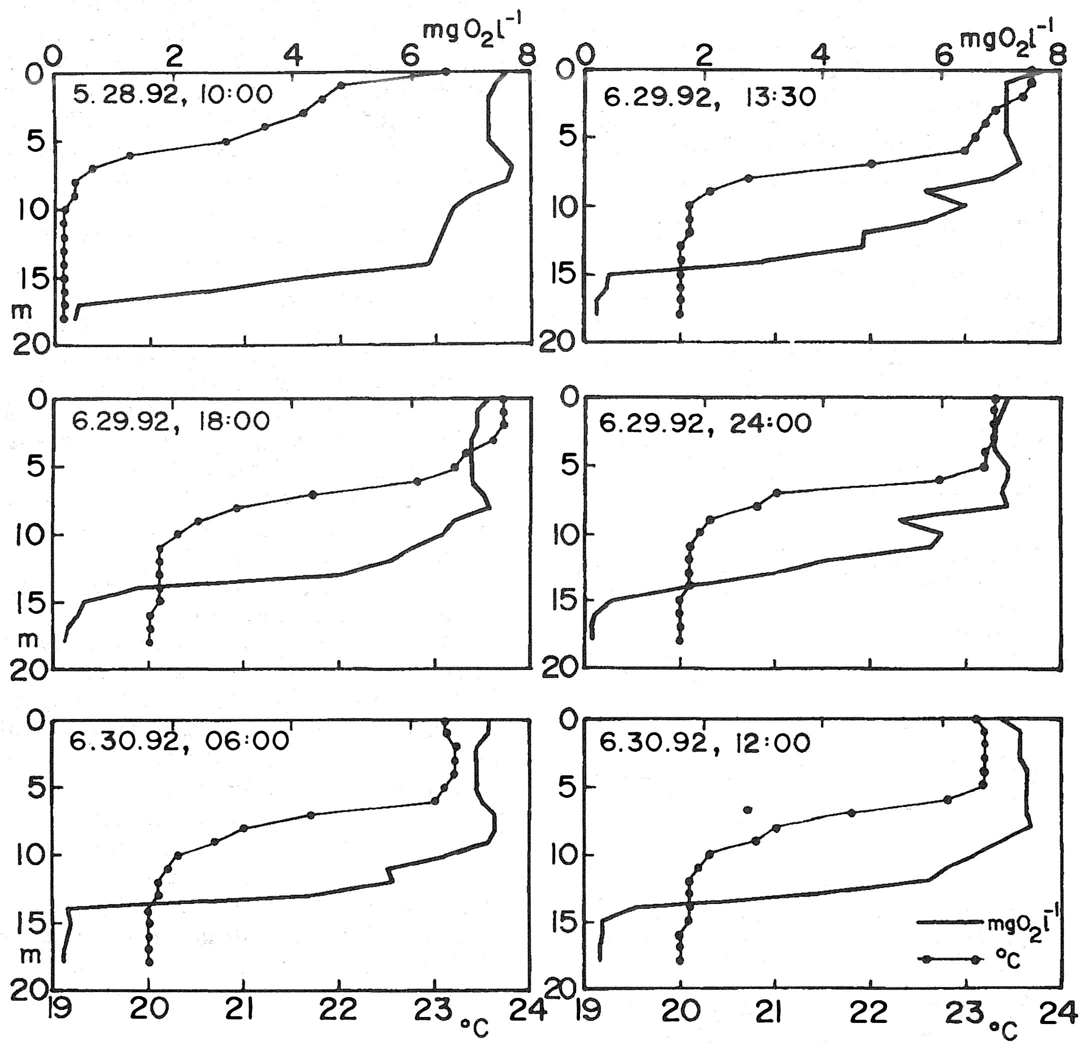
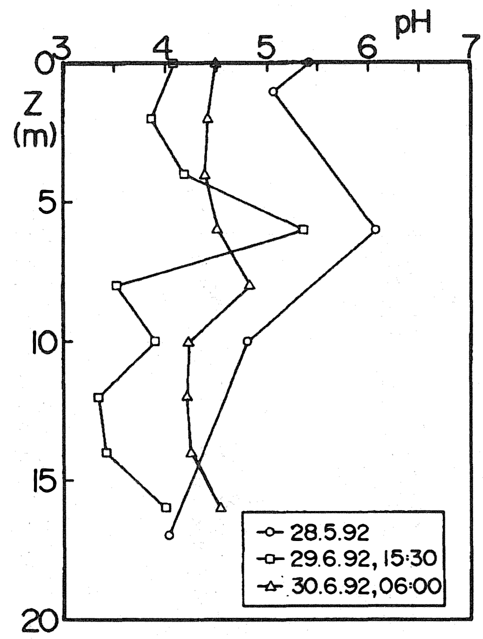


