A biodiversity assessment of the Flamingo Lakes of eastern Africa

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Abstract. *The Flamingo Lakes are part of a chain of lakes found on the floor of the eastern arm of the Great Rift Valley of Africa. The Eastern Rift Valley has three distinctive ecological types of lakes based on their physio-chemical constitution. These include (i) fresh water lakes with low ionic concentration (ii) moderately saline lakes with conductivity ranging from 600-6,000 µS/cm and (iii) hyper-saline "soda" lakes with conductivity ranging from 6,000-160,000 µS/cm. The Flamingo Lakes fall in the third category and they are the major feeding and nesting grounds of Flamingos. These lakes are all hyper-saline and highly alkaline hence the name "soda" lakes. The Flamingo Lakes are distinctively different from the other two types of Rift Valley lakes in that they have: a very high pH - above 9.6, hyper-salinity with electrical conductivity ranging from 6,000-160,000 µS/cm, and high alkalinity caused by sodium carbonate salt called trone ($Na_2CO_3.10H_2O$). The Flamingo Lakes in Ethiopia, Kenya, and Tanzania include Lakes Bogoria, Nakuru, Magadi and Elmenteita in Kenya; Manyara, Natron and Eyasi in Tanzania; Abijata, Shalla and Chitu in Ethiopia.*

The biodiversity value of the Flamingo Lakes can be viewed in three ways: (i) as a continuous resource system of lakes, wetlands, and savannah vegetation that is shared by riparian countries (ii) as part of a migratory pathway for water birds such as the palearctic flyers and (iii) as a framework for addressing shared natural resource management problems. The Flamingo Lakes and their associated environs in Eastern Africa are well known as the cradle of mankind. The area has a long history of human evolution and socio-cultural diversification. This has enabled the indigenous peoples of the Rift Valley, especially in Ethiopia, to domesticate wild plants which have become a major food source for modern day civilisation. Wild plants are used medicinally for both humans and domestic animals and there is a need to conserve these resources before they are lost altogether. The biodiversity of these lakes is threatened by both natural and anthropogenic activities. Climatic change has accelerated water stress in the lake catchment. Deforestation, agriculture, livestock, industries, mining, soil erosion, fertilisers, and conflict in resource use in the region have caused the deterioration of the lake environment. Information gaps do exist in the baseline biodiversity of these lakes. Regular ecological monitoring is required. It is proposed that in order to make an impact on the conservation of biodiversity values in the Flamingo Lakes, management-driven basic scientific research is needed. This research should be used to make informed decisions in the management, conservation, and wise use of the Flamingo Lakes. Advocacy, networking, the improvement and harmonisation of conservation policies and legal framework in the three Eastern Africa riparian counties should be facilitated. International collaboration in terms of financial assistance, expertise, and ratification of international treaties is also required.

Figure 1.
Map of the Flamingo Lakes of the Eastern Rift Valley.
Courtesy of S. Matagi

About the Author
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INTRODUCTION

This paper is divided into six parts: **Part 1** introduces the problem, the objective of the assessment, **Part 2** gives the background to the Flamingo Lakes, **Part 3** describes the details of the biodiversity resources of the Flamingo Lakes, identifies information gaps and research needs, **Part 4** highlights the pressure and threats to biodiversity and where possible identifies the magnitude of the threats, **Part 5** identifies knowledge gaps, **Part 6** provides the conclusion and recommendations. The Biodiversity Matrix is given at the end of the article, it summaries the biodiversity data available on the Flamingo Lakes.

The inhospitable limnochemical environment of the Flamingo Lakes limits their biodiversity. However, there are organisms that have evolved and adapted to the conditions. The most noticeable are the Lesser Flamingos (*Phoenicopterus minor*) that congregate in millions at these lakes. The Flamingo Lakes of the Eastern Rift Valley are estimated to share between them about 3 million flamingos. Flamingos are monolithic feeders specialising on the cyano-bacteria *Arthrospita fusiformis*, the most successful algae to colonize the alkaline waters. Because Flamingos depend only on this one source of food they are in essence evolutionary gamblers. This makes them susceptible to any environmental changes that may affect their food supply. Their specialised diet may have been a contributing factor to the massive die offs of Flamingos that took place in 1993, 1995, 1997/98 and 2000.

Primary production in the lakes is generally dominated by *A. fusiformis*, although sometimes *Ectothiorhodospira sp*. plays that role. Other algae species include *Nitzchia sp*. and *Navicula sp*. The secondary producers are composed of *Lovanula africana, Brachionus didiatus* and *B. plicatilis*. Chironomids dominate the macro-invertebrates. Only salt tolerant sedges and grasses are adapted to the mudflats adjacent to the littoral zones of the lakes. These include *Cyperus laevaigatus*, *Sporobolus spicatus*, *C. leneriffae*, *S. consimilis*, and *Cynodon dactylon*.

Hippopotamus amphibius is the only large mammal known to be associated with the Flamingo Lakes. In 1973 there were 15 hippos in Lake Nakuru feeding on grass during the night and defecating in the water during the day. Three fish species, *Oreochromis alcalicus grahami, O. amphimelas*, and *O. alcalicus* endemic to Lakes Magadi and Natron occupy the hot springs around these lakes. These fish can live at temperatures of 39° C and can tolerate up to 41° C for short periods of time.

Figure 2. Congregating Lesser Flamingos. Photo Gerry Ellis, courtesy of World Wildlife Fund (WWF).

About 500 species of birds occur in the Flamingo Lakes, their associated wetlands, and surrounding vegetation; 4 of these are globally threatened, 18 regionally threatened and 8 species are endemic to the Ethiopian part of the Rift Valley. The assemblage of about 1.5 million Flamingos on Lakes Nakuru, Elmenteita, Bogoria, and Abijata is a spectacular scene that attracts tourists to these lakes.

This paper synthesises baseline data on the biodiversity of these lakes. It provides a first step to understanding how these lakes function, what is not yet known, and suggestions for future research topics so that the ecosystem dynamics can be understood and the biodiversity of the lakes can be effectively conserved. To achieve this, policy implemation, co-ordinated research, monitoring, advocacy, and networking need to be conducted by all stakeholders.

BACKGROUND

The Great Rift Valley System

The Great Rift Valley system is an extension of the world-girdling system of the mid-oceanic ridges. The Rift Valley extends southwards for 6,000 km from the Dead Sea, through the Red Sea, coming ashore at Afar and passing through Ethiopia up to Mozambique. It has two main branches, the Western Rift Valley or Albertine Rift Valley (named after the husband of Queen Victoria of England) which passes through the Democratic Republic of Congo, Uganda, Rwanda, Burundi, Western Tanzania, Zambia, Malawi, and Mozambique; and the Eastern Rift Valley or Gregory Rift Valley, which runs through Central Ethiopia, Central Kenya and Central Tanzania. This arm is named after Joseph Gregory, the first scientist who described the depression on the earth's surface in 1896 to imply the Great Rift Valley of Africa, and later in 1922 described its formation (Ojany and Ogendo 1973).

