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BATHYMETRY OF LAKE BOGORIA, KENYA

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ABSTRACT

This paper presents the first bathymetric map for the approximately 17 km by 2 km alkaline Lake Bogoria situated in the eastern Rift Valley of Kenya. Longitudinal and transverse cross sections of the lake are also provided. Northern, central and southern basins of the lake had maximum depths of 5.9 m, 10.2 m and 8.4 m respectively. Average depth was 5.68 m and volume was calculated to be 164 $x10^6$ m^3.

INTRODUCTION

Lake Bogoria is situated at 0º 16′ N and 36º 06′ E, 240 km north of Nairobi in the floor of the eastern Rift valley of Kenya, and has an elevation of approximately 980 m (a.s.l.). It is a closed-basin alkaline saline lake with many boiling springs and fumaroles present along its shores (Cioni *et al.*, 1992). Principal freshwater inflows comprise two perennial, spring-fed streams at the southern end of the lake and the seasonal Waseges-Sandai River to the north. The lake forms part of the Lake Bogoria National Reserve which not only is a popular tourist destination but also provides resources such as grazing and access to medicinal plants for the local community (Jones, 2000). The Reserve is a proposed World Heritage Site, an Integrated Management Plan is in preparation and a community based Wetlands Conservation Project has been initiated (Wetlands International, 2003).

Lake Bogoria is one of the lakes upon which the lesser flamingo (*Phoeniconaias minor* Gray) depends for its life strategy, making it an important aquatic resource. The lake usually supports dense blooms of the cyanobacterium *Spirulina platensis* (Nordst.) Geitl., principal food of the lesser flamingo. Up to 1,074,000 flamingos, 98.8% of the central Rift population, have been counted on Lake Bogoria at any one time. (Owino *et al.*, 2001).

In 1988 the International Lake Environment Committee Foundation (ILEC), in co-operation with the United Nations Environment Programme (UNEP), started a data collection project to gather basic information on natural and artificial lakes and its World Lakes

Database (ILEC, 2001) now holds data on more than 500 lakes in 73 countries. An attempt is being made by ILEC to update the information on lakes covered by the database and additional information has been requested. For Lake Bogoria the currently available information on bathymetry is limited to figures for mean and maximum depth of 5.4 m and 10 m respectively.

One of the most diagnostic physical features of a lake is its depth with knowledge of such being an important tool for the limnologist. Accordingly, the purpose of this paper is to place previously unavailable information on the bathymetry of Lake Bogoria into the domain of future researchers. At the present time, ongoing work includes: organic inputs (authors), primary production (Mills, pers. comm.), secondary production (Otieno, pers. comm.), flamingo ecology (Childress, pers. comm.), climate change indicators (Verschuren, pers. comm.).

METHODS

Lake Bogoria was surveyed during the period 16–26 August 2002 using a Lowrance X-15A chart recording echo-sounder with a 20° transducer beam as used previously by Hickley *et al.* (2002) to determine the depth of Lake Naivasha. The soundings were carried out in calm conditions from a small boat driven at constant speed along transect lines (figure 1), the positions of which were monitored with a Garmin 12 hand held GPS receiver running 4.59 software. To optimise the yield of the survey in terms of accuracy, the recommended system

Transect No.	Eastings		Northings		Transect Length (m)
	Start	Finish	Start	Finish	
WE 1	174255	175625	36282	36862	1607
WE 2	174082	176273	35549	35603	2247
WE 3	174671	175546	33886	34470	1054
WE 4	175113	175566	33704	33983	532
WE 5	175243	175581	33431	33527	352
WE 6	175297	175755	32887	33054	490
WE 7	175459	176127	32471	32691	703
WE 8	175945	177632	30577	31067	1758
WE 9	175588	179045	29456	29889	3521
WE 10	175610	178674	28127	28605	3130
WE 11	176318	178759	27195	27503	2471
WE 12	176331	178888	25803	26597	2684
WE 13	176925	179493	24448	25247	2691
WE 14	178267	179408	22735	23854	1599
WE 15	179334	179467	22494	22456	140
WE 16	178385	179722	21272	21378	1361
WE 17	174786	175558	33847	34004	788
SN 1	175571	174430	32996	36620	3826
SN 2	175263	175246	33801	36784	2986
SN 3	177413	175426	26740	33581	7143
SN 4	178824	175570	26636	34485	8747
SN 5	178192	177105	24141	27615	3642
SN 6	178267	177592	22735	27000	4540
SN 7	178497	178190	20748	24467	4298
Total all transects					62310

