Ostrich 2007, 78(2): 463–468
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OSTRICH
EISSN 1727–947X
doi: 10.2989/OSTRICH.2007.78.2.55.135

# East African flyway and key site network of the Lesser Flamingo (*Phoenicopterus minor*) documented through satellite tracking

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In October 2002, four adult Lesser Flamingos were tagged at Lake Bogoria, Kenya: two with solar-powered platform transmitter terminals (PTTs) and two with battery-powered PTTs, one of which stopped transmitting after 38d. In July 2003, an additional four birds were tagged with solar-powered PTTs. During the first two years (November 2003–October 2004), flight patterns of the tagged birds were independent. Interlake flight distances ranged from 16–441km (mean: 111.5km, n = 243), 68.3% being less than 100km and 96% less than 300km. There was no significant difference among the birds in the median length of their interlake flights. The number of days spent at each stopover ranged from 0 (less than 1d) to 153d (mean: 14.4d, n = 250). There was a significant difference among the birds in the number of days spent at each stopover. This difference was due to one very active bird that made 133 interlake flights during the period, visiting 12 different sites, spending a mean 5.2d at each site and travelling 12 600km. There was no significant difference among the other six birds. The seven birds' flights were confined to a 940km north-south range within the Great Rift Valley between Lake Logipi in northern Kenya and Bahi Swamp in central Tanzania. Their key site network consisted of eight alkaline lakes (Logipi, Bogoria, Elmenteita, Nakuru, Natron, Empakai Crater Lake, Manyara and Eyasi), and Lake Bahi, a seasonal lake in central Tanzania. The conservation status of these nine sites varies from well-protected to completely unprotected. None of the birds appears to have bred during either the 2002–2003 or the 2003–2004 breeding seasons (October–January), although other Lesser Flamingos bred at Lake Natron during both seasons, Lake Natron being the only East African site where the Lesser Flamingo has bred successfully during the past 45 years.

## Introduction

The Lesser Flamingo (*Phoenicopterus minor*) is the smallest and most numerous of the world's six flamingo species. It occurs in four regional populations in Africa and central Asia, the largest of which (1.5–2.5 million birds) occurs on the alkaline lakes of East Africa (Wetlands International 2006). Hundreds of thousands frequently gather on Lakes Bogoria and Nakuru in Kenya, and Lake Manyara in Tanzania (Brown 1975, Vareschi 1978, Howard 1994), creating spectacles that are vital to ecotourism in this region.

Despite its large numbers, the species is classified as Near Threatened, due to its dependence on a limited number of breeding sites and a narrow range of required breeding conditions that occur irregularly and infrequently (BirdLife International 2000). The East African population is only known to have bred successfully at one location during the past 45 years — Lake Natron in Tanzania — and this lake on the border with Kenya is unprotected. Schemes like the recently proposed soda-ash extraction business and hydroelectric power generation at Lake Natron could result in degradation of this lake and rapid population declines for the Lesser Flamingo in East Africa (BirdLife International 2000).

The Lesser Flamingo is a highly itinerant species (Evans 1985), moving frequently and unpredictably from lake to lake within the Great Rift Valley (Brown 1975, Vareschi 1978, Tuite 1979, Brown *et al*. 1982, Tuite 2000), and between salt pans and other wetlands in southern Africa (Borello *et al.* 1998, McCulloch *et al.* 2003), but returning to the same breeding sites. Traditionally, the frequent interlake movements have been thought to be associated with fluctuation in food abundance (Vareschi 1978, Tuite 1979). However, it is not clear that this alone is responsible. At Lake Bogoria, the Lesser Flamingo population can double or halve during periods as short as two weeks, despite an almost constant density of *Arthrospira fusiformis*, the Lesser Flamingo's primary food (Brown 1975, Vareschi 1978, BC unpublished data). Other hypotheses have included: changes in fresh-water availability or lake-water conductivity, movement to breeding sites, and disturbance by predators (Vareschi 1978).