The Great Rift Valley has an average width of 45 km. It is neither continuous nor strictly linear throughout its length (Willock 1974). The Rift Valley is a result of tectonic movements that caused faulting - uplifts and downwarping in the interior of the African continent. This took place in three main phases: during the Triassic (200 million years ago), the Cretaceous (80-130 million years ago), and the late Cainozoic (within the last 20 million years). During the Oligocene (40 million years ago) major rifting produced some of the largest lakes, forerunners of the present day smaller lakes in the Eastern Rift.

Flamingo Lakes

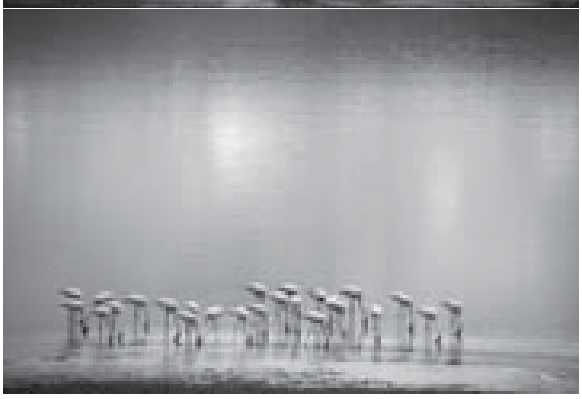
The Flamingo Lakes are part of a chain of lakes found on the floor of the eastern arm of the Great Rift Valley of Africa. The Eastern Rift Valley has three distinctive ecological types of lakes based on their physio-chemical constitution (Njuguna 2000). These include (i) fresh water lakes with low ionic concentration, examples include Lakes Zwei, Awassa, Baringo, Naivasha, Kitangiri and Babati (ii) moderately saline lakes with conductivity ranging from 600-6,000 µS/cm, these include Lakes Langano, Abaya, Chamo and Turkana and (iii) hyper saline "soda" lakes with conductivity ranging from 6,000-160,000 µS/cm, these include Lakes Abijata, Nakuru, Bogoria, Magadi, Natron and Manyara. The Flamingo Lakes, which provide the major feeding and nesting grounds of Flamingos, are the subject of this paper and are all hyper-saline and highly alkaline "soda" lakes. The Flamingo Lakes are distinctively different from the other two types of Rift Valley lakes in that they have a very high pH (above 9.6), hyper-salinity with electrical conductivity ranging from 6,000-160,000 µS/cm, and high alkalinity caused by sodium carbonate salt called trona ($Na_2CO_3.10H_2O$). Situated in Ethiopia, Kenya and Tanzania they include major lakes (greater than 20 km^2 in area) and minor lakes (less than 20 km^2). In Kenya the major Flamingo Lakes are Bogoria, Nakuru, Magadi and Elmenteita. Other minor Lakes where Flamingos are found in Kenya are Lakes Naivasha, Oloidien, Simbi, Amboseli and Shampoleb (Nasirwa 1997). In Tanzania the main Flamingo Lakes are Manyara, Natron and Eyasi. The minor Flamingo Lakes in Tanzania include the Momela lakes in Arusha National Parks, Lake Burungi, Lake Embakai, Ngorongoro crater, Lake Magadi in Ngorongoro Conservation Area, Lake Lagarja, Basuto, Balangida and Lelu (Katondo and Mwasaga 1997). In Ethiopia the main Flamingo Lakes are Abijata, Shalla, Metehara, Chitu, and Aranguade. The other lakes where Flamingos are found in Ethiopia are Lake Koka, Lake Ruphi and Lake Abbe on the Djibouti boarder (Desta 1997). This paper will only cover Lakes Bogoria, Nakuru, Magadi and Elmenteita in Kenya, Manyara, Natron and Eyasi in Tanzania, and Abijata, Shalla and Chitu in Ethiopia**.** Below is a brief description of each Flamingo Lake. For more information see the Biodiversity Matrix at the end of this article.

Lake Abijata. Lake Abijata (altitude: 1578 m above sea level (asl), area 230 km^2, located 7°33'-7°43'N and 38°27'-38°40'E) is an open lake which receives inflow from Lakes Ziway and Langano via the Bulbula and Horakelo Rivers. It is an exceptionally saline lake, rich in sodium carbonate and bicarbonates. Currently Lake Abijata has declined in size because of the combined effects of several years of low rainfall and water abstraction for irrigation from in-flowing tributaries.

Lake Shalla. Lake Shalla (altitude: 1558m asl, area 205 km^2, is very deep (maximum depth: 266m), 7°24'-7°33'N and 38°23'-38°39'E is rich in sodium carbonate and has extremely high salinity compared with the other Rift Valley Lakes. Lake Shalla is fed by several rivers. However, it has a high salinity which is thought to be caused by the influx of saline water from ground water that is heated geothermally, and rises under pressure as hot springs (Harlcrow and Partners 1992).

Lake Chitu. Lake Chitu has an area of 0.8 km^2 and a maximum depth of 21 m and is highly saline. It is a deep crater-lake with an enclosed system. There are hot springs at the mouth which permanently supply the lake.

Lake Nakuru. Lake Nakuru is a shallow soda lake that lies at 0° 23'S and 36°2'-36° 07'E. The climate at Nakuru is bimodal with two wet and dry seasons. Seasonal streams, rivers, and treated sewage from the town feed the lake. The water level and area fluctuates over cycles of a few years and the lake has been known to dry up completely (Melack 1996; Matangah *et al.* 2000).



Figures 3-6 (top to bottom): 3, Pair of Flamingos, Lake Bogoria. Photo courtesy of Javier Gomez-Garcia, Editor, www.kenyalogy-.com; 4, Lake Manyara, North end, 11 August 1978 (Photo by G.G.E. Scudder); 5, Lesser Flamingos flying (Photo by Gerry Ellis, courtesy of WWF); 6, Flamingos (Photo by Steve Morello, courtesy of WWF).

Lake Elmenteita. Lake Elmenteita is located at 0° 27'S and 36° 15'E and covers an area of 18 km^2 at an altitude of 1776m asl. It is a shallow saline soda lake with a maximum depth of 1.9m. It is fed by the Kekopey hot springs at the southern end and two small streams, Meroronyi and Kariandusi, from the eastern plateau (Hughes and Hughes 1992; Matangah *et al*.. 2000).

Lake Magadi. Lake Magadi (altitude: 580m asl, area 100 km^2) is located at 1°44'-2°00'S and 36°12'-36°16'E. The total dissolved salts sometimes exceed 30% w/v saturation (Grant *et al* 1990). The lake bed is covered by a vast expanse of solid sodium carbonate and bicarbonate (trona) deposits which can be 40m thick (Eugster and Hardie 1978). Generally the lake is fed by hot springs. Shallow lagoons at both the northern and southern extremities of the basin are perennial and are fed by hot springs (Hughes and Hughes 1992; Matangah *et al.* 2000).