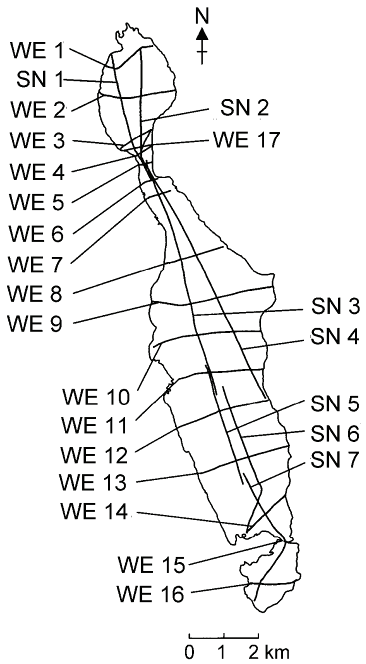

Figure 1. Locations of echo-sounding transects used to produce depth profiles and bathymetric map for Lake Bogoria. eastings (mE) and northings (mN) are GPS co-ordinates within the UTM grid zone 37N.

of tracks crossing the main track was used (Håkanson, 1981). For each paper echo-recording chart, the positions along the transect line at which the depths of 1 m, 2 m, *etc.* and maximum depth occurred were converted by interpolation to UTM grid readings. The mE and mN values were then plotted as x:y co-ordinates on a plan outline of the lake. Mathematical interpolation not being necessary (Håkanson, 1981), these spot depths were joined using best fit by eye to form contour lines. The lake outline was derived from Survey of Kenya 1:50,000 scale maps made in 1973 and based on aerial photographs taken during January – February 1969. To produce depth profiles for each transect line, actual depths to the nearest 0.1 ft (3 cm) were read at 10 m intervals from the echo-recording charts. Morphometrical values were determined according to Håkanson (1981).

RESULTS

A summary of morphometrical data for Lake Bogoria is given in table 1. A bathymetric map is presented in figure 2 and shows the lake to comprise northern, central and southern basins, the northern being the shallowest. Bed profiles are shown in figure 3 (longitudinal), in figure 4 (transverse) and, as an example of where the bed appeared noticeably undulating, in figure 5. The hypsographic curve and associated depth distributions are given in figure 6, indicating the lake form to be Lme (Linear meso (Håkanson,1977)). By way of a benchmark for the shoreline at the time of the echosounder survey, the waters edge was 45.6 m distant from the highest-spouting geyser (GPS reading: 0028028 mE, 0175457 mN) which is located about halfway along the western shore in the area referred to as the Hot Springs.

Table 1. Morphometrical data for Lake Bogoria, Kenya, August 2002.

Parameter	Unit	Value
Maximum length	km	17.25
Maximum width	km	3.75
Mean width	km	1.68
Maximum depth	m	10.2
Mean depth	m	5.68
Modal depth	m	7.8
Median depth D_{50}	m	6.49
1st quartile depth D_{25}	m	4.81
3rd quartile depth D_{75}	m	8.16
Shoreline length	km	44.0
Lake area	km^2	28.95
Volume	$m^3 \times 10^6$	164.4

DISCUSSION

Some of the morphometrics of three basins, such as the steep gradients on the eastern side, are likely to be symptomatic of the lake being situated in a region of notable faulting and volcanic activity (Young *et al.*, 1991; Grimaud *et al.*, 1994). The strong variations in depth which occurred in places (figure 5), and which were up to 2 m vertical per 100 m horizontal, are not an artefact of the echo-sounding technique. The calm conditions in which the survey was carried out, the use of a wide (20°) transducer beam and the occurrence of

