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Cultural eutrophication of a Ugandan highland crater lake: a 25-year comparison of limnological parameters

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Introduction

Volcanic crater lakes are widely distributed throughout the tropics. Although early limnological expeditions to East Africa focused on large spectacular lakes, the SUNDA expedition of 1928–29 paid particular attention to crater lakes throughout Indonesia (RUTTNER 1931, CRISMAN & STREEVER 1996). A modest resurvey of the Indonesian crater lakes has been conducted (GREEN et al. 1996). In spite of early surveys (JUDAY 1915, DEEVEY 1957), interest in Central American crater lakes has lagged until recently (BARLOW et al. 1976, JIMENEZ & SPRINGER 1994, UMANA & JIMENEZ 1995).

Our understanding of crater lakes in Ghana (WHYTE 1975) and Cameroon (KLING 1988) in West Africa and Ethiopia (WOOD et al. 1984, GREEN 1986, ZINABU 1994) and Kenya (MELACK 1996) in East Africa is slowly developing. The earliest investigations on crater lakes in Uganda were by BEADLE (1932, 1963, 1966). Later, MELACK (1978) surveyed the four geographic clusters of crater lakes in western Uganda and divided the 89 lakes into broad groups, saline lakes (conductivity >15,000 µmhos/cm) and dilute lakes (conductivity <1,000 µmhos/cm). Recent investigations on dilute crater lakes of the western Ugandan Highlands near Fort Portal have been focused on physical/chemical parameters (KIZITO et al. 1993, CHAPMAN et al. 1998, LIVINGSTONE unpublished) and plankton (KIZITO & NAUWERCK 1995).

Dilute crater lakes serve as an important water supply for human populations in rural areas of western Uganda. With a 3.4%/annum growth rate in the human population and an associated deforestation rate of 1.3%/annum, the quality of this essential water supply is in danger (KAUFMAN et al. 1996). Forests are currently being cleared even on the steepest crater walls for agriculture and firewood.

The purpose of the current paper is to present the initial results from a limnological/paleolimnological investigation of one of the few eutrophic crater lakes in western Uganda. We present a 3-year database for dissolved oxygen and temperature for multiple sites within the basin and compare these with historical data collected by MELACK in 1971. Possible landscape modifications are discussed as causal mechanisms for the observed eutrophication.

Site description and methods

Lake Saka (0° 40' N and 30° 15' E, elevation 1,520 m) lies at the northernmost extreme of the crater lakes in western Uganda, and has maximum dimensions of 1.4 km long and 1.0 km wide (Fig. 1). A small crater forms an embayment at the southeast corner of the lake, and is surrounded by a weakly developed rim 3–15 m in height (MELACK 1978). Several wetlands drain into the lake, and the drainage basin has been almost totally cleared for agricultural production by subsistence farmers and a large Ugandan government prison farm. Nile perch (*Lates niloticus*) were stocked into the lake in the early 1970s.

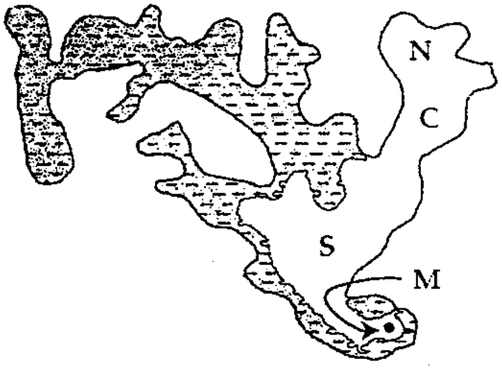

Fig. 1. Locations of northern (N), central (C), and southern (S) sampling stations of the current study of Lake Saka, Uganda. The historical station of Melack is indicated by M.

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Three sites were monitored in Lake Saka (Fig. 1). Temperature and dissolved oxygen profiles were constructed for the northern (2 m deep) and central (3 m deep) sites based on monthly monitoring (July 1995–January 1998) using a YSI meter (Model 51B or 95). Secchi transparency and water level fluctuations were reported monthly, and conductivity and pH were recorded periodically. A third station at the southern end of the lake (8 m deep) was added to this monitoring regime for the period July 1997 to January 1998.

Results

Water level fluctuations were estimated from monthly measurements on a fixed marker (Fig. 2). Maximum fluctuation in water level in Lake Saka was less than 1 m from September 1995 through January 1998. Water level extremes corresponded roughly to the bimodal pattern of annual dry periods (May–August and December–February) for western Uganda. Our lowest lake level (February–March 1997) coincided with the period of least rainfall during the study period (Chapman & Chapman unpublished data).

Conductivity and pH were collected sporadically during the study period. Mean pH during the period July 1995–January 1998 was 7.7 for all stations, compared with 7.2 reported by Kilham (1971) and 7.34 by Melack (1978). Conductivity during our study was measured during August 1997 (low water) and December 1997 (high water). Mean water column values for the north, central and southern sites during August were 614, 563 and 623 µmhos/cm and 583, 580 and 584 µmhos/cm for December, respectively. Kilham (1971) and Melack (1978) reported 535 and 532 µmhos/cm for the southeastern embayment of the lake. It appears that pH has remained roughly the same, while conductivity has increased since the early 1970s.