Lake Natron. Lake Natron is a shallow endorheic lake, situated (2°05'-2°36'S/35°53'-36°08') on the floor of the Eastern Rift Valley, reaching the Kenyan border in the north. It is 5.7 km long, has a maximum width of 15 km, and an open water surface of 855 km^2 at an altitude of 610 m asl (Hughes and Hughes 1992). It is fed by four permanent rivers (Ewaso Ng'ro, Peninj, Moinik, and Engare Sero), and by numerous seasonal streams.The principle affluent, the Ewaso Ng'ro River, rises on the western slopes of the Mau Escarpment in Kenya and flows southwards to Lake Natron through the Ngare Ng'ro Swamp.

Lake Manyara. Lake Manyara is oriented almost due N-S and lies in a trough at 960m asl along the eastern margin of the Eastern Rift Valley. The lake has an area of 480 km^2 at high water and a maximum depth of 3.7m. It is of the alkaline saline type and has been known to dry up completely. Its catchment covers an area of about 10,000 km^2.

Lake Eyasi. Lake Eyasi is oriented SW-NE and is 80 km long, with a mean width of 14.5 km. It has an area of 1160 km^2 and is located at an altitude of 1030m asl. Lake Eyasi is highly saline and is so shallow that it dries up during the dry season, leaving a thin crust of salt. Almost all the streams and rivers are ephemeral.

Geology

The Rift Valley is composed of crystalline precambrian rocks of the Central African plateau which covers much of the region, overlain by Cenozoic volcanic basalts, rich in sodium, ignimbrites and other sedimentary rocks (Burgis and Mavuti 1987). Lacustrine deposits are found around the major lakes, while alluvium occurs along the river valleys.

Soils

The soils are light sandy loams of either volcanic or alluvial origin (Ondieki *et al*. 2000). The light nature of the soil, although easy to work, is highly susceptible to wind and water erosion and hence, loss of fertility. The soils of the central plain of the rift valley are mainly derived from lacustrine deposits and volcanic ashes. Because of this origin, the soils are grey, deep and poorly drained and slightly calcareous to alkaline. Around Lake Nakuru the soils underlying the open plain grassland are derived from pumice beds and ashes of recent volcanoes and appear to be well-drained friable loam to sandy clay loam. In the upper parts of the catchment, soils are red, well developed, fertile, and formerly supported dense tropical mountain forests. Cliff and rock outcrops are of the basaltic formation. The lake bottoms normally contain weathered material from the catchment area. The soil type is mainly sandy alluvium, of volcanic origin indicated by the soda ash and fine sandy/loam soils.

Climate

One major characteristic of the Eastern Rift Valley is that it is water-stressed with evapo-transpiration far exceeding rainfall. For example, typical precipitation in the central part of Tanzania is 500-750 mm/year while the eastern and western regions receive about 750-1250 mm/year. Only about 4% of the country receives over 1250 mm/year. Comparatively, evaporation is about 2000-2200 mm/year, causing a minimum water deficit of about 1000 mm/year (Annersten 1975).

The climate of the Flamingo Lakes is Afro-tropical and is either arid or semi-arid. Rainfall in the region is influenced by the Inter-Tropical Convergence Zone (ITCZ), hence the characteristic bimodal rainfall pattern, with alternating wet and dry seasons (Ondieki *et al*. 2000, Kahata *et al*. 2000). In the Ethiopian lakes the ITCZ separates the air streams of the Northeast and Southeast monsoons. In Kenya both the ITCZ and the presence of Lake Victoria, a large inland continental water mass, influence rainfall. In Tanzania the Rift Valley System is influenced by seasonal hot and dry northeast winds blowing from Kenya and southeast winds blowing from southern highlands, which is relatively dry resulting in low precipitation. Rainfall varies considerably with altitude throughout the region. In general, the northern lakes are at higher altitudes than the southern lakes and the mountain ranges are higher in the north than in the south. In the Tanzanian Flamingo Lakes the average rainfall is 600 mm to 800 mm per year, while in Kenya it varies from 450 mm at Lake Magadi to 750 mm at Lake Nakuru. In the Ethiopian Lakes average annual rainfall ranges from 545 mm to 600 mm. The Kenyan highlands adjacent to the Rift Valley receive relatively higher amounts of precipitation with up to 2000 mm per annum. The mean annual rainfall along the entire length of the Rift Valley is 535 mm (Philip-Heinemann 1991).

Topography

The landscape of the Eastern Rift Valley is divided into four categories: highlands, lowlands, modified (built-up) environment and Young Volcanic and Scarp Landscapes (Ndede *et al.* 2000).

Highlands. The Rift Valley highlands are areas above 2000 m asl. They are characterised by forest ecosystems,

although open grasslands dominate in some places. Because of their altitude they receive a relatively higher amount of rain (up to 2000 mm per annum). Therefore, these highland areas provide the main sources of water for the rivers, streams, swamps and the Flamingo Lakes within the Eastern Rift. Several escarpments separate the highlands from the valley, examples include Mau (3,098 m), Siria, Bahati, Cherangani (3,325 m), Kinangop (3,325 m), Ngongo Hills and Kikuyu escarpments (Ndede *et al.* 2000).

Lowlands. The Eastern Rift Valley lowlands lie below 2000 m asl and are characterised by lake basins, mature rivers, grass plains, saltpans, arid and semi-arid lands. The lowest point is 400 m asl around Lake Turkana while the lowest for the Flamingo Lakes is Lake Magadi which is 600 m asl. River systems from the highlands feed the many lakes of the lowlands. Some of the lakes are saline, such as the Flamingo Lakes, but lakes like Baringo and Naivasha are freshwater. The grasslands constitute the savannah woodland, bushland, and shrubland which are the renowned game dispersal areas and wildlife sanctuaries (Ndede *et al.* 2000).

Young Volcanic and Scarp Landscape. Because of the weak faults along the Rift Valley, volcanicity is active. All the Flamingo Lakes have steam vents, hot springs and geysers. There are other unique features of the landscape associated with the volcanoes, such as volcanic plugs (Fisher's Tower), calderas or cones with crater lakes like Longonot (2776 m), Mt. Menengai (2279 m), Mt. Suswa (2355 m) and Chitu, volcanic ash, cliffs and gorges (Ndede *et al.* 2000).

Modified Landscape. Population growth, urbanisation, industrialisation, and agriculture in the riparian countries of the Flamingo Lakes have changed much of the landscape. Towns such as Nakuru and Magadi have grown around the lakes because of tourism, soda ash mining, and other economic activities associated with the lakes. These activities and the settlement of humans adjacent to the lakes have necessitated the infrastructural development of a network of roads, electric power transmitters, telephone lines, water pipelines, oil pipelines, and airstrips.However, this level of development is restricted to Kenya. The Flamingo Lakes in Tanzania and Ethiopia are remote, but experience the impacts of overgrazing and deforestation within their catchment basins (Ndede *et al.* 2000).