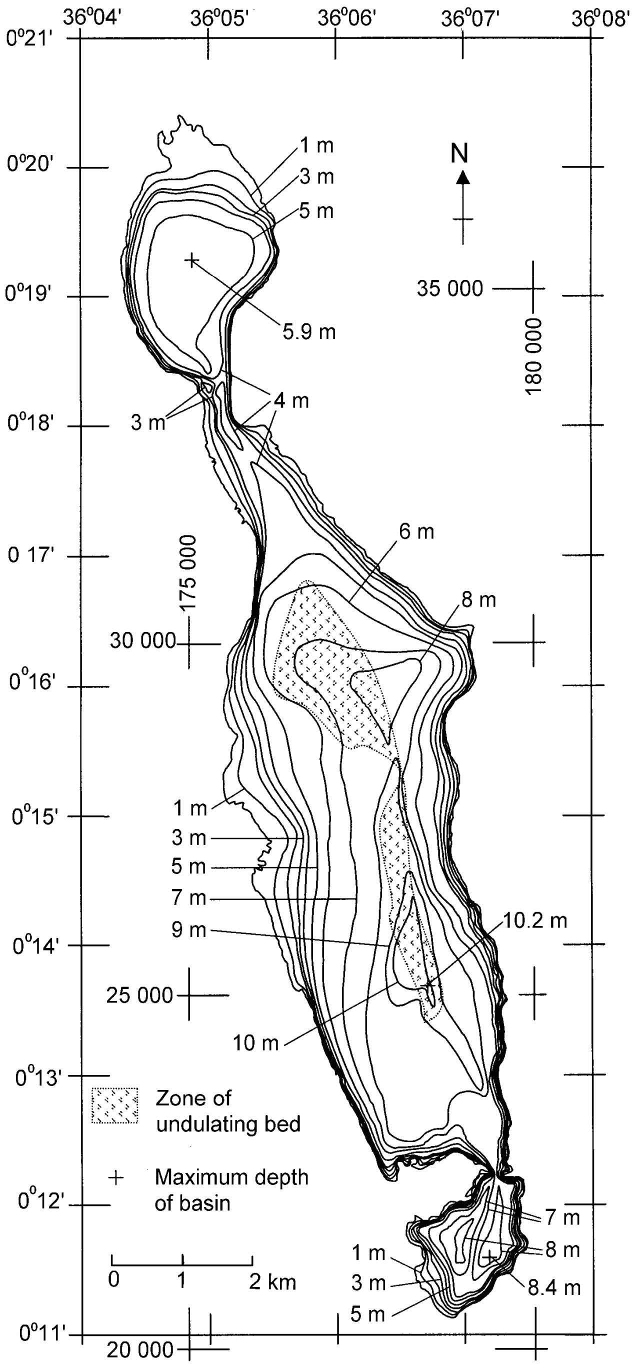

Figure 2. Bathymetric map of Lake Bogoria (August 2002) showing 1 m contour lines together with maximum depths for northern, central and southern basins. The shaded zone of undulating bed is an area where the lake bottom was noticeably more uneven than elsewhere. The frame shows latitude and longitude co-ordinates. Also marked are representative mE and mN intersections of the UTM grid as used in figure 1.

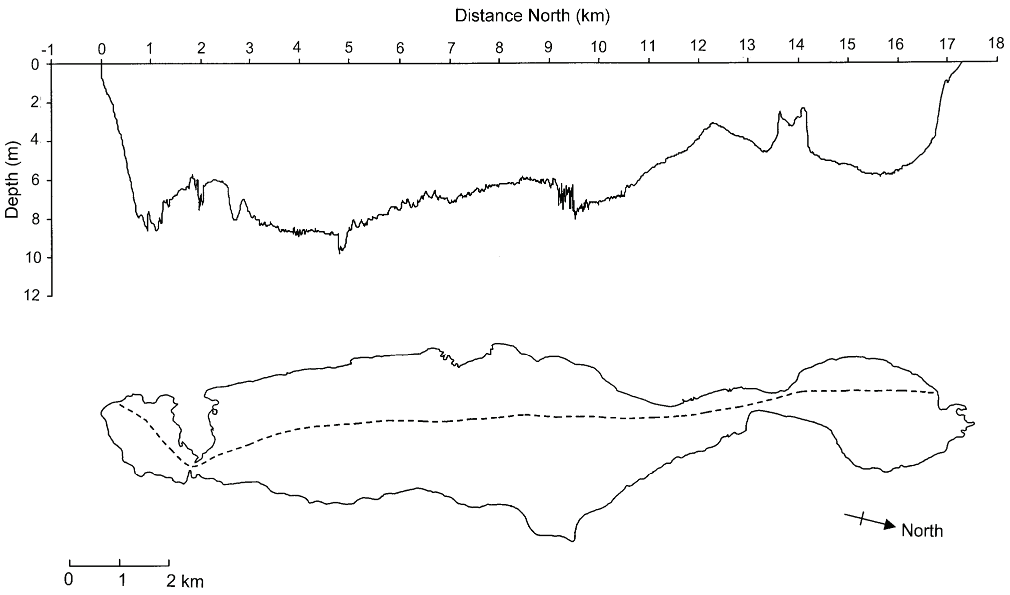

Figure 3. South to North depth profile of Lake Bogoria (August 2002). The dotted line within the lake outline marks the position of the profile that was derived from transect lines SN1, SN3, SN5 and SN7 (figure1).