No clear pattern between Secchi transparency and water level was evident from our database (Fig. 2). Secchi transparency ranged from 30 to 70 cm and tended to decrease progressively throughout the study period. Melack (1978) reported a mean Secchi reading for noon during his week-long survey of Saka during May 1971 of 65 cm, compared to a noon reading during May 1996 of 49 cm for the northern and 44 cm for the central stations during the current study. Mean Secchi readings for July 1995–January 1998 at the northern, central and southern stations of Lake Saka were 45, 47 and 45 cm, respectively. It appears that the lake has become more turbid during the past three decades, presumably associated with enhanced phytoplankton production.

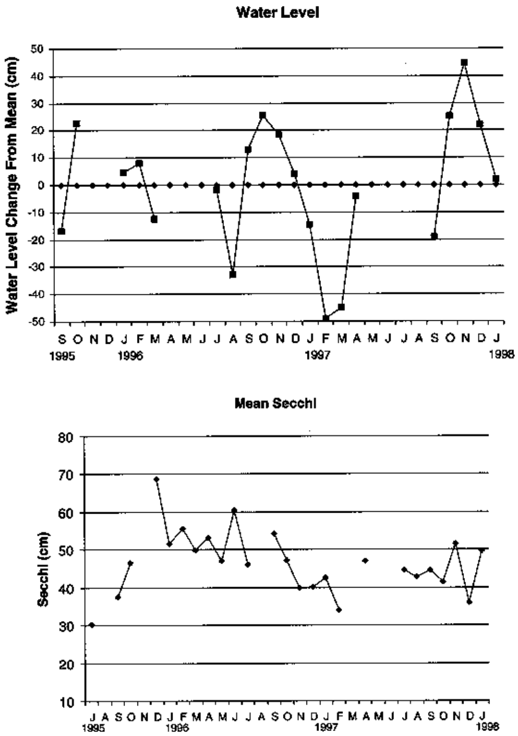

Fig. 2. Monthly water and Secchi depth transparency levels.

Water temperature displayed less than 5 °C water column variance throughout the study (Fig. 3). Seasonally, temperatures were generally highest (25 °C) during low water (dry season) periods (Fig. 2). Dissolved oxygen maxima at all three stations tended to occur during periods of lowest water temperature, the rainy season (Fig. 4). Water column anoxia was never reported for the northern station (2 m), but was found for one date at the central station (3 m), and four dates for the southern station (12 m).

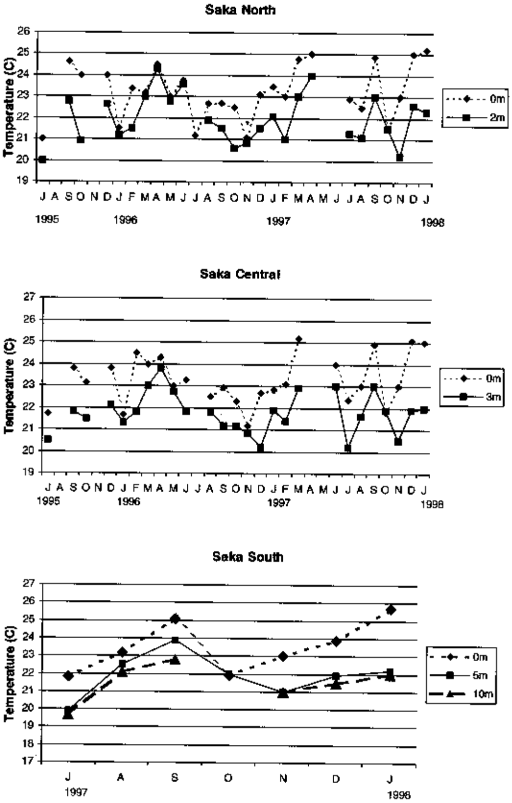

Fig. 3. Variations in water temperatures at the three sites.

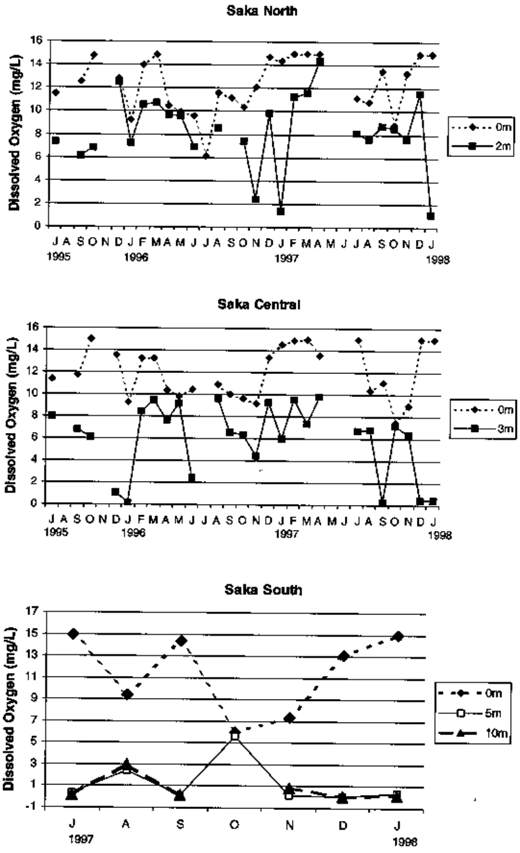

Fig. 4. Dissolved oxygen levels at the three sites.

