Ecology and Management of Lake Naivasha, Kenya, in Relation to Climatic Change, Alien Species' Introductions, and Agricultural Development

by

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INTRODUCTION

Lake Naivasha, a shallow freshwater lake in the Eastern Rift Valley chain of Kenya (Fig. 1), is situated at an altitude of around 1,890 m approximately 100 km north-west of Nairobi. It has always been an important ecological site to Kenya, because of the diversity of flora and fauna in the range of vegetation-zones associated with the Lake and its hinterland, which is greater than that of other Rift Valley lakes (Lincer *et al.*, 1981). This importance has been maintained even though the Lake has no statutory protection or reserve status.

The area of Lake Naivasha also has a high economic value; cattle-watering by Maasai in former times has given way during the present century to settled agriculture — including the raising of export cash-crops around its shores — though this agriculture is heavily dependent upon Lake water for irrigation. Naivasha town is a centre for both the lake-shore farms and the ranches and small-holdings of the adjacent Kinangop Plateau (*cf.* Fig. 1). A commercial fishery has been built up over the past 30 years on the basis of introduced species, the products being exported to Nairobi and Nakuru in addition to local consumption.

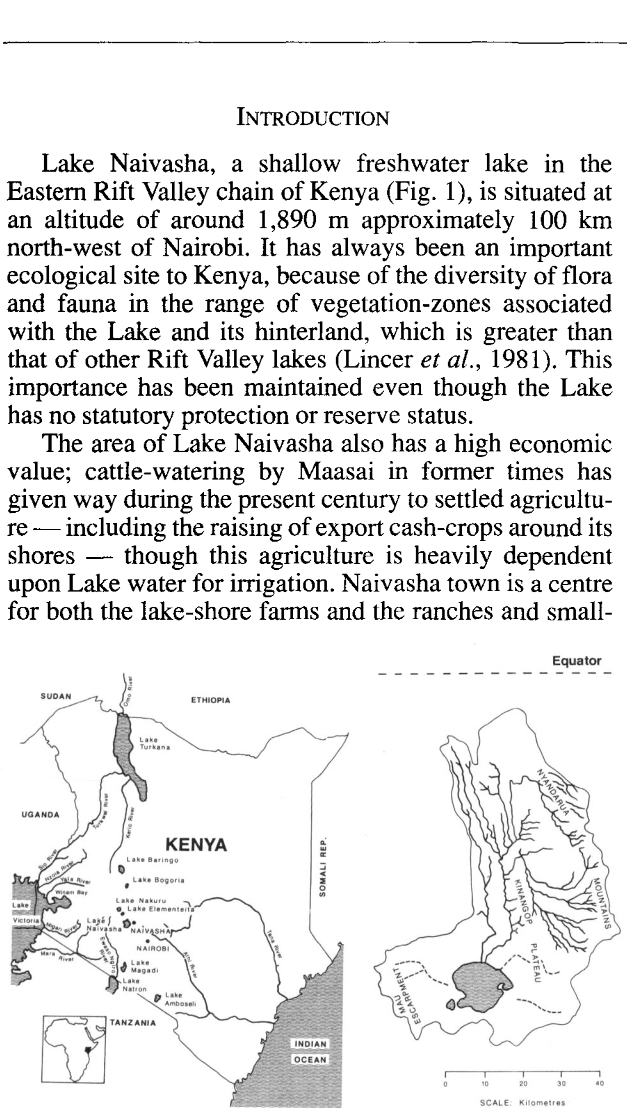

FIG. 1. *Location map of Lake Naivasha and its catchment (scale indicated by its nearest point being* c. *100 km from Nairobi). Some details of its surroundings are indicated in the larger-scale map on right.*

Lake Naivasha is also a focus for tourism and recreation, which have been growing in volume ever since the first sport-fishing began in the late 1920s. Its catchment streams provide the main water-supplies for both Naivasha and Nakuru towns. Most recently, the area has become industrially significant as a consequence of the development of Olkaria, just to the south of the Lake, as a site for geothermal energy generation, producing about 43 megawatts which is 15% of Kenya's total energy-consumption.