smooth sections of lake bed on the continuously recorded echograms for all transects confirm the reality of the undulations. These undulations are less likely to represent structural geology than they are to reflect long term patterns in sedimentation caused by currents generated by underwater, geothermal springs and wave action. Recent local faulting, however, has made a noticeable contribution to bed morphology, with the leading fault being N-S on the eastern shore. Transects WE 6, 7 & 8 (figure 4) show good examples on their eastern sides of a consistent break in slope.

The accuracy of the volume estimate for subsequent limnological calculations will depend upon the amount of annual variation in lake level that is likely to occur. Although Lake Bogoria is the only alkaline lake within the Rift Valley that has relatively negligible water level fluctuations (Wetlands International, 2003), a consequence of step-faulting within the region is a poor supply of water from a small catchment area (Onywere *et al.*, 1996). Accordingly, lake levels are likely to be linked closely to local rainfall patterns. Indeed, the seasonal Wasengas-Sandai river was noted to have zero flow at both the time of the August 2002 survey and the same time the previous year.

Twenty-five years (1977–2001) of daily precipitation records from a rain gauge located within the Lake Bogoria National Reserve (0° 21′ N, 36° 04′ E) have been collated by LaVigne and Ashley (2001). Annual average precipitation over the period was 708.3 mm, distributed bimodally throughout the year. The wettest year was 1977 (1053.4 mm) and the driest was 1984 (243.1 mm). These local rainfall patterns are likely to have been influenced by the effects in East Africa of El Niño and La Niña events (Ogallo, 1987; Nicholson, 1996; Nicholson & Selato, 2000) but is also complicated by the topography of the Rift Valley which widens in a triangular shape northwards with escarpments and mountain ranges rising from its widened floor. Evapotranspiration is high at *c.* 2500 mm/yr. Some variation in lake level was observed in the three years prior to the bathymetric survey. This was very noticeable at the northern end of the lake where the gradient was slight but much less so