Hypoxic conditions, however, were common near the bottom (3 m) of the central site, especially during December–January of 1995–96 and 1997–98. The southern site was essentially anoxic below 5 m on all dates of 1997–98 except one.

A mean oxygen profile was developed for May 1971 from noon time values collected during a week in the crater embayment at the southeastern corner of the lake by MELACK (1978) and compared with a noon profile from the center of the lake for one date in May 1996 (Fig. 5). Only the surface and at 0.5 m displayed oxygen supersaturation (110% and 108%, respectively) during May 1971, and total anoxia was noted below 4 m depth. Although the May 1996 profile was only 3 m deep, supersaturation ranged from 120% at the surface to 115% at 3 m. In addition, dissolved oxygen in surface waters often exceeded 15 mg/L (180% saturation) at all stations during 1995–1998. In total, these data are suggestive of enhanced phytoplankton productivity in surface waters during the past 25 years.

Discussion

Based on preliminary comparison of historical and current data, it appears that Lake Saka has been undergoing cultural eutrophication since at least the early 1970s. Conductivity has increased, Secchi decreased, and the dissolved oxygen supersaturation of surficial waters has increased markedly suggesting elevated phytoplankton productivity. The presumed recent eutrophication of Lake Saka is also supported

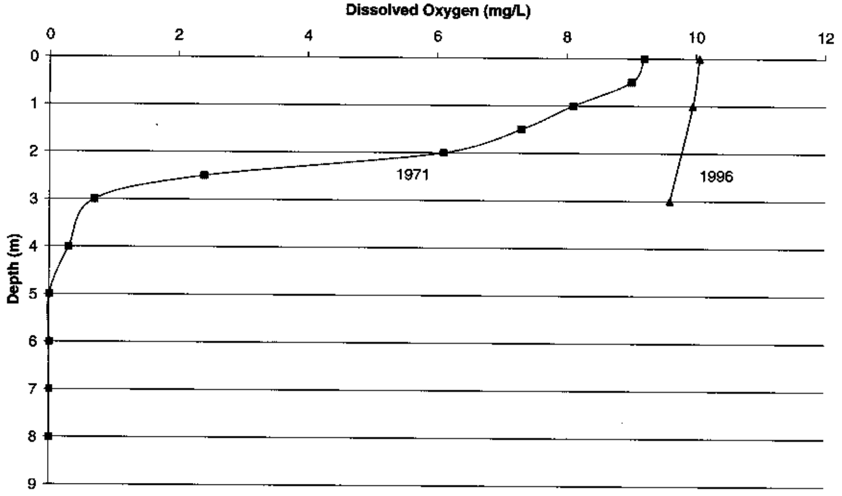

Fig. 5. Noon profiles of dissolved oxygen developed for May 1971 and May 1996.

by the personal observations of a priest who has lived on the lake since the 1960s and has noticed a recent increase of algal blooms.

Several factors have likely contributed to a change in lake trophic state. A Ugandan government prison farm along the southeastern shore of the lake has expanded its operation within the past decade. Row crops are planted on the exterior flanks of an old crater perpendicular to the summit to maximize inmate observation. Such planting against elevation contours has facilitated erosion and possibly increased inorganic and nutrient loading to the lake. Based on examination of governmental maps, extensive drainage of wetlands within the catchment has occurred between 1961 and 1996. In addition to the loss of two small wetlands adjacent to the prison farm, a wetland almost twice the size of the lake and bordering the north shore was also drained, most likely for agricultural production. Finally, the lake was stocked with Nile perch (*Lates niloticus*) in the early 1970s. If Lake Saka responds to such introductions as Lake Victoria has (Goldschmidt et al. 1993) serious food web alterations could have taken place leading to the observed increase in trophic state.

Rapidly increasing human populations and their associated need for expanded agricultural production and firewood has resulted in pronounced land clearance on even the steepest crater walls in Uganda (Chapman & Crisman personal observation). In Ethiopia, such increased human pressures have resulted in pronounced cultural eutrophication of crater lakes (Green 1986, Zinabu 1994). Throughout the tropics, including Uganda, crater lakes are a significant water supply for rural populations. Unfortunately, we do not have sufficient data to formulate sound management plans for the crater lakes of Uganda. It is hoped that our ongoing study of Lake Saka and other western Ugandan crater lakes will help in this endeavor.

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