The key to both ecological and economic values is the freshness of the Lake's water, in contrast to most of the eastern Rift Valley lakes, which are saline. This is due in part to the large catchment area in the Nyandarua Mountain range (formerly called Aberdares) (*cf.* Fig. 1) and in part to outflow processes. Initially there was assumed to be some undiscovered subterranean outlet (Gregory, 1921) together with very dilute inflows (Worthington, 1932). This view was refined, however, by Gaudet & Melack (1981), and Ase (1987), who showed that the Lake was hydrologically a seepage lake, with input *via* ground-water seepage in the northern area and outflow in the southern area (*cf.* Fig. 1). They concluded that the Lake remained fresh — partly because of its dilute inflows and seepage losses but additionally because of biochemical and geochemical sedimentation removing certain ions such as sulphates and carbonates.

The Lake receives drainage water from two perennial streams; the larger of these is the river Malewa, draining the Nyandarua Mountains (drainage area 1,730 km^2), while the smaller, the Gilgil, drains the Rift Valley floor from the north (drainage area 420 km^2). Several ephemeral streams drain the Lake in the southern part. The Rift Valley was formerly an area of volcanic activity which has left four depressions in the Lake, three of which are at least partially connected (Fig. 2). The largest water area, the main Lake (approximately 150 km^2) is shallow, deepening towards its southwestern end to a maximum of 8

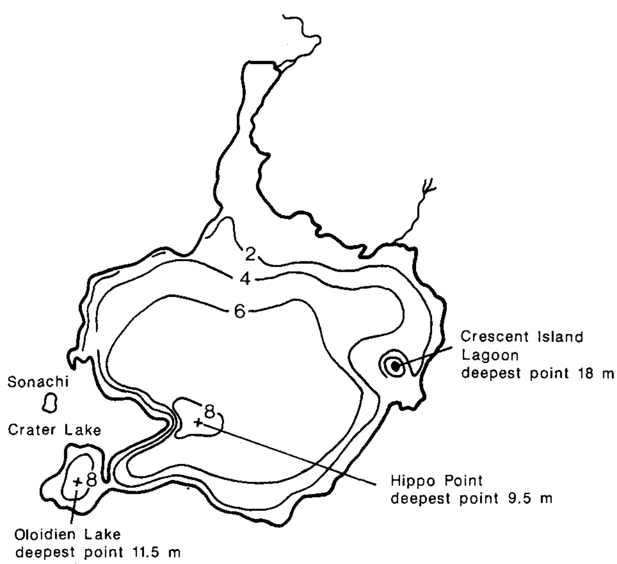

FIG. 2. *Depth contour map of the basins of Naivasha, recorded in January 1983 and drawn to the water-level of that time.*

m (at 1983 water-levels). At the eastern side of the main Lake is a partially-submerged crater of which the highest rim section forms Crescent Island and of which the basin is the deepest part of the Lake (18 m deep at 1983 water-levels). At low water-levels this partially-submerged crater is separated from the main Lake and becomes chemically distinct. A much smaller, more alkaline, Lake Oloidien (5.5 km^2 in area) is adjacent to Naivasha to the west of its southern end, separated by Papyrus swamp but connected by an open-water channel at times of high water-levels. Within 3 km of the western shore of Oloidien Lake lies an isolated, highly alkaline, crater lake — Sonachi — with an area of about 0.2 km^2 and maximum depth of about 4 m (in 1983).

Lake and Climatic History

Lake Naivasha has only a short written history, though it was known to Maasai and other original inhabitants of the Rift Valley for centuries. It was first described in European writing by the traveller Thompson (1884), but its earliest record is that, according to Maasai oral history, there was a period immediately before the arrival of the first Europeans when the Lake was completely dry (Sikes, 1936; Edmondson, 1977).