Vegetation

The vegetation of the Flamingo Lakes is varied. On the rift valley floor and slopes it is tropical savannah, whereas the highlands are forested. In Kenya, the Rift Valley system falls within the Somali-Maasai biome. This is mainly savannah woodland, bushland, and shrubland dominated by Yellow Acacia. Surprisingly, the Flamingo Lakes are surrounded by freshwater wetlands. The most common wetland vegetation species are *Cyperus papyrus*, sedges, *Cyperus lavigatus*, *Pharmaites* and *Typha*. The common grassland species are *Chloris gayana*, *Digitaria abyssinica*, *Themesda trindra*, *Cynodon digitaria* and Boma Rhoda grass. This forms the bulk of the food for ungulates found in the region. Most highland forests have *Euphorbia candeladra*, *Olaea africana*, *Teclea simplicifolia and Juniperus sp*. *Acacia xanthophlea* is the dominant species in the Acacia woodland.

The Flamingo Lakes and associated environs in Eastern Africa are well known as the cradle of mankind and the area has a long history of human evolution and socio-cultural diversification. This has enabled the indigenous peoples of the Rift Valley, especially Ethiopians, to domesticate wild plants which have become the major food items of modern day civilisation. There are wild plants that are used for medicinal purposes for both humans and domestic animals. There is a need to conserve these resources before they are lost altogether (see Table 1).

Botanical names of plants used	DISEASE / CONDITIONS	
	Local ailment name	English ailment name
Acacia nubica Benth.	Oldepe	Anaplasmosis
Acacia senegal (L) Wild	Olderkesi	Wounds and burns
Acacia tortilis (Forssk.) Hayne	Oltepesi	Diarrhea, Difficult birth
Acalypha fruiticosa Forssk.	Ossiaitiado	Naval ill, pox, ticks
Acokanthera schimperi (A. DC) Schweinf.	Ol-morijo	Black quarter
Aloe spp.	Esuguroi	Coccidiosis, F.M.D coughs
Boscia coriacea Pax	Engamuliki	Mosquitoes and eye problems
Commiphora africana (A. Rich.) Engl.		
Carissa edulis (Forssk.) Vahl	Olamuriaki	Ring worms, Heartwater
Croton dichogamus Pax	Ol-logerdangai	Anaplasmosis
Ficus sycomorus L.	Olng'aboli	Abortions
Grewia villosa Wild	Olmankuhai	Retained after-birth
Juniperus procera Endl.	Oltarakwa	Mange
Ricinus communis L.	Oldule	Constipation, intestinal worms
Salvadora persica L.	Oremit	Trypanosomiasis, Anthrax, Brucelosis
Wurbugia ugandensis Sprague	Ol-sogonoi	Blackwater, Anthrax

Table 1.
Plants used in treating livestock diseases by the Masai Community in Kajiado District, Kenya.

Table 2.
Bacteria Biodiversity

BACTERIA BIODIVERSITY	KENYA				TANZANIA			ETHIOPIA		
	Nakuru	Elmenteita	Bogoria	Magadi	Natron	Eyasi	Manyara	Abijata	Shalla	Chitu
Thermophilic Bacteria strains	+	+	+	+	+	+	+	+	+	+
Magatibacter afermentans		+								

Hydrology

The Rift Valley constitutes an internal drainage system with a series of endorheic lakes (lakes with no outlet), which vary in size and character. For instance, it is hypothesised that water from the freshwater Lake Naivasha seeps underground and returns to the surface as the hot springs around the lake. The remainder of the underground seepage is thought to either drain into Lake Elmenteita or Magadi (Becht, per. com). The major lakes have an area of greater than 20 km^2 and these include Ziway, Abijata, Shalla, Langano, Awassa, Turkana, Baringo, Nakuru, Elmenteita, Naivasha, Magadi, Natron, Manyara and Eyasi. Some of the lakes have smaller drainage basins within major drainage basins. For instance all the water draining into Lake Shalla finally ends up in Lake Abijata. Geological evidence shows that the Rift Valley lakes are remnants of larger lakes that existed in the past. Formerly, the northern floor of the Rift Valley basin in Ethiopia was occupied by one large lake of which Lakes Ziway, Abijata and Langano are remnants.

Water levels in all the Rift Valley Lakes have experienced large fluctuations during both recorded history and the more distant past. Evidence derived from surveying elevations of ancient shorelines and from examination of sediment cores in Naivasha basin concurs that a much larger (about 610 km^2) and deeper (about 100m) lake existed between 10,000 to 12,000 years Before Present (BP) and overflowed through Njorowa Gorge (Hell's Gate) to the south (Melack 1996).

The hydrology of the Eastern Rift Valley System in Tanzania, like the climatic pattern, is influenced by the topography of the escarpments and the volcanic highlands. The annual precipitation is highly variable. The Rift Valley lakes are subject to great fluctuations because of climatic, geologic, or even biological events that occur within or outside the lakes themselves. Surface evaporation in the closed lake basins is higher and as a result of this, the hydrological balance of the Eastern Rift Valley system is always negative.

The Rift Valley lakes are fed with water from several permanent rivers and springs, which originate from the western and Eastern highlands lined along the Rift Valley. Water volume in these rivers fluctuates seasonally thereby affecting the amount of water discharged into the lakes at different periods of the year. Seasonal rivers dry up during prolonged dry spells. These changes in water supply are reflected by fluctuations in the lake water levels.

Water Quality

The geochemical and biogeochemical processes that control the chemical composition of the Flamingo Lakes are similar to those in other closed-basin lakes: evaporation, intermittent flooding and desiccation, absorption and ion exchange with sediments, reactions of cation with alumino-silicate precursors to form clay minerals (reverse weathering), precipitation of primarily carbonates and sulphides from moderately saline waters and of other salts from hypersaline brines, and carbon dioxide and sulphide loss by degassing and sulphate reduction (Eugster and Hardie 1978).

The physical-chemical characteristics of these hyper-saline soda lakes of the Eastern Rift Valley are characterised by high pH (average 10 and above), high conductivity (between 16,000 - 160,000 µS/cm) and high salinity (45%). The abundance of algae makes the water of these alkaline lakes thick, slimy and greenish in colour. In deep alkaline lakes, like Lake Shalla in Ethiopia, the water is soapy to touch because of its carbonate content. The water is clear, but the lake looks black because of the colour of the rocks. In the shallow lakes such as Lake Nakuru, Elmenteita, Bogoria, and Abijata the abundant algae gives a greenish tint to the water (Brown 1971). The hyper-alkaline lakes have high levels of sodium carbonates that are leached out of the volcanic-based basalt soils of the Rift Valley catchment, which are rich in sodium. When the lakes have no subterranean outlets nor outflowing rivers, they act as evaporating pans, concentrating salts in the water. In the case of Lakes Magadi and Abijata incoming waters are already strongly alkaline, and then, during the dry season, evaporation far exceeds rainfall so that crystalline soda ash lines the lakes' edges. Soda ash mining has been established on these two lakes.

Water within the Lake Shalla basin seeps underground and is heated geothermally, only to rise under pressure as hot springs (Halcrow and Partners 1992). Lakes Magadi and Bogoria also have freshwater and saline springs that feed the lakes. Freshwater Cichlid Fish of the genus *Oreochromis* that tolerate high alkalinity and high temperatures inhabit the freshwater springs.