Fig. 3. Oxygen profiles at Cerro Chatos lake on 28 May 1992 at 10:00 a.m. and on 29, 30 June 1992, at different times of day in a 24-hour cycle.

The water of the lake is rather dilute and the lake level seems to remain fairly constant throughout the year despite variations in rainfall. Water is probably lost to seepage because Cerro Chato is closely related to highly fractured Arenal Volcano nearby. Actually the topographic maps (scale 1:50000) show about three rivers and other minor creeks flowing out from the cone, at about 700 m of altitude.

The small peak of oxygen at 6 m depth was fairly consistent and may originate from a number of causes. First, it might be the result of photosynthesis from a localized dense layer of algae, a hypothesis supported by the higher level of chlorophyll a and the pH at this depth. However this does not seem likely since the maxima were located below the theoretical depth of the compensation point, according to Secchi readings (max. 6 m).

The heavy rainfall on the lake is suggested as a second factor producing the slight deep oxygen maxima. Rainfall is high on the lake, with annual precipitation ranging between 4500 and 5000 mm (Barrantes, Liao and Rosales 1985), it is usually colder than surface lake waters and well oxygenated. Rain water might then sink in the lake to a depth of equal density creating the oxygen maximum observed. This



4. Depth profiles of pH at Cerro Chato lake in different dates and at different times of day: 05.28.92 (12:00) 06.29.92(15:30) 06.30.92 (06:00).

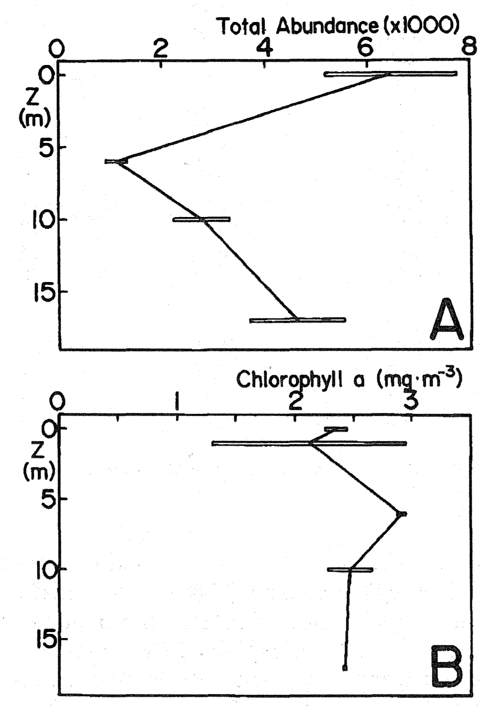


Fig. 5. Depth distribution of A) Phytoplankton and B) Chlorophyll a at Cerro Chato lake. Bars indicate the range of two readings. Samples were taken on 05.28.92 around noon.

idea is reinforced by the fact that the deep maximum was more pronounced after a heavy rain fall during the 24 hour cycle measured in June.

The reversed distribution of chlorophyll a and phytoplankton abundance probably reflect adjustements in cells to adapt to different light regimes. At high light intensities there is usually a reduction in chlorophyll content due to photoinhibition, whereas the chlorophyll content of cells tends to increase at low light intensities (Harris 1978).