Evidence concerning climates and lake levels prior to last century has come from cave excavations to the south of Lake Elementeita, from levelling of ancient shorelines (Leakey, 1931; Nilsson, 1938; Washbourne, 1967) and, most recently, from examination of cores from the deepest part of the Lake (Richardson & Richardson, 1972). There is agreement from these studies that the former climate of the Rift Valley was far wetter than the present-day one, and that a much larger lake existed around 10,000 and 12,000 years BP (Before Present), following a period of maximum aridity between 15,000 and 13,000 years BP (Street & Grove, 1972). Nilsson (1938) gave the level at that time of maximum as about 40 m higher than the present Lake, whilst Bishop (1971), and Richardson & Richardson (1972), suggested that it was once more than 100 m higher than at present, overflowing Njorowa gorge to the south of Naivasha and cutting the lip to its present height.

Those high Lake-levels were maintained for several thousand years — to about 5,700 years BP, as is indicated by a stable planktonic diatom assemblage in the basal 3 m of the lake-core (Richardson & Richardson, 1972). For the next 1,500 years, the Lake's level fell to approximately present-day levels, then dried out for a short period of perhaps not more than 100 years at around 3000 BP. For the last 3,000 years, variations in diatoms from the core indicate that the Lake has fluctuated considerably, with levels generally below those of the present day. However, at the end of last century, the writings of European travellers indicate that the Lake's level must have been rising between the years 1880 to 1895 — to a maximum height of 1,896 m asl (above sea level) (Sikes, 1936; Ase *et al.*, 1986), which is some 4–5 m higher than any level reached since that time. Levels then declined in a drought which lasted for about 4 years at the turn of the century, so that when continuous recording commenced in 1908 the level was 1,890 m asl (Ase, 1987).

Since 1908, continuous records have been maintained at several places and these are combined in Fig. 3 — taken from Ase (1987) and extended with data from the Ministry of Hydrology and the Elsamere Conservation Centre. This shows a general decline to a low point in the decade 1945–55 of around 1,882 m asl, which would have given the Lake a maximum depth of around 13 m at Crescent Island Lagoon and an area of about 100 km^2. There was then a period of rapid increase in 1961–3 to just over 1,887 m — a level retained for about 10 years but followed by a decline of 2–3 m in the early 1970s. An increase occurred thereafter over the last four years of that decade, and by late 1982 the level had exceeded 1,887 m, where it remained for about a year. Since early 1984 the level has been falling steadily, and in January

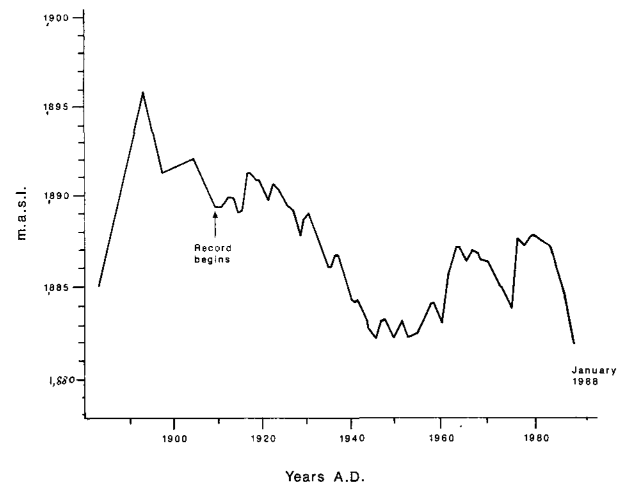

FIG. 3. *Water-level changes in the main basin of Lake Naivasha during the present century. Initial data taken from Ase (1987), who explains their derivation in some detail, modified to January 1988 with records taken daily at the Elsamere Conservation Centre, Naivasha, Kenya.*

1988 it was 5 m below the 1983 peak, having indeed come to its lowest level in this century (*cf.* Fig. 3). The onset of the long rains in April 1988 brought an end to this decline at least for the time being.