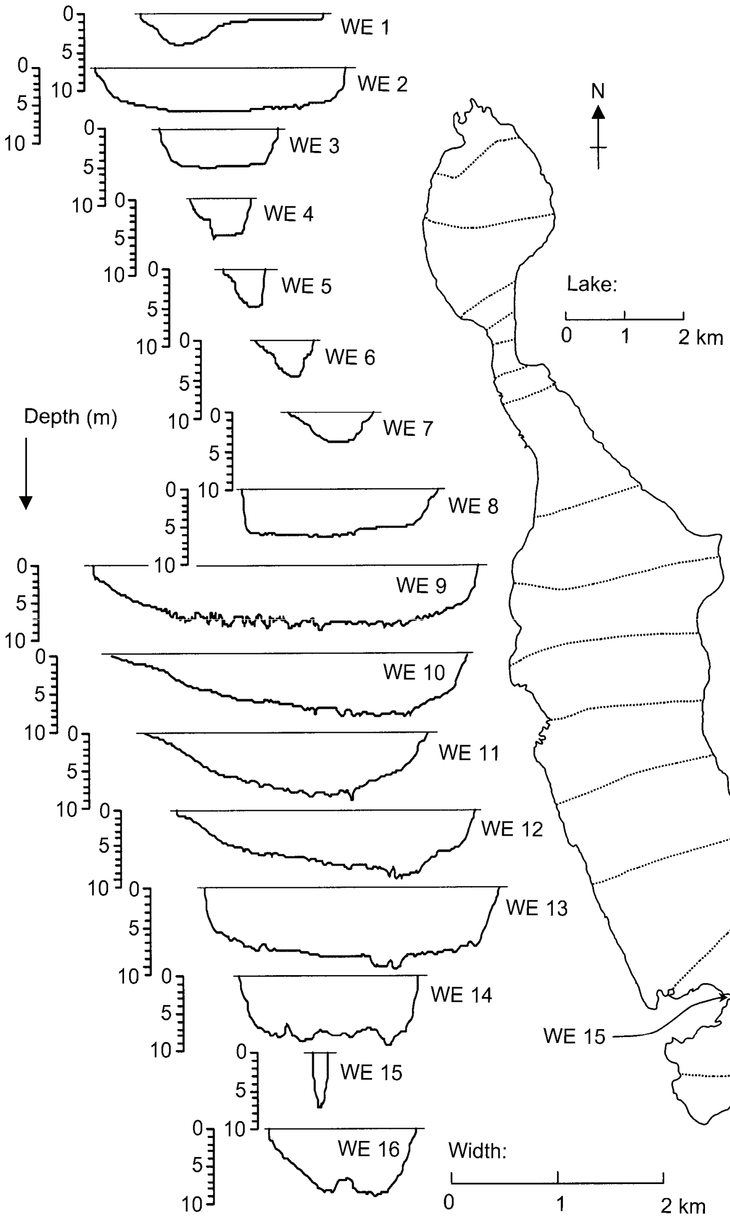

Figure 4. West to East depth profiles of lake Bogoria (August 2002). The dotted lines within the lake outline mark the positions of the profiles where WE1-WE16 are transect lines as shown in figure 1.

elsewhere. Aerial photographs taken in September 1999 (plate 1) and August 2001 (plate 2), when precipitation in the preceding 3 months was 227 mm and 87 mm respectively, show that the northern lake edge was 280 m further receded in the drier of the two years. At the time of the echosounder survey in August 2002, the lake was even shallower (plate 3) with

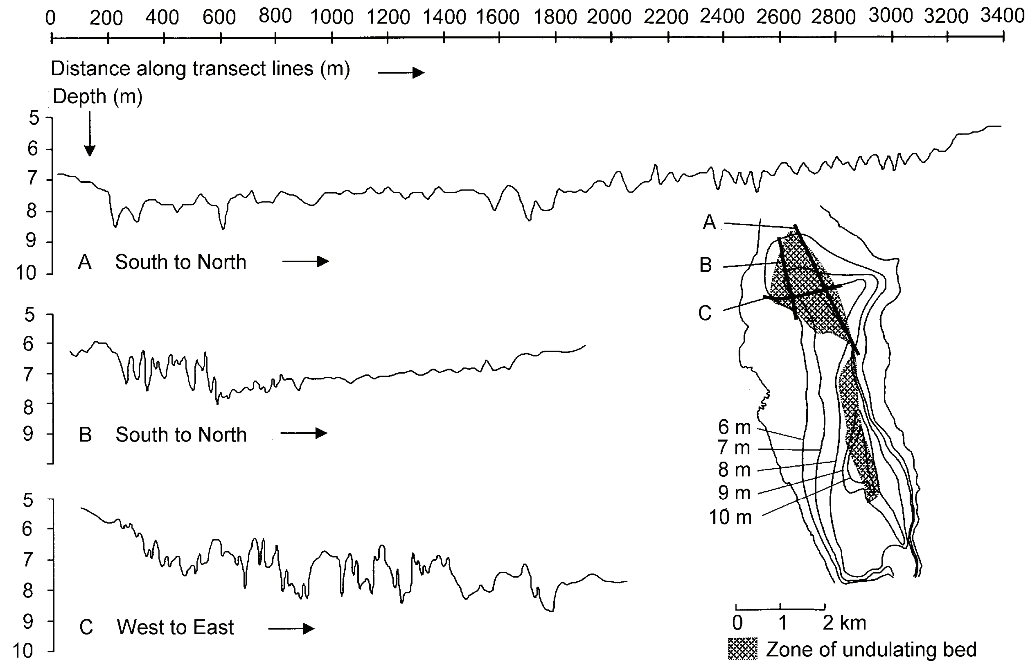

Figure 5. Examples of bottom profiles of Lake Bogoria in the zone of undulating bed. Positions of the profiles are marked on the selected portion of the bathymetric map as solid lines A, B and C.