The high content of fluoride in the young volcanic soils of the Kenyan and Tanzanian part of the Rift Valley leads to high levels of fluoride in the water. For instance, Lake Bogoria has a fluoride content of over 100 mg/l.

In general, information on the limno-chemistry of the Flamingo Lakes is scanty and inadequate. The Flamingo

Lakes Programme should put in place a water quality-monitoring program that will help to elucidate the dynamics of the lakes. The results will enable further study to qualify the impact of catchment activities on the lakes. This in turn will assist in the development of recommendations for catchment management.

BIODIVERSITY

Considering that most of the physical-chemical characteristics of the Flamingo Lakes presented above are hostile in nature i.e. high pH, high salinity and high alkalinity, very few organisms would be expected to survive in the lakes, yet there are organisms that have evolved to occupy these environments. These include bacteria, phytoplankton, zooplankton, macro-invertebrates, amphibians, reptiles, fish, birds, mammals, and terrestrial macrophytes (Matangah *et al*. 2000).

BACTERIA

Very little is known about the bacteria of the Flamingo Lakes apart from the maiden work of Tindall (1980) and Mwatha (1991). However the main types of bacteria known to occur in these lakes are thermophilic bacteria that are adapted to high temperatures and alkalinity, found to inhabit the hot springs (Table 2). Recently a new species was isolated from Lake Elmenteita (Jones *et al*. 1994). This entirely new genus is related to the genera *Vibrio* and *Aeromonas*, and is called *Magatibacter afermenta*. Lake Elmenteita maintains a steady population of 10^5 bacteria/ml, while Lake Bogoria has 10^6 bacteria/ml of lake water (Mwatha 1991).

Although Table 2 shows that the diversity of bacteria is low this is because information and basic research on the microbial composition of the Flamingo Lakes is limited.

PHYTOPLANKTON

Phytoplankon, or algae, are minute aquatic organisms that carry out photosynthesis in water. The phytoplankton biodiversity of the Flamingo Lakes is lower than that of nearby fresh water lakes (Table 3). *Arthospira fusiformis* (formerly called *Spirulina platensis*), a blue-green alga, is the most abundant phytoplankton.

The abundance of cyano-bacteria is responsible for giving the Flamingo Lakes their characteristic greenish colour. Very few organisms can survive such inhospitable environments, so it is expected that one species may dominate. Those species that can survive tend to be numerous because of a lack of competition (Matagi 1996). Ironically, there are times when population crashes occur and *Arthrospira fusiformis* is almost absent! In its absence, the photosynthetic bacteria *Ectothiorhodospira* is the main primary producer (Grant and Mwatha 1989). Phototrophic diatoms of the genera *Nitzchia spp.* and *Navicula spp.* are also common and

PHYTOPLANKTON BIODIVERSITY	KENYA				TANZANIA			ETHIOPIA		
	Nakuru	Elmenteita	Bogoria	Magadi	Natron	Eyasi	Manyara	Abijata	Shalla	Chitu
Arthrospira fusiformis	+	+	+	+	+	+	+	+		+
Anabaeropsis	+	+	+							
Anabaeropsis abijatea								+		
Cyanospira			+							
Chloflexus		+								
Synechococcus		+	+							
Brachionus sp										
Paradioptomus africana	+									
Nitzchia	+		+							
Navicula	+		+							
Sodababacter nakuruenes	+									
Chrococcus			+							
Ectothirhodospira	+		+							
Natronobacterium			+							
Natronococcus			+					+		
Spiralara laxissom G.S. West										
Bogoriella caseilytica			+							
Cryptophyceae								+		
Aulacoseira sp									+	
Aulacoseira granulata									+	
Aulacoseira agazzizti									+	
Chaetoceros Maclleri Lemn									+	
Anomoeoneis sphaero									+	
Cymbella keptoceros									+	
Fragilaris frustlum									+	
Oocytis								+		+
Scroederia sp.										+
Bogoriella caseilytica			+							

Table 3. Phytoplankton Biodiversity Key: + denotes species papered

Table 4. Zooplankton Biodiversity.

ZOOPLANKTON BIODIVERSITY	KENYA				TANZANIA			ETHIOPIA		
	Nakuru	Elmenteita	Bogoria	Magadi	Natron	Eyasi	Manyara	Abijata	Shalla	Chitu
Lovanula africana	+	+								
Brachionus dimidiatus	+	+								
Brachionus plicatilis	+	+								
Lytocyclops gibsoni									+	
Cyclops agiloides									+	
Diaphanosoma sp.									+	

contribute significantly to productivity in the ecosystem (Mwatha 1991; Hecky and Kilham 1973).

Thick green or orange algal mats inhabit areas adjacent to the hot springs. Some of the green-orange mats are known to be of the C*hlofleus-Synechococcus* association, but the majority are still not known in terms of species composition.

Lake Magadi and Lake Natron share similar populations of prokaryotes. There is a noticable lack of cyano-bacteria as the major primary producers. Primary productivity is attributed to large populations of *Ectothiorhodospira*. Although cyano-bacteria of the genus *Cyanospira sp* have been isolated from Lake Magadi (Florenzano *et al*. 1985), cyanobacterial blooms occur only occasionally after extensive rainfall causes dilution of the brine.

In the Ethiopian lakes, 16 species of phytoplankton have been found in Lake Shalla, 7 species in Lake Abijata and 1 species in Lake Chitu (Kebede and Willen 1996). *Arthrospira fusiformis* is a strongly dominant species usually found forming dense blooms, in the saline-alkaline Abijata and Chitu lakes. It is the major food source for vast flocks of Lesser Flamingo (*Phoenicoptrus minor*) that inhabit the lakes. A new Cyanophyte, *Anabaenopes abijatae*, was described from Lake Abijata. The species is dominant or co-dominant with *Arthrospira fusiformis*. These species both reach high population levels and form thick algal mats on the surface of the lake (Kebede and Willen 1996).

Kebede (1996) studied the phytoplankton composition and diversity in the alkaline/ saline series of Ethiopian Rift Valley lakes and concluded that salinity, alkalinity, inorganic turbidity, and mixing depth, play an especially important role in species composition and diversity. Alkaliphilic cyarophytes, *Arthrospira fusiformis* and *Anabaenopsis abijatae* dominate the most saline lakes. Species diversity is the richest in lakes with intermediate salinity and alkalinity and with no strong species dominance. However, no relationship was found between salinity and the total phytoplankton biomass. The remarkable difference in phytoplankton composition and biomass between the saline lakes of Abijata and Shalla, with nearly similar chemical composition, is mainly due to deeper mixing and a proportionally shallower edaphic (soil) zone in Lake Shalla which limits the development of a large bio-mass. Lake Chitu is the most saline lake with *Arthrospira fusiformis* being the single dominant species.

Zooplankton

Zooplankton are secondary producers in aquatic ecosystems. Zooplankton diversity, like phytoplankton diversity in the Flamingo Lakes, is also low compared to freshwater lakes in the Rift Valley (Table 4). In Lake Nakuru the dominant zooplankton is the Calanoid Copepod, *Lovanula africana*. Its abundance is seasonal and it is much more common after the rains when the conductivity is diluted. Rotifera include *Brachionus dimidiatus* and *B. plicatilis*. In Lake Elmenteita *Lovanula africana* is the only abundant zooplankton (Table 3). In Lake Shalla two species of plankton were found, *Argulus africanus* and *Diaphanosoma sp*. More surveys and research on the taxonomic status of the zooplankton in the Flamingo Lakes is needed.