The Lake-level fluctuations do not show any general relationship with local rainfall, except that periods of exceptionally high rainfall are followed by Lake-level rises (*e.g.* in 1922, 1930, and 1961–63), and annual evaporation always exceeds annual rainfall (Ase *et al.*, 1986). In a statistical analysis, however, Vincent *et al.* , (1979) suggested that the Lake's level is an indicator of the long-term pattern of high-level climate — particularly the penetration of equatorial westerlies and their influence on land above 2,500 m asl. Evidence for this hypothesis came from the correlation of monthly Lake-level changes with high-altitude meteorological stations such as that of Equator at 2,700 m, and the correlation of Lake-level with the altitude of the snout of the Lewis Glacier on Mount Kenya, which is SW-facing. Long-term Lake-level fluctuations showed close similarities with those of Lake Turkana, which also has a mountainous catchment and no surface outlet — compared with no similarities with the fluctuations in Lake Victoria.

Until the 1970s there was no indication that the considerable Lake-level fluctuations had any major effect upon the biota; comparison of vegetation transects across the Lake-edge from 1930 (Worthington, 1932) and the early 1970s (Gaudet, 1977; Gaudet & Muthuri, 1981) revealed little structural difference. The limited information available suggests that any change in the animal species between the 1930s and 1970s (Beadle, 1932; Jenkin, 1932, 1936; Worthington, 1932; Millbrink, 1977) was also slight. Latterly, however, a series of introductions of alien species has occurred, with marked effects which became apparent in the late 1970s and early 1980s.

Species Introductions to the Lake

Fishes

Prior to 1925 there had only been a single species of fish in the Lake — an endemic zooplanktivorous Small-tooth Carp (*Aplocheilichthyes antinorii* (Vinc.)). It is assumed that this paucity of fish species, highly unusual in a tropical freshwater lake, was due to the earlier periods of drying-out of Lake Naivasha. In 1925 and 1926, the mouth-brooding cichlid *Oreochromis spilurus niger* (Gunther) was introduced by the colonial Kenya Game and Fisheries Department. This fish flourished in the littoral fringe of the Lake (Trewavas, 1983), and in 1927 the American Large-mouthed Bass (*Micropterus salmoides* Lacepede) was introduced to feed on it and provide the basis of a sport-fishery (Elder *et al.*, 1971). Both species were successful until the low water-levels of the late 1940s and early 1950s, when they appeared to have died out (Litterick *et al.*, 1979).

Large-mouthed Bass were re-introduced on several occasions between 1951 and 1956 — in 1956 together with a second cichlid, the herbivorous *Tilapia zillii* (Gervais). The batch of *T. zillii* unintentionally contained some individuals of *Oreochromis leucostictus* (Trewavas). The latter unexpectedly flourished and is now the basis of the subsequent commercial fishery. To these fishes were added the Louisiana Red (Swamp) Crayfish (*Procambarus clarkii* (Girard)), which, introduced in 1970 (Parker, 1974) to broaden the range of the commercial fishery, has been exploited since 1975 (Lowery & Mendes, 1977*a*). The most recent new arrival is the only natural one — a small riverine fish, *Barbus amphigramma* Blgr, which first migrated down to the Lake from the Malewa during the high water-levels of 1982 (Harper, 1984) and at times since then has been present in large enough quantities for limited commercial exploitation at the Malewa inflow.

Several other fish species have been introduced over the past 50 years without any lasting success. Sporadic reports of Rainbow Trout (*Salmo gairdneri* (L.)) derive from introductions to the catchment streams for sport. Three cyprinodont species were introduced for mosquito control — *Gambusia* sp., *Poecilia* sp., and *Lebistes reticulata* Peters, of which only the last-named was found in 1982 (Harper, 1984). *Oreochromis niloticus* Linnaeus was introduced in 1965 and was last found in 1969. Recently, however, experimental netting during 1986 recorded this species in Oloidien Lake (*cf.* Fig. 4), and unconfirmed reports from fishermen since then suggest its continuing presence in the main Lake Naivasha.