The phytoplankton composition of Cerro Chato lake differs from that reported for Botos lake, another crater lake in Costa Rica, in which a dinoflagellate *(Peridinium inconspicuum)* dominated the plankton community (Hargraves and Víquez 1981, Haberyan *et al.* in press). Hargraves and Víquez also reported 19 other species, mainly littoral diatoms. Haberyan *et al.* (in press) also found a species of *Oocystis* sp. abundant in Botos lake. The phytoplankton assemblage for Cerro Chato lake did not differ greatly from that found in Barva lake (Umaña 1990), another crater lake sampled in a way similar to that of Cerro Chato. Small desmids and cryptophytes also dominate in this later lake. It is possible that the time of the year may play a part in the differences reported, but we have no data on seasonal succesion on these three volcanic lakes.

Phytoplankton diversity was low with a high degree of dominance by a few species. Small-sized algae were dominant, most of which were in the range of particles filtered out by cladocerans (Lampert 1987). Perhaps because of their rarity, cladocerans seem to be ineffective in removing phytoplankton and exerting a definite influence on the algal communit of this lake. Part of the explanation may be that most of Cerro Chato lake's cladocerans are also small-sized, and probably feed on bacteria rather than on phytoplankton (Brendelberger 1991).

Another factor may be the presence of Cyclopoids. These are reported to be raptorial feeders (Pennak 1978), either detecting large or mobile algal cells from a distance (DeMott and Watson 1991) or predating on *Daphnia* neonates (Gliwicz and Umaña. in press). Thus, cyclopoids may be acting in two ways, i.e. removing the larger algae and arresting *D. laevis* population growth.

The lake also has a large population of *Notonecta* sp. (Notonectidae: Hemiptera) that were

TABLE 1

List of species of phytoplankton from cerro chato lake numbers per mililiter

Depth (m)	0	6	10	17
Chlamydomonas sp.	0.47	0.00	0.00	0.00
Ankistrodesmus Braunii (Naeg.)Brunnthaler	0.95	0.55	0.47	0.00
Coccoid sp. 1	705.22	180.50	221.42	85.47
Coenocystis subcylindrica Kors	0.00	0.00	1.41	0.89
Cylindrocystis cf. *diplospora*	0.47	0.55	0.94	0.00
Monorhaphidium griffithii (Berk.)Kom.-Legn.	26.03	2.76	5.16	46.28
Oocystis pusilla Hansgirg	1.89	0.00	7.04	0.47
Oocystis Borgeii Snow	0.47	0.00	0.00	0.00
Scenedesmus bijuga (Turp.)Langerheim	0.47	0.00	0.00	1.42
Scenedesmus brasiliensis Bohlin	0.00	0.00	0.00	0.47
Spherical cells 1	150.04	18.77	30.49	131.27
Tetraedron minimum (A.Braun)Hansgirg	0.00	0.00	0.47	0.00
Tetrastrum komarekii Hind.	0.00	0.00	0.00	0.94
Arthrodesmus bifidus Breb.	5538.08	912.46	2488.58	4271.99
Cosmarium subexcavatum West & West	0.47	0.00	0.00	1.42
Staurastrum manfeldtii Delp.	0.00	0.00	2.35	0.47
Staurastrum curvatum West	0.00	0.00	0.00	0.94
Trachelomonas volvocina Ehrenberg	0.00	0.00	0.00	0.94
Peridinium cf. *cunningthonii*	25.08	1.10	0.47	0.47
Peridinium sp. 2	0.95	0.00	0.00	0.00
Peridinium sp. 3	0.00	0.00	0.47	0.00
Cryptomonas caudata Schiller	0.95	0.00	0.00	0.00
Cystodinium cf. *Steinii*	0.95	0.00	0.47	3.31
Coscinodiscus sp.	0.00	0.00	0.00	0.47
Cyclotella stelligera Cleve & Grunow	0.00	0.00	1.88	4.72
Navicula sp.	0.47	0.00	0.00	0.00
Synedra ulna	0.47	0.00	0.00	0.00
Tetracyclus sp.	0.95	0.00	0.00	0.00
Anabaena sp.	0.47	0.55	0.00	0.47
Merismopedia glauca (Ehrenb.)	0.00	0.00	0.00	55.72
Aphanocapsa Grevillei (Hass.)Rabenhorst	0.47	0.00	3.28	0.94
Filament 1	0.47	0.00	0.00	0.00
Filament 2	0.00	0.00	0.00	3.31
Flagellate 1	0.00	0.00	0.47	0.00
Unknown sp. 1	5.68	0.00	0.00	1.89
Unknown sp. 2	1.42	0.00	0.94	0.00
No. of species	23	8	17	22
Total Sum	6462.91	1117.25	2766.28	4615.28
Shannon's H'	0.46	0.06	0.74	0.77
Simpson's c	3.33	2.28	3.71	3.85
J (H'/H'max)	0.15	0.03	0.26	0.25