Historically, it was thought that the three African populations were separate and that no regular interchange took place (Brown 1973). However, circumstantial evidence has been assembled to show that East African Lesser Flamingos may fly to Botswana and Namibia to breed during periods when the Etosha and Makgadikgadi salt pans are flooded (Tuite 1979, Borello *et al*. 1998, McCulloch and Borello 2000, Simmons 2000), and that there may be interchange

between the western and other African populations (Trolliet and Fouquet 2001). Still, very little is known about the movements of individual Lesser Flamingos. Only McCulloch *et al.* (2003) have used satellite tracking previously, following three Lesser Flamingos in southern Africa.

The primary aim of this multi-year study was to use satellite tracking to document the flyway and key site network used by this near-threatened species in East Africa during different periods of the year, in order to support the development of an effective international site conservation plan. Secondary aims were to improve our understanding of the movements of individual Lesser Flamingos and document whether there is any regular interchange between the East African population and the smaller populations elsewhere in Africa and India.

## Methods

### Study site

The birds were tagged at Lake Bogoria, Kenya (0°11–20'N, 36°06'E), located within the Lake Bogoria National Reserve, a protected area of 10 700ha (Bennun and Njoroge 1999), 64km north of Nakuru town in the eastern Great Rift Valley (Figure 3). Designated a Ramsar wetland of international importance in 2001, Lake Bogoria is one of the two main feeding lakes for the Lesser Flamingo in Kenya. It is a long (16km), narrow (3km), shallow (maximum depth 10.2m), alkaline (1 160 ± 14.2 meq $l^{-1}$) lake with a pH of 10.2–10.3 situated at 975m asl (Vareschi 1978, Harper *et al.* 2003).

### Bird capture

The birds were captured using loops of 50lb test polyethylene fishing line attached to a 120 x 245 wire mesh grid consisting of 3mm wires in 7.5cm squares (Childress *et al.* 2004). Approximately 50 loops were tied to the grid, which was placed in the water perpendicular to the shoreline in a shallow flat area where flamingos gathered and walked back and forth. The birds were captured when their feet became entangled in the loops.

### Transmitters and harnesses

Four adult male Lesser Flamingos were captured and tagged with PTTs in October 2002, and another four were tagged in June–July 2003. The initial four birds were tagged with two battery-operated PTTs and two solar-powered PTTs. The two battery-powered PTTs were supplied by Microwave Telemetry Inc. They were 45g PTT–100 units with estimated transmission lifetimes of 1 200h. The preset duty cycle specified for both was 8h on–60h off, which was estimated to result in operational periods of approximately 15 months. These units represented 2.2% and 2.3% of the body mass of the birds to which they were affixed. The two solar-powered PTTs had been reconditioned by their manufacturers, North Star Science and Technology LLC and Microwave Telemetry Inc., respectively. The North Star unit weighed 40g and its duty cycle was preset to be 8h on–18h off. As a test, the Microwave Telemetry PTT (weight 35g) had no preset duty cycle. With no preset duty cycle, the PTT shuts itself off when its battery power is low, and then restarts automatically every 6h. If its battery has recharged sufficiently, it continues to transmit; if not, it shuts down for another 6h. These PTTs represented 1.9% and 1.6%, respectively, of the body mass of the birds to which they were affixed and were expected to have operational lifetimes of 3–5 years.

The PTTs were affixed to the birds using a 'backpack' harness especially designed for multi-year studies of large birds such as storks and flamingos (van den Bossche 2002). It consisted of 3mm braided nylon cord inside a Teflon sleeve (Childress *et al.* 2004). The PTTs were positioned as high as possible on the birds' backs, and we fitted the harness to allow all four fingers of a flat hand to pass easily between the unit and the bird. A nine-month pilot study was conducted to test the viability of the solar-powered PTTs and the different duty cycles.

In July 2003, based on the satisfactory performance of the solar-powered PTTs in the pilot test (Childress *et al.* 2004), four additional adult Lesser Flamingos were tagged with 40g solar-powered PTTs from North Star Science and Technology LLC at Lake Bogoria. The duty cycle for all four PTTs was specified as 8h on–60h off.