Other Introductions

In 1961 the first unintentional immigrant species, the floating Water-fern *Salvinia molesta* Mitch., was reported (*cf.* Someren, 1972). It was known in ornamental ponds, and was available from aquarists in Nairobi in the 1950s (Mitchell, 1969). Its arrival was closely followed by the Coypu (*Myocastor coypus* (Molina)), which had been imported to the Kinangop Plateau (*cf.* Fig. 1) for fur-farming in 1950. Individuals escaped and arrived at Lake Naivasha from 1965 onwards (R. Mennell, pers. comm.), where, by the early 1970s, there was a large population of Coypu.

Initially, *Salvinia molesta* was seen as more of a potential threat than a real problem because of fears that its effect on the new reservoir at Kariba*, on the Zimbabwe/Zambia border, would be repeated (Boughey, 1963). For the first few years, spraying the plant with herbicide whenever it was discovered kept it under control, but it increased in area in the late 1960s, covering 2–3 km^2 (Mitchell, 1969). By 1973 it had spread along the whole of the Lake shoreline (Gaudet, 1976*a*), but had no measurable effect as yet on the overall ecology of the Lake. Biological control by the orthopteran *Paulinia ecuminata* was tried, but with little more success than with the herbicide treatment — without strict control of the plant, its rapid vegetative reproduction can quickly make up any losses (Mitchell & Tur, 1975).

Recently, research into the possibility of releasing a weevil, *Cyrtobagous salviniae* Caldr & Sands, which has been evaluated elsewhere for *Salvinia* control (Room *et al.*, 1981; Julien *et al.*, 1987), has been initiated in Kenya. At present, however, the proposal of any such introduction has been rejected by the Kenyan National Environment Secretariat on the basis that it would be risky to introduce the weevil until enough is known about its wider ecology in a tropical environment.

* Hence its widely-used name of 'Kariba-weed.' — Ed.

Biological methods of control were also tried on Coypu. Pythons (*Python rebae*) were introduced, the descendents of which are still reported to exist in areas of the northern Papyrus Swamp of the Lake (*cf.* Fig. 4). However, these introductions were ineffective, at least at first, and a rapid Coypu population-increase occurred in the early 1970s (Gosling, 1976). Thereafter for about a decade, Coypu were frequently observed by lakeside residents, though in decreasing numbers after 1980. No individuals have been seen since 1984, and it is assumed that the population has died out.

Recent Vegetation Changes in Lake Naivasha

The work of Gaudet (1976*a*, 1976*b*, 1977, 1979, 1980) described the aquatic vegetation of Naivasha and established that, with the exception of the spread of *Salvinia molesta*, the overall species composition and distribution had remained relatively stable for forty years. Patterns of change were apparent, as in the successive 'reefs' of Papyrus that were formed when 'island' masses rooted in places of low water-level (Gaudet, 1977); but all the main vegetation-types — terrestrial colonizers of the draw-down, emergent swamp vegetation, a floating-leaf zone of