Macroinvertebrates

The most abundant macroinvertebrates in the Flamingo Lakes are the chironomids (Table 5). In Lake Bogoria chironomid dipterans have been papered (Mutangah *et al*. 2000). In Lake Nakuru *Culicinae* sp, annelids,

Table 5. Macro-invertebrates Biodiversity

MACRO INVERTEBRATES BIODIVERSITY	KENYA				TANZANIA			ETHIOPIA		
	Nakuru	Elmenteita	Bogoria	Magadi	Natron	Eyasi	Manyara	Abijata	Shalla	Chitu
Chironomid *Tanypus*	+									
Chironomus sp.	+	+	+	+	+	+	+	+	+	+
Limnochironomus deribae	+									
Culicine sp.	+									
Oligochaetes	+									
Corixids								+		
Brachinella spinosa		+								
Micronecta spp.		+								
Bellamya unicolor								+		
Helicarion ruppellianum								+		

Chironomid *Tanypus*, Oligochaetes and *Leptochironomus deribae* are present (Vareschi 1982). In Lake Elmenteita the anostracan *Brachinella spinosa* and Hemipterans *Micronecta* spp are present (Vareschi 1982). Four Heteroptera, one Notonectid, and three Corixids have also been identified in Lake Nakuru. In Lake Abijata the molluscs *Bellamya unicolor* and *Helicarion ruppellianum* are present (Hughes and Hughes 1992).

Amphibians and reptiles

Despite the fact that few herpetological studies have been done on Flamingo Lakes the number of species seems to be few. In the lakes themselves there are no amphibians because of the salinity and alkalinity. The wetlands around Lake Nakuru have two frog species *Hyperrolius virdiflavus virdiflavus* and *Ptychadena mascariensis*. The Kenyan horned Viper *Bitis worthingtonii*, endemic to the Rift Valley, is known to occur in Lakes Nakuru and Elmenteita.

More surveys and research on the status of amphibians and reptiles is urgently needed. The Flamingo Lakes Programme should include a monitoring programme for amphibians and reptiles.

Fish

The ichythyofauana of the Flamingo Lakes is restricted to the Cichlid genus *Oreochromis*, which alone has been able to adapt to the hostile environment. The only fish species present are *Oreochromisa alcalicus*, *O. amphimelas* and O. a. *grahami* (Table 5). *Oreochromisa alcalicus* is endemic to Lake Magadi, but was introduced in to Lake Nakuru in 1953 and 1959 and again in 1962 after the lake had dried up and reformed, to control mosquitoes in Nakuru town.

Some of the endemic fish are capable of surviving in waters of high temperatures and salinity. For example, *O. a. grahami* is able to live permanently in waters up to 39° C and can tolerate up to 41° C for short periods of time (Beadle 1981). *O. a. grahami* is also a filter-feeder and primarily consumes the blue-green bacteria (*Arthrospira fusiformis*). However, *O. a. grahami* also shows a large degree of adaptability in utilizing available food resources in the harsh lake environment (Hammer 1986). *O. alcalicus* lives in springs and small waterways around Lakes Magadi, Natron, Manyara, and Nakuru (introduced), sometimes in waters with salinity higher than 40 ppt (Hughes and Hughes 1992). These hot springs can reach temperatures of up to 44° C (Hammer 1986). Even the often-dry Lake Eyasi, with hot springs around the edges, along with Lake Manyara, hosts the species *O. amphimelas* in hot springs on lake margins (Hughes and Hughes 1992).

Further studies in the physiological adaptation strategies of fish in the Flamingo Lakes and their surrounding hot springs are needed.

Birds

There are over 50 species of birds found in the Flamingo Lakes of the Eastern Rift Valley. Four are globally threatened, 18 regionally threatened and eight species of the birds are endemic to the Rift Valley in Ethiopia (Table 7) (Njuguna 2000).

These are normally found in the associated wetlands and surrounding vegetation. The most noticeable are the Lesser Flamingos with an estimated population of 3 million (Howard 1997). Flamingos are monolithic feeders specialising on the cyano-bacterum *Arthrospita sp.*, an abundant algae that has been able to colonise the alkaline waters of the lakes successfully. Because Flamingos depend only on one source of food, they are vulnerable to any environmental changes that may affect their food source. This may have been a contributing factor to the massive die-offs of 1993, 1995, 1997/98 and 2000 (Motelin *et al.* in press).

Although birds are the most monitored taxa, their significance to the lakes and vice versa is least understood. With diminishing habitat, ecological monitoring is required, in addition to the development and enforcement of conservation policies and law. Birds are very good bio-indicators of environmental degradation. Perhaps the recent deaths of Lesser Flamingos indicate a deteriorating environment. Therefore a detailed ornithological research study on the Flamingo is required.

Mammals

The Hippopotamus, *Hippopotaus amphibius*, is the only mammal found to associate directly with the Flamingo Lakes. In Lake Nakuru between 1972 and 1974 there were 15 hippos which fed on the surrounding vegetation during the night and defecated in the water during the day (Burgis and Symoens 1987). Hippos are also known to be present in Lake Elmenteita, probably having immigrated from nearby freshwater Lake Naivasha.

In the adjacent wetlands and savannah, wild mammals are abundant including Buffaloes, Waterbucks, Impalas, Gazelles, Kobs, and Zebras. Lions, Leopards, and Hyenas are amongst the carnivores that roam in the lakes catchment. Lakes Nakuru, Abijata and Shalla have National Park Protection status because of the game animals. This forms the basis of a tourism industry in the Rift Valley, a means of vital foreign currency for the riparian countries.

Terrestrial Macrophytes

FISH BIODIVERSITY	KENYA				TANZANIA			ETHIOPIA		
	Nakuru	Elmenteita	Bogoria	Magadi	Natron	Eyasi	Manyara	Abijata	Shalla	Chitu
Oreochromisa alcalicus grahami	+			+	+					
O. alcalicus	+			+	+					
O. amphimelas							+			

Table 6.
Fish Biodiversity.