### Location data collection

Argos CLS (Collecte Localisation Satellites) in Ramonville Cedex, France (Taillade 1992) was used to calculate and report the locations of the study birds, utilising the USA National Oceanic and Atmospheric Administration (NOAA) satellite system to receive transmissions from the PTTs. Argos's multi-satellite service was used to enable location calculations from all six satellites that pass over the Great Rift Valley.

As our purpose was to identify the lake or wetland being used by the study birds during each transmission period, we used locations in Argos's Classes 0–3 (3: <150m, 2: <350m, 1: <1 000m and 0: >1 000m with no upper limit; Taillade 1992) and compared the locations reported with the latitudinal and longitudinal ranges of the different lakes. The length of each stopover visit was established by subtracting the first date a location calculation was received from that lake (assumed date of arrival) from the first date a location calculation was received from a succeeding lake. We assumed that the dates of departure from one lake and arrival at a new lake were the same, although this may not have been the case in all instances, as we were unable to tell when a movement was made if it was made when the PTT was in its 'off' phase (60h out of every 68h). In addition, as most interlake movements seemed to be made during the night, it is likely that many flights were begun on one date and completed on the next, but using this assumption added an extra day to each stopover. In most cases, the quality of the location calculations was sufficient to determine that the bird had indeed moved from one lake to another. However, in some cases, the quality of the location calculations received was too poor to enable us to distinguish between two locations that were fairly close to each other (i.e. Lakes Nakuru and Elmenteita, only 21km apart). In these cases, we assumed that the bird had not moved.

### Statistics

Statistical analyses of interlake flight distances and lengths of stopovers were conducted with non-parametric tests in

Minitab Statistical Software, Release 13 (Minitab 2000), as these data were either counts (length of stopovers) and/or not randomly distributed (or both). We gave each bird a Swahili name (i.e. Bahati, Safari, Imara, etc.) for discussion and presentation purposes, rather than using their unique PTT numbers.

## Results

### Transmitter performance

One of the initial two battery-powered PTTs stopped transmitting after 38d while the bird was still at Lake Bogoria. The remaining battery-powered PTT (Bahati) continued transmitting for 541d, 20% longer than predicted. Of the two initial solar-powered PTTs, expected to continue operating for 3–5 years, one (Safari) stopped transmitting after 660d and the other (Imara) was still operating after 734d (Table 1). A detailed review of the performance of these PTTs in the pilot study is provided in Childress *et al.* (2004).

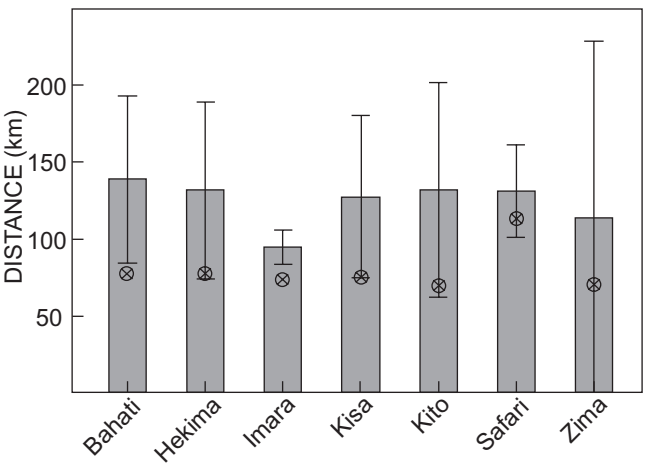


**Figure 1:** Mean and median lengths of interlake flights of seven adult male Lesser Flamingos in the Great Rift Valley, East Africa, November 2002–October 2004, with 95% confidence intervals for the means. Cross-hair symbols are medians

Of the four new solar-powered PTTs affixed in July 2003, one (Zima) stopped transmitting after 306d and a second (Hekima) stopped transmitting after 412d. A third (Kisa) stopped transmitting after 415d, but then started transmitting again after a hiatus of three weeks. The fourth solar-powered PTT affixed in July 2003 was still operating after 487d.