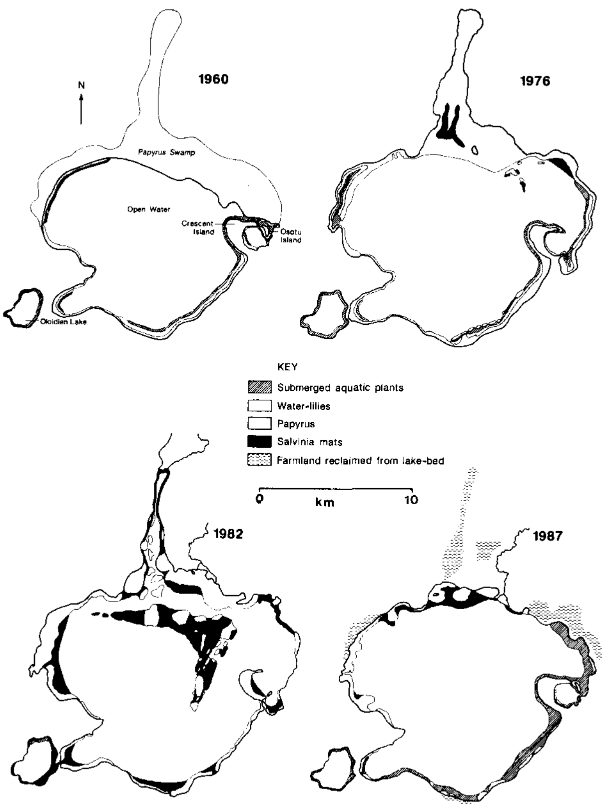

Fig. 4. *Changes in the aquatic vegetation of Lake Naivasha, 1960–87. 1960 map drawn from the Ordnance Survey map of Kenya and personal recollections of lakeside residents. 1976 map drawn from the published sketches in Gaudet (1977), Tarras-Wahlberg (1986), and the personal recollections of residents. 1982 map drawn from personal observations of the Authors together with the photographs from Gaudet & Falconer (1982). 1987 map drawn from personal observations and aerial photographs of the Authors.*

Water-lilies (*Nymphaea caerulea* Savigny), and a submerged-plant zone — were dynamic, with new populations developing as old ones were disappearing. However, the last two decades have seen dramatic changes in the plant communities, shown in Fig. 4.

There was relatively little change between 1960 (a period at the end of a low water-level phase) and 1976 (a period of relatively high water-level), except that the raised levels in 1976 had resulted in the formation of more Papyrus lagoons, islands, and 'reefs', than had existed previously. Mats of *S. molesta* had formed within these lagoons in some areas (Fig. 4, above).

By 1982, however, the period of rapid water-level increase had raised almost all of the Papyrus to form floating islands. These, together with an increased quantity of *S. molesta* mats, covered around 25% of the Lake's surface at any one time (Fig. 4, lower left), moving to all corners of the Lake at the mercy of the winds. The Water-lilies and all species of submerged plants had completely disappeared from the main Lake, with consequences at all levels of the Lake's ecosystems (Harper, 1984; Tarras-Wahlberg, 1986; Clark *et al.*, in press). Submerged plants grew continuously in the nearby Oloidien Lake throughout this period; but Water-lilies, Papyrus (*Cyperus papyrus*), and *Salvinia molesta*, cannot survive in Oloidien because of its higher alkalinity (*S. molesta* mats there blew apart in 1982–83, whereafter the plants rapidly died and sank).

After 1983, the Lake's water-level started to decline; between 1983 and 1985 Kenya (along with most of eastern Africa) experienced a severe drought. By 1984 most of the Papyrus had become grounded again as reefs, and much of the *S. molesta* had been stranded by the receding water-line. By 1987 the Lake had returned to levels similar to those experienced in the 1950s; but its appearance was considerably changed in two respects (*cf.* Fig. 4, lower right). The area of Papyrus had been more or less restricted to fringing reefs, the swamps having been reduced by agricultural clearance in most of the northern half of the Lake — such that, by 1986, approximately 12 km^2 of original swamp had been reduced to 2 km^2, causing considerable public concern (Anon., 1986, 1987). Further, between 1986 and 1988, Water-lily seedlings germinated in the Lake's shallows, for the first time in almost a decade, producing flowering clumps in many places along the eastern shores. Extensive beds of submerged plants also reappeared, growing up to 400 m wide and in water down to 2 m in depth.