Other species present but not seen in actual counts: *Docidium* sp., *Botryococcus*, *Navicula* sp. 2, *Cymatopleura* sp., *Rhizosolenia* sp., *Gomphonema* sp.

seen swiming in the open water (M. Springer, pers. comm.). These insects are probably the main planktivores according to Dodson and Havel (1988). Their presence could be one of the factors explaining the small body size of zooplankton in this lake, as described earlier.

The low diversity of zooplankton, even allowing for the effect of mesh size which could have excluded small rotifers, seems to be a common fact in tropical lakes (Fernando 1980a,b, Lewis 1979). Fernando (1980a) also noted the small size of tropical zooplankton. Both characteristics have been explained by a number of factors from high temperatures to predation from fish all year long. However, due to this lake's isolation from rivers, there is an absence of fish. Other common invertebrate predators, such as *Chaoborus* larvae (Chaoboridae: Diptera) are also missing. Further study of the trophic web in this lake may yield better understanding of tropical plankton communities.

Tadpoles were fairly abundant in the open water of the lake at the time of sampling. We examined the gut contents of one specimen to see whether they were predating on zooplankton. It's content consisted mainly of vegetal detritus, cells of *A. bifidus, Oocystis* sp., *Phacus* sp., *Cynomatopleura* sp., bits of filaments of *Oedogonium* sp. and *Lygbya* sp., but also carapaces of cladocerans and exosqueletons of Oligochaeta. All these suggest that tadpoles are mainly feeding by scraping the 'Aufwuchs' although they may consume organisms which are typicaly planktonic.

Cerro Chato lake is similar to other crater lakes in its low conductivity, low pH and general morphometry. However its low elevation, compared to other crater lakes is an important factor determining its differences, accounting for greater stratification and higher temperatures compared to lakes Botos and Barva. It is also necessary to study the possible seasonality of stratification and planktonic populations, since few crater lakes have been studied for long periods of time in the tropics.

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RESUMEN

El lago de Cerro Chato se visitó varias veces en 1992 para estudiar su limnología básica. El lago se localiza en un antíguo crater a una altitud intermedia (1020 m) en Costa Rica, América Central. Tiene paredes empinadas y alcanza una profundidad máxima de 18.8 m. No posee salida superficial, sin embargo el agua posee una baja concentración de solutos, posiblemente como resultado de una alta tasa de renovación del agua por la alta precipitation, la cual se pierde por infiltración. La columna de agua estuvo siempre estratificada con una curva de oxígeno tipo ortogrado y condiciones anóxicas en el fondo. El fitoplancton se compuso principalmente de clorofitas y otras algas de tamaño pequeño, para un total de 43 especies. La diversidad fue baja debido a la alta dominancia de *Arthrodesmus bifidus.* El zooplancton está dominado por *Tropocyclops prasinus prasinus* e incluye también cuatro especies de cladoceros. No se observaron filtradores grandes en el zooplancton; esto puede explicar la dominancia de algas de tamaño pequeño en el fitoplancton.

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