### Interlake movements

Between November 2002 and October 2004, the seven birds were recorded making 243 interlake flights ranging from 16–441km (mean distance: 111.5km ± 86.6km SD) and totalling approximately 27 164km (Table 1); 68.3% of the flights were <100km and 96% were <300km. There was no significant difference among the birds in the length of their interlake flights ($H = 5.20$, $df = 6$, $p > 0.05$, adjusted for ties, Kruskal-Wallis Test, Figure 1).

### Length of stopovers

During the two-year period, the birds spent a mean of 14.4d ± 27.4d SD (range: <1–153d, n = 250) at each stopover (Table 1); 72.8% of the stopovers were <10d and 83.2% were <20d. There was a significant difference among the birds in the length of their stopovers ($H = 59.5$, $df = 6$, $p < 0.001$, adjusted for ties, Kruskal-Wallis Test), but this difference was due entirely to the many short stays by Imara (Figure 2). There was no significant difference among the other birds ($H = 7.77$, $df = 5$, $p > 0.05$, adjusted for ties, Kruskal-Wallis Test).

### East African flyway and key site network

All interlake flights by the seven study birds were within the Great Rift Valley within a 940km range between Lake Logipi in northern Kenya and Lake Bahi in central Tanzania (Figure 3). There were no flights outside these two countries.

The seven birds spent 96% of their total stopover days on eight alkaline lakes in Kenya and Tanzania (Logipi, Bogoria, Nakuru, Elmenteita, Natron, Empakai Crater, Eyasi and Manyara), and 83% on just four of these lakes (Logipi, Bogoria, Nakuru and Manyara). Bahati spent more than four months continuously at an ephemeral wetland in central Tanzania (Lake Bahi), representing 4% of the combined stopover days. These nine sites accounted for 99.9% of the combined stopover days in the two years reported.

**Table 1:** Summary of tag duration, number of interlake flights, number of different lakes visited, mean number of days spent at each stop and approximate total distance moved by seven satellite-tagged adult male Lesser Flamingos in the Great Rift Valley, East Africa, November 2002–October 2004

| Bird | Tag duration (d) | No. interlake flights | No. different wetlands visited | Mean days spent at each stop ± SD (range) | Approximate interlake distance flown (km) |
|---|---|---|---|---|---|
| Zima | 306 | 6 | 5 | 43.7 ± 58.6 (2–153) | 684 |
| Hekima | 412 | 17 | 8 | 22.9 ± 36.3 (0–139)* | 2 243 |
| Kito | 487 | 14 | 6 | 32.5 ± 37.6 (0–141)* | 1 853 |
| Kisa | 487 | 14 | 7 | 32.5 ± 44.4 (2–125) | 1 786 |
| Bahati | 541 | 23 | 8 | 22.5 ± 33.3 (2–137) | 3 198 |
| Safari | 660 | 36 | 7 | 17.8 ± 25.5 (0–87)* | 4 796 |
| Imara | 734 | 134 | 12 | 5.2 ± 11.3 (0–91)* | 12 604 |
| Totals | 3 627 | 244 | | 14.4 ± 27.4 (0–153) | 27 164 |

* 0 = less than 1d

## Discussion

### Movements

During the first two years of this multi-year study, the seven tagged birds made 243 interlake flights, all within a 940km range between Lake Logipi in northern Kenya and Lake Bahi in central Tanzania. They travelled independently from one another and, although two or more were often on the same lake at the same time, they rarely arrived on the same day, never stayed the same length of time and rarely visited the lakes in the same order.