Coincident with changes in the rooted aquatic vegetation, has been an increase in the phytoplankton; the standing-crop biomass has risen from around 20 mg/m^3 (as chlorophyll 'a') in 1987. Transparency of the Lake's water, measured by Secchi Disc, decreased over the same period from a mean of 164 cm to 40 cm. The Lake is now displaying the same signs of eutrophication as are all-too-many lakes in temperate regions.

These vegetation changes have been the most obvious changes in the Lake. No less significant, however, have been the fluctuations in the fortune of the commercial fishery.

The Lake Fishery

The fishery of the Lake is based (with the exception of the *Barbus amphigramma* catch) upon the artificiallyintroduced species. These species are also essential in the maintenance of some 80 species of piscivorous birds, together with several species of amphibians and two of mammals. Although fish introductions began in the 1920s (*see* above) the commercial gill-net fishery did not open until 1959, exploiting *Oreochromis spilurus niger* and *Tilapia zillii*. The latter was initially only present as a small proportion of the catch: the first few years of the fishery coincided with a period of rapidly rising water-level which was probably not favourable for the feeding and nesting behaviour of *T. zillii*. *O.s. niger* was subsequently replaced by a hybrid between it and *O. leucostictus* (Elder *et al.*, 1971) which dominated the catch through the early 1960s.

From 1964 to 1976 the water-level remained high and was stable within a range of about 2 m, resulting in the formation of lagoons and littoral zones extensively colonized by macrophytes. Siddiqui (1979) found that lagoons were the preferred habitat of the herbivorous, substrate-breeding *T. zillii*, whilst the lagoons and littoral were preferred by *O. leucostictus*, as accumulations of detritus provided its major food-source, namely chironomid larvae. Most hybrids and all *O. s. niger* had disappeared by 1971; this was attributed by Siddiqui (1979) to the disappearance of weed-free breeding and nursery grounds, the preferred habitat of this species. By 1975 the cichlid catch consisted of about 74% *O. leucostictus* and 26% *T. zillii* (Siddiqui, 1977).

A decade later, following the high water-levels and disappearance of lagoons and submerged plants in the early 1980s, the catch was less than 2% *T. zillii*, being 98% *O. leucostictus*. This is still the proportion in the commercial catch, although recent experimental netting during 1987 has recorded a higher proportion of *T. zillii* in the main Lake and the dominance of this species in Oloidien Lake (which is closed to commercial fishing).

The gross tonnage of fish harvested from the Lake has fluctuated considerably in the three decades of the fishery (Fig. 5). Initially the mesh-sizes of nets used were 13 and 14 cm. This was reduced to 11 cm by 1961 and to 10 cm

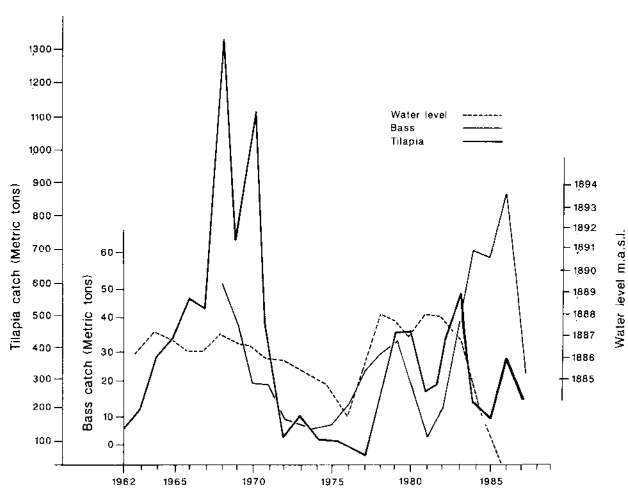

FIG. 5. *Changes in the yield of the fishery of Lake Naivasha. Records provided by the Department of Fisheries, Ministry of Tourism & Regional Development, Nairobi, Kenya.*