Table 7.
Bird Biodiversity

BIRD BIODIVERSITY	KENYA				TANZANIA			ETHIOPIA		
	Nakuru	Elmenteita	Bogoria	Magadi	Natron	Eyasi	Manyara	Abijata	Shalla	Chitu
Lesser Flamingo	+	+	+	+	+> 1,000,000	+ 700,000	+> 1,000,000	+	+	
Great Flamingo	+	+	+	+	+	+	+	+	+	
Lesser Kestrel	+									
Madagsacar Squacco	+									
White Pelican	+			+	+ 15,000	+ 15,831	+ 10,000	+		
Pink Pelican						+ 18,000				
Stork African Spoon Bill					+ 1000					
Stork Yellow Billed					+ 1000	+ 11,072	+ 1,000			
White Stork					+ 4,360	+ 14,000				
White-necked cormorant	+			+						
Egrets	+			+						
Terns	+			+						
Gulls	+			+						
Waders								+		
Shovelers							+ 14,650	+		
Stilt								+		
Ruff								+		
Insectivorous								+		
Cormorants									+	
Stock									+	
Pelicans									+	
Ibises									+	
Wagtails										
Caspian Plover						+ 398	+			
Pin tail							+			

In open freshwater aquatic environments, plants (aquatic macrophytes) are important primary producers. This paper uses the term macrophytes for vascular plants (plants with xylem and phloem). Because of the inhospitable conditions, the Flamingo Lakes are devoid of macrophytes except at the points of entry of in-stream estuaries (Njuguna 1984). There are no macrophytes in the lakes, but salt-tolerant sedges and grass species are found adjacent to the mud flats that surround the lake (Table 8). *Cyperus laevigatus* and *Sporobolus spicatus* dominate the vegetative cover surrounding the lake.

A description of the macrophytes in the lake catchments is given under section 2.7 above. Table 8 gives the main species of macrophytes found in each catchment.

BIODIVERSITY PRESSURES AND THREATS

The Flamingo Lakes of the eastern Rift Valley are part of a landscape that has varied terrestrial ecosystems such as forests, deserts, cultivated land, and ever increasing human settlements and cities. The increase in human population, with consequent changes and intensification of land use and increasing exploitation of water and aquatic resources, has led to the deterioration of the lakes environment (Ndede *et al.* 2000).

Major threats in many of the Flamingo Lakes include climatic changes, erratic rains - especially those experienced during *El Nino*, and prolonged drought. These have led to a fall in lake levels. These changes are further exacerbated by unregulated water abstraction for domestic, industrial, irrigation, horticulture and hydroelectric development projects. Because the lakes are fragile ecosystems and the region is water stressed, changes in climate or land use patterns make them susceptible to drought. An increase in the water inflow, caused by the rains of *El Nino*, will increase lake volume, lower the salinity of the lakes, and in turn, lower algal production by *Arthrospita fusiformis*. With less *Arthrospita fusiformis* to feed on, the Flamingos become stressed.

Lake Nakuru, home of the spectacular assemblage of over one million Flamingos, is highly threatened by sewage, industrial pollution, urban drainage, and solid waste from the Nakuru Town (Koyo *et al.* 2000). There is a proposal to build a large dam on River Malewa in the Nyandarua Highlands and divert water to Nakuru Town. This will mean more sewage effluent into Lake Nakuru. Lake Natron, the major breeding ground of Flamingos, is also threatened by a proposed hydroelectric power station on river Ewaso Ngiro. Inter-basin transfer from Mara into Ewaso Ngiro, at a rate of 2 m^2/s, will further exacerbate the situation. Additional water into Lake Natron may dilute the salinity and this will in turn prohibit the reproduction of *Arthrospita fusiformis*, the main food of Flamingos. There is also a proposal to build a soda ash extraction factory on the shores of the lake. Associated chemicals used in the extraction of soda may pollute the lake.

Severe pressure to the Flamingo Lakes also comes from deforestation, followed by poor agricultural methods like cultivation on steep slopes, overgrazing, and wetland destruction in the catchment of these lakes.

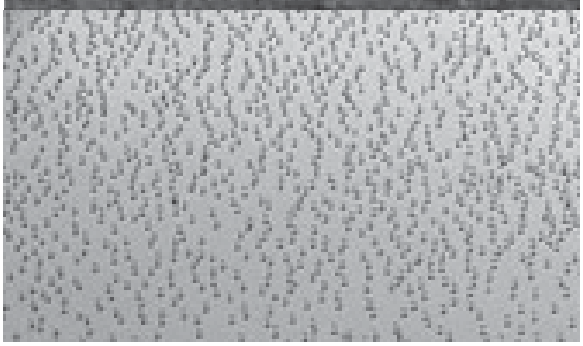
These activities have led to wind and water soil erosion. A comparison of soil erosion in a cultivated hectare in Lake Nakuru is five times more than in a hectare of forest (WWF 2001). The result of soil erosion is siltation of the rivers and lakes. Frequent droughts and unregulated water abstraction have led to lower lake depths. The rise of horticultural farms along some of the Rift Valley lakes in Kenya has also caused fertilisers to run off into the lakes. The resultant nutrient enrichment from sewage, silt, and urban and agricultural run-off into these lakes has caused algal blooms. As an end result, cyano-bacteria endotoxins and microcystin poisonous toxins have been detected in Lakes Elmenteita, Nakuru, and Bogoria. These are likely to be strongly associated with the Flamingo die-offs and the death of some livestock in water impoundment reservoirs in the region.

The die-off of large numbers of Flamingos in recent years is greatly troubling. An unexplained die-off was first observed in 1993, then another occurred in 1995, and they occurred again throughout 1997-98 and in 2000. During the first incident of mass deaths in 1993, an estimated 40,000 birds died in only three months, whereas at least 20,000 flamingos died over a similar period during the second episode in 1995. Between 1997 and 2000, Lake Bogoria supported a stable Lesser Flamingo population of over 1 million birds. Throughout this period deaths were observed at the lake, occurring in spikes. It is estimated that 50,000 birds died in 2000, with the deaths distributed over the entire year. Pathological results show that the birds had lesions in the spleen, kidney and liver (Motelin *et al*, 2000). The lesions suggested toxicosis. Habitat degradation has already occurred in Nakuru where xenobiotic contaminants (heavy metals, pesticide residues, oil, and grease) are building up in the bottom sediments and water column (Nelson *et al*. 1998; WWF 2001). The accumulation of these xenobiotics including algal toxins in Flamingo tissues may be an indication of a degraded environment and responsible for the Flamingo deaths. Further investigation is required.

One of the major threats to biodiversity in the Flamingo Lakes region is resource use conflict. There is competition for grazing land, charcoal, wood fuel, water for irrigation and industrial use, agriculture, as well as land for investment activities and conservation purposes. For instance, Abijata-Shallas Park is supposed to be reserved for conservation. The local communities use the park for grazing, cultivation, charcoal and fuel wood production. The conflict lies between the government authorities and the local communities. In Lake Manyara there are conflicts between pastoralism and wildlife, settlements and wildlife, agriculture, forestry and mining versus biodiversity conservation.