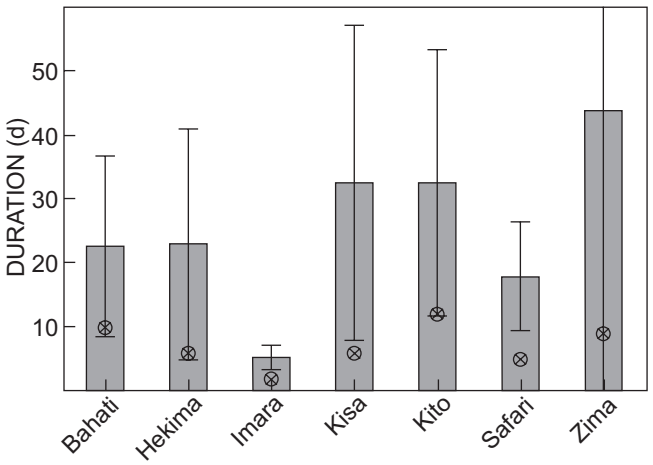


**Figure 2:** Mean and median lengths of stopovers of seven adult male Lesser flamingos in the Great Rift Valley, East Africa, November 2002–October 2004, with 95% confidence intervals for the means. Cross-hair symbols are medians

The reasons for their interlake movements are still unclear. It was often the case that one of the tagged birds would depart from a lake within days of another arriving at the same lake, or that one of the birds remained on a lake for several days or weeks after another had departed. This phenomenon became more apparent with the addition of four new birds to the study in July 2003 and indicates that the movements are probably not related to major fluctuations in food availability. There are occasions, such as those reported in Tuite (2000) and Vareschi (1978), where substantial changes in food availability result in large-scale population shifts away from or towards one particular lake. However, these large-scale changes in food availability do not occur overnight (Vareschi 1978), and do not seem to be directly related to the daily arrivals and departures of Lesser Flamingos at a given lake.

Although the monthly correlations are weak and not significant, there appeared to be a positive relationship between the amount of rainfall at a lake and the amount of time the tagged flamingos spent there. At both Lakes Nakuru and Manyara, lakes for which we have been able to obtain the