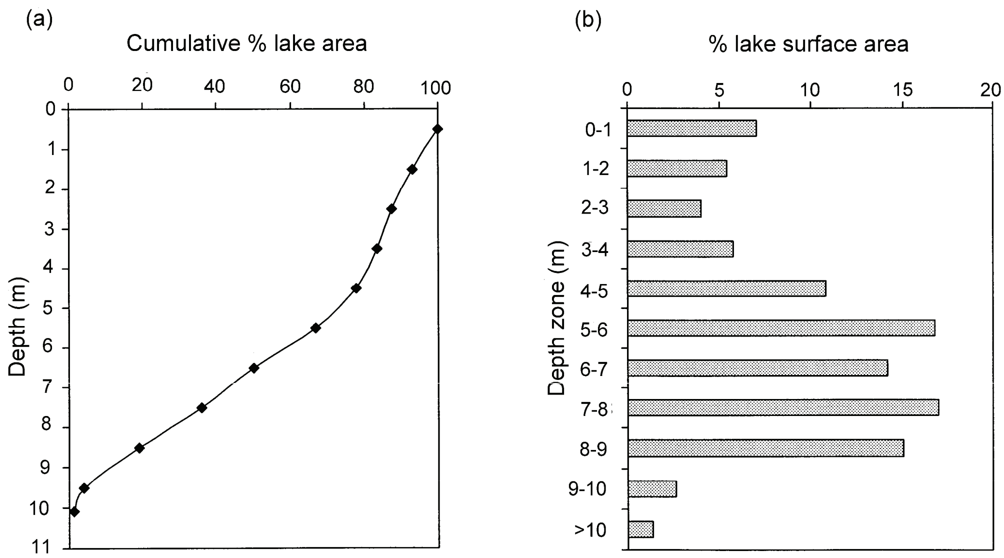

Figure 6. (a) Percentage hypsographic curve and (b) Percentage of lake area underlain by each depth zone for lake Bogoria (August 2002).

Plate 1. Aerial view across the northern end of lake Bogoria looking towards the eastern shore in September 1999. Top left is a partially inundated belt of riparian trees along the Waseges-Sandai river. The solid and open circles mark positions on the shore that are also marked in Plates 2 and 3. The pale dots scattered all over the water surface are lesser flamingos. (Photograph by P. Hickley)

Plate 2. Aerial view across the northern end of lake Bogoria looking towards the eastern shore in August 2001. The solid and open circles mark positions on the shore that are also marked in Plates 1 and 3. The dotted lines show the approximate position of the water's edge in September 1999 (Plate 1). (Photograph by P. Hickley)

Plate 3. Aerial view across the northern end of lake Bogoria looking towards the eastern shore in August 2002. The solid and open circles mark positions on the shore that are also marked in Plates 1 and 2. The dotted line shows the approximate position of the water's edge in August 2001 (Plate 2). (Photograph by P. Hickley)