MACROPHYTES BIODIVERSITY	KENYA				TANZANIA			ETHIOPIA		
	Nakuru	Elmenteita	Bogoria	Magadi	Natron	Eyasi	Manyara	Abijata	Shalla	Chitu
1.Mud Flats Sites										
Cyperus laevigatus	+	+	+	+	+	+	+	+	+	
Sporobolus spicatus	+	+	+	+	+	+	+	+	+	
Sporobolus consimilis			+							
Typha domingesis	+		+							
Cyperus leneriffe			+							
Cyperus immensus	+									
Cynodon dactylon	+	+								
Cyperus papyrus				+						
Phragmites manuritianus				+						
Tyhpa domingesis				+						
2.Catchment Sites										
Combretum			+							
Grewia			+							
Acacia	+	+	+							
Balanites			+							
Commihora			+							
Ficus capensis			+							
Acacia xanthophloea	+		+							
Acacia tortilis	+		+							
Tarchonathus	+									
Olea africana	+									
Euphorbia candelabrum	+									
Typha		+								
Cyperus papyrus		+								
Diplachne fusca							+			
Odyssea jaegeri							+			
Sporobolus							+			

Table 8. Terrestrial Macrophytes Biodiversity



GAPS IN KNOWLEDGE AND RESEARCH NEEDS

This review has identified information gaps and research needs for the conservation of the Flamingo Lakes. These gaps and needs need to be addressed in order to understand how the intricate dynamics of the Flamingo Lakes ecosystems function and secondly to develop programmes for the sustainable use of the natural resources of these lakes.

INFORMATION GAPS

- Lack of baseline data on most components of the Flamingo Lakes biodiversity. There is a notable paucity of information on the lower life forms especially viruses, bacteria, phytoplankton, zooplankton, macro-invertebrates, amphibians and reptiles.
- Lack of continuous ecological monitoring and assessment of biodiversity.
- Lack of a regional policy and legal framework to manage the Flamingo Lakes.
- Lack of trans-boundary mechanism to handle biodiversity issues.
- Lack of information on the ecological dynamics of the Flamingo Lakes and fac-tors affecting the sustain-ability of these ecosystems.

RESEARCH NEEDS

The research recom-mended below should be part of the conservation and management effort of the Flamingo Lakes. It should not be a stand-alone effort, but should be management driven.

- Baseline taxonomic inventory for fauna and flora of the Flamingo Lakes and their surrounding catchment.
- Ecological monitoring in order to understand ecosystem functioning. Results will be able to show trends. Interpretation of trends will give the "cause-effect" and appropriate conservation and management plans will be developed.
- Hydrological studies and water balance models to allow prediction of changes arising from drought and upstream water abstraction.
- Indigenous knowledge in the wise use of natural resources.
- Socio-economics studies in order to understand the communities, change attitudes, create awareness and involvement of communities in the sustainable use of natural resources.
- Population pressure and trends.
- Limno-chemistry and water quality to elucidate the dynamics of Flamingo Lakes.
- Overgrazing of livestock is one of the most degrading activities in the Flamingo Lakes catchment. Appropriate carrying capacity should be established.
- Impact of industries and mining.
- Reforestation.
- Soil erosion in the Flamingo Lakes catchment is one of the major problems. Its prevention is an important area of study.
- Pollution studies to protect the biodiversity of the lakes from pollution effects and water scarcity.
- Harmonisation of national and regional policies and legal frameworks for the three countries.

RECOMMENDATIONS

- Carry out a detailed biodiversity inventory for all components of the major Flamingo Lakes, i.e. Bogoria, Nakuru, Magadi and Elmenteita in Kenya; Manyara, Natron and Eyasi in Tanzania; Abijata, Shalla and Chitu in Ethiopia. The following areas

Images *(Top to Bottom):* Ibis (Photo by Sven Olof-Linblad, Linblad Expeditions, courtesy of WWF); Lake Elmenteita Flamingos (Photo courtesy of WWF); White Pelicans. (Photo by Sven-Olof Linblad, Linblad Expeditions, courtesy of WWF); Yellow-billed Stork (Photo by Howard Buffett, courtesy of WWF); Hippo with calf (Photo by Steve Morello, courtesy of WWF).

require detailed study: the limno-chemistry of the lakes, viruses, bacteria, algae, zooplankton, macro-invertebrates, amphibians and reptiles, mammals and birds.

- Develop lake and catchment management plans for selected lakes, e.g. Lake Natron, Lakes Abijata, Shalla and Chitu in Ethiopia and Lakes Elmenteita and Magadi in Kenya.
- Carry out a detailed study of the water balance of the lake ecosystems. This will assist in catchment management.
- Install hydrological and meteorological monitoring stations.
- Carry out taxonomic studies (classification, composition and distribution) for all biodiversity, i.e. viruses, bacteria, algae, zooplankton, macro-invertebrates, amphibians, reptiles, mammals and birds.
- Fund at least 1 Ph.D. student and 6 M.Sc. students in each country to do research on the microbial biodiversity. The research should be part of the conservation and management plan of the lakes. Information on phytoplankton of the Flamingo Lakes is scanty. Only Lake Nakuru and Abijata have had some attention. Most of the information is either in MSc. or Ph. D theses, which are not published and hence not easily available. The Flamingo Lakes Programme should assist Ph. D and MSc. students to do further research and compare their work with that previously completed. The trends in phytoplankton composition could then be ascertained. Comparison with palaeontological results will help elucidate changes over time and will assist in measuring the impact of climate and anthropogenic activities on the lakes. Results from these studies can then be used to assist in designing catchment plans and restoration programmes.
- Institute ecological monitoring for all biodiversity components. Impacts of anthropogenic activities in the catchment will be identified, quantified and monitored through ecological monitoring.
- Promote sustainable use of the resources within the Flamingo Lakes.
- Resolve resource use conflicts.
- Involve the participation of the local communities in the management of resources within the Flamingo Lakes.
- Assist in capacity building of national and regional institutions to develop the assessment of biodiversity, sustainable use of the natural resources, conflict resolution and management of trans-boundary resources.
- Harmonisation of regional biodiversity conservation policies and legal framework.
- Ornithological research on the Lesser Flamingo is required, as an indicator of environmental quality.

CONCLUSION

- Biodiversity information on the Flamingo Lakes is very scanty and inadequate. Very little is in the public domain mainly in international scientific journals. Most of the information is in unpublished Ph. D and MSc. theses. The rest is in consultancy papers.
- The Flamingo Lakes, unlike their freshwater counter-parts in the Eastern Rift Valley, support a less rich biota. However, those species that can tolerate the hostile environment are found in abundance, e.g. the algae *Arthrospita fusiformis* and Flamingos.
- The terrestrial environments and wetlands associated with the Flamingo Lakes support a high biodiversity of fauna and flora. Some of these environs have protected status like National Parks and are a source of foreign revenue through tourism.
- The region is water stressed and this has been exacerbated by deforestation. Therefore, any meaningful conservation measures must include maintaining vegetative cover (forest or grassland) in the catchments, which will change the microclimate. Vegetation cover will ensure moisture content is kept in the soil.
- The catchments of the Flamingo Lakes have many resource users, whose interests normally conflict. Therefore, conflict resolution will be a necessary skill for undertaking conservation efforts in this region.
- The Flamingo Lakes have been abused and used as a repository of waste, including agricultural run-off, sewage, and industrial wastewater.
- Water abstraction for industrial, domestic, irrigation, and horticulture uses have a negative impact on the lakes.

Figures 12-13: 12 *(top)*, Flamingo Lakes, Ngorongoro Crater, 8 August 1978 (Photo by G.G.E. Scudder); 13 *(bottom)*, Momella Lakes, general view, 12 August 1978 (Photo by G.G.E. Scudder).

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