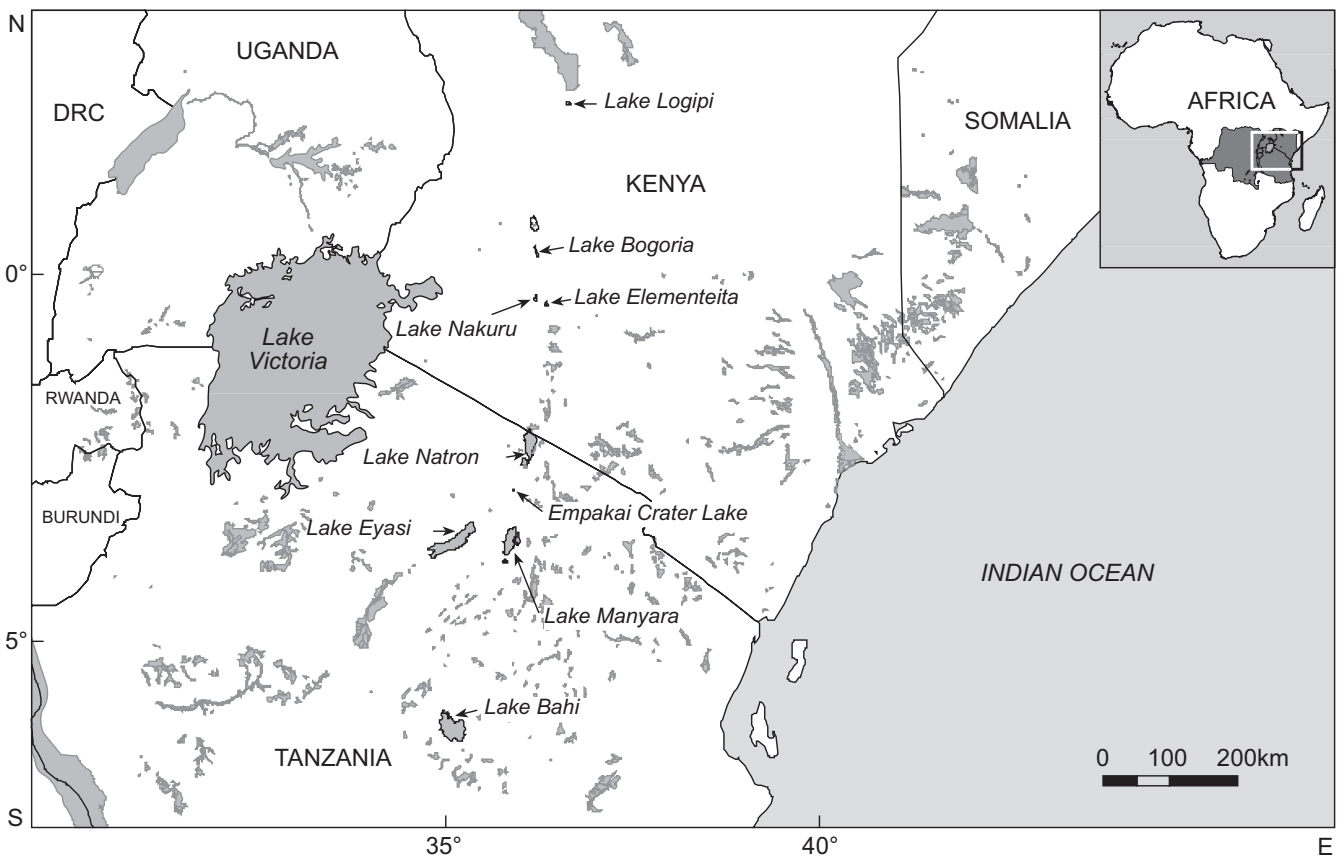


**Figure 3:** Lesser Flamingo East African flyway and key site network, November 2002–October 2004

most complete rainfall data, the mean number of days per bird spent at these lakes is generally greatest during the wet seasons and least during the dry seasons. These findings are confounded by limited data (only two years and three to seven birds, depending on the time period), the patchiness of East Africa's rainfall and the increased irregularity of the timing of the seasons. However, we believe that with a longer study, the existence of this relationship will be shown. The nature of such a relationship is also not clear. It could be simply the increased availability of freshwater needed for drinking and feather care, or increased freshwater following a dry period may affect the conductivity of the alkaline lake water with positive effects on the abundance of the cyanobacteria and diatoms on which the flamingos feed (C Tuite *in litt.*). On the other hand, Vareschi found no correlation between rainfall and conductivity, either at Lake Nakuru or Lake Elmenteita (E Vareschi *in litt.*).

There may also be seasonal patterns in the movements related to the annual breeding season (October–January) at Lake Natron. However, none of the birds we have been tracking appears to have attempted to breed during 2002–2003 or 2003–2004, although other Lesser Flamingos bred in large numbers at Lake Natron during both breeding seasons. During October 2002–January 2003, two of the three birds that were tagged at that time did not visit Lake Natron at all, while the third made seven visits to that lake, all between 1 and 3d in length. During October 2003–January 2004, two of the three tagged birds did not visit Lake Natron at all, while the other visited the lake ten times during this period, but no visit lasted longer than 3d. Each of the four birds tagged in July 2003 made one 3d visit to Lake Natron in November, no visits in October or December, and only two visits in January, once for less than a day and once for 6d. Since Lake Natron is the only breeding site in East Africa for this species, it appears that the birds were all non-breeders during these two years.

Each of the birds in the study moved independently of the others and, although there was no significant difference among the birds in terms of the median length of their flights, there were substantial differences in timing and the patterns of their movements. The reasons for these differences in movement patterns are as unclear as the reasons for the interlake movements themselves. Since Lesser Flamingos rarely fly alone (BC pers. obs.), all of the recorded movements are believed to have been made within flocks of other Lesser Flamingos, which confirms the general view that the Lesser Flamingo is a truly itinerant species. During the two-year period reported here, there were no flights outside Kenya and Tanzania, providing no direct evidence as yet of any interchange between the East African population and any of the other smaller populations.