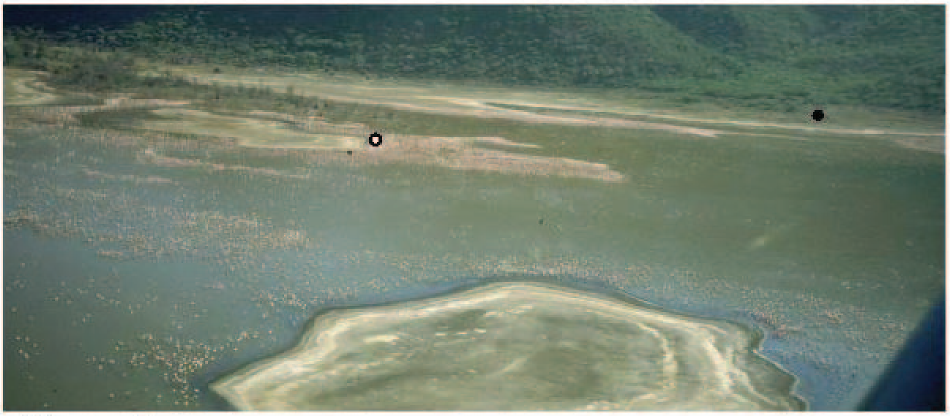

Plate I

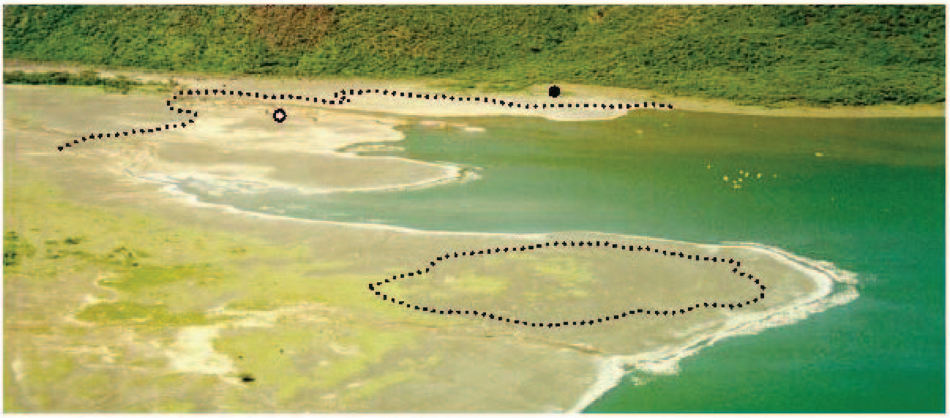

Plate II

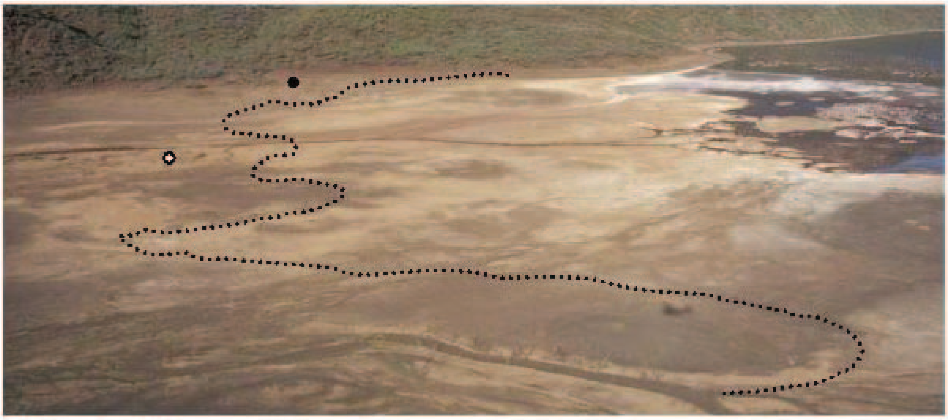

Plate III

the northern lake edge being 190 m further down the shore than in August 2001, 470 m further than September 1999. On that part of the western shore with the shallowest gradient, about midway along, the shoreline receded approximately 50 m in the same three-year period. Although seemingly dramatic to the casual observer, the impact of these changes in level on lake area was a reduction of less than 5%, this because, in contrast with the above, the position of the shoreline around the rest of the lake with its steeper gradients receded only 5–10 m. Moreover, and importantly, from checks made against GPS readings the position of the lake edge at the time of the echosounder survey aligned closely to the outline used for the bathymetric map.

The difference in lake level observed during the period September 1999 to August 2002 was calculated to represent a 7.4×10^6 m^3 (4.5%) reduction in lake volume. Direct implications for lake ecology of any such reduction in volume include changes in the behaviour and distribution of flamingo with indirect impacts on ecology being linked to primary production by *S. platensis* through changes in lake chemistry and mixing of the water column (Harper *et al.*, 2003). Also, exposure of the shallow gradient on the western shore creates opportunity for colonization by the dominant shoreline grass, *Sporobolus spicatus* Kunth although simultaneous drying of seasonal freshwater inflows would presumably reduce the contribution to primary production on the lake shore by the important sedge-dominated (*Cyperus rubicundus* Vahl and *C. laevigatus* L.) community. On the much steeper eastern shoreline where the plant community is dominated by *Acacia* and *Commiphora* species on unstable slopes, changes in water level will have comparatively small implications for riparian primary production.

Some of the alkaline lakes of the Rift Valley are known to have periods of significant reduction in size. Lake Nakuru, for example, dried out twice during the 1990s (Nasirwa, 2000) although such an event is much less likely to happen to Lake Bogoria since it has been the most stable of the alkaline lakes within Kenya (Wetlands International, 2003). Notwithstanding the likelihood, when Lake Nakuru was being studied in the 1970s, Lake Bogoria was reported by Vareschi (1978) to be 12 m deep, 2 m deeper than now.

The outcome of the above echo-sounding survey has been to provide the first satisfactory description of the bathymetry of Lake Bogoria, Kenya. Such information should be of value to subsequent limnological and ecosystem research.

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