Conditions at the Makgadikgadi salt pans in Botswana and at Etosha Pan in Namibia during the 2002–2003 breeding season were not conducive to breeding, as it was a drought year in southern Africa and both locations were too dry for nest building (G McCulloch and R Simmons *in litt.*). The 2003–2004 breeding season was wetter and Lesser Flamingo breeding occurred at both locations (G McCulloch and R Simmons *in litt.*). However, because there was breeding at Lake Natron during both years, the finding that the tagged birds showed no interest in breeding at Lake Natron probably indicates that conditions in southern African had no effect on their movements during these periods.

**Key site network: implications for protection and conservation**

On a combined basis, the seven study birds spent 96% of their stopover days at eight alkaline lakes in Kenya and Tanzania (Logipi, Bogoria, Nakuru, Elmenteita, Natron, Empakai Crater, Eyasi and Manyara), and these eight lakes, along with the ephemeral Lake Bahi, appear to comprise the key site network for Lesser Flamingos in East Africa. It has been known for many years that the eight alkaline wetlands cited are important for this species in East Africa (e.g. Bartholomew and Pennycuick 1973). This study documents their relative importance and adds Bahi Swamp, not previously considered an important site for Lesser Flamingos. The conservation status of the nine sites varies considerably. In Kenya, Lakes Bogoria and Nakuru are well protected, Lake Bogoria being entirely within a national reserve, while Lake Nakuru is within a national park. Lake Elmenteita is partially within a private wildlife sanctuary and partially unprotected (Bennun and Njoroge 1999). It is a small lake (1 800ha) with several tourist facilities around its perimeter. Lake Logipi is completely unprotected and suffers from high levels of insecurity and overgrazing (W Kimosop pers. comm.).

In Tanzania, the Empakai Crater Lake is well protected, being within the Ngorongoro Conservation Area. However, only the north-western quadrant of Lake Manyara is within the Lake Manyara National Park. The remainder of the lake, where the Lesser Flamingos congregate more often, is outside the park and thus unprotected. Incredibly, Lake Natron, the only successful breeding location for the East African population of Lesser Flamingos during the past 45 years, is also unprotected. This lake has been threatened in recent years by proposals for a major dam and hydroelectric power-generation project on one of the major inflows from Kenya and a new soda ash extraction scheme (BirdLife International 2000), and there is currently a proposal for a new tourist lodge and facilities along its shore (N Baker *in litt.*). Lake Eyasi and Lake Bahi are not protected in any way and their surrounding areas are under heavy pressure from deforestation, overgrazing and agriculture (Baker and Baker 2002, N Baker *in litt.*).

In view of the critical importance of these nine sites to the survival of the Lesser Flamingo in Africa, it seems clear that there is an urgent need to extend protection to those sites that remain outside protected conservation areas. Proposals for such protection will be included in the forthcoming global Flamingo Conservation Action Plan currently being prepared by the Wetlands International/IUCN-SSC Flamingo Specialist Group, supported by the findings from this study.

*Acknowledgements* — This study was conducted under the auspices of the Department of Ornithology, the National Museums of Kenya, the Baringo and Koibatek County Councils, and William Kimosop, Senior Warden, Lake Bogoria National Reserve. DH thanks the Ministry for Science and Technology for permission to

conduct research in Kenya. In addition to their own organisations, the authors thank the following organisations and individuals for their financial and logistical support: the International Flamingo Foundation, the Darwin Initiative, the Earthwatch Institute, the Vodafone Group Foundation, the Research Centre for Ornithology, Max Planck Society, Vogelwarte Radolfzell, the Peter Scott Trust for Education and Research in Conservation, Cicely Port, Anthony van Nice and Errett van Nice, Peter Berthold and Ulrich Querner. We also thank the volunteers in Earthwatch Institute's Lakes of the Rift Valley research programme for their assistance with the fieldwork.

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