by 1970, with a period in the late 1960s when sizes down to 7.5 cm were used in order to sustain a frozen-fillet factory (Siddiqui, 1977). There was a rapid decline in catches in 1970–72 which Siddiqui (1977) attributed to over-fishing, followed by strict enforcement of the 10 cm mesh by the Fisheries Department from 1973 onwards (Litterick *et al.*, 1979). Malvestuto (1974) showed that the 10-cm mesh-size, however, caught *O. leucostictus* at a length of 20 cm, which was only 3 cm (or *c.* 6 months) past their attainment of sexual maturity, leaving them only a very short time to breed before exploitation. The fishery started to recover after 1975–76; since that time it has fluctuated, with two peaks and two troughs. In 1987–88, catches of both the *Tilapia* and the Bass were low.

The Crayfish fishery has had mixed fortunes in its shorter time-span. Initially opened in 1975, catches of several hundred metric tons annually were exported, mainly to Europe, up to 1983. Since then, annual catches have averaged around 40 metric tons — for local, mainly tourist, consumption.

UNDERLYING CAUSES OF ECOLOGICAL CHANGE

Most of the dramatic changes in vegetation and fisheries have occurred over the last 15 years, during times when there has been no continuous wide-ranging ecological monitoring of the Lake. Possible explanations can be pieced together from a chronological interpretation of scattered observations and events, as follows.

In the late 1970s the fishery's fortunes began to revive, as the regulation of minimum mesh-sizes became effective. Bass catches recovered first, and this may have been a consequence of the Crayfish introduction in 1970, as by 1975 the Crayfish were thriving (Lowery & Mendes, 1977*b*), when they made up 78% of the Bass diet (Siddiqui, 1977). After 1977, *Tilapia* catches began to recover, probably associated with the increased productivity of the littoral zone which occurs on the rising phase of tropical lakes (McLaughlan, 1974; Malvestuto, 1974).

Aquatic vegetation-change began with the reduction of Water-lilies, which had disappeared from the eastern part of the Lake by 1973–74 (R. Mennell, pers. comm.), and from the rest of the Lake by the end of the decade. Coypu are generally blamed for the disappearance of Water-lilies, on which individuals were widely observed feeding (J. Hayes, pers. comm.), and Water-lily shoots made up a major part of the Coypus' diet (Gibson, 1973). However, it is difficult to see how they could have eliminated the rhizomes of the plant sufficiently to wipe out the entire Lake population. Over the same period, though, the Louisiana Red (Swamp) Crayfish, *Procambarus clarkii*, spread throughout the littoral regions following its first introduction to the eastern part of the Lake in 1970 (*see* above).

It is probably not coincidental that Water-lilies began to disappear in the eastern part of the Lake at around the same time that the Crayfish populations were high there (up to 4 per m^2 were reported by Lowery & Mendes (1977*b*)). *P. clarkii* is omnivorous in Lake Naivasha (personal observations) but herbivorous on aquatic plants in the southern United States (Penn, 1943). Many related species are known to have severe effects upon aquatic macrophytes, including both submerged and floating-leafed species, at densities above about 3 per m^2 (Magnuson *et al.*, 1975; Lodge & Lorman, 1987). It is likely that Water-lilies disappeared under the combined grazing pressure of Coypu and Crayfish — initially from the eastern shores, where the Crayfish were denser, and by 1980 from the entire Lake. Crayfish would then have had a substantial grazing effect upon the submerged vegetation, which was reported to be abundant in 1979 but had completely disappeared from the Lake by 1983, the last year in which Crayfish harvests exceeded 100 metric tons.

When once the macrophytes had disappeared, Crayfish could only subsist as detritivores; since 1984, Lakeside residents have noted a marked reduction of Crayfish in the littoral zone. Residents of Oloidien have never noted many Crayfish in that Lake, although Crayfish colonized it during the late 1970s. The density of Crayfish in Oloidien Lake probably did not reach levels high enough to cause plant damage.

In the early 1980s the wind-blown floating mats and Papyrus 'islands', of up to about 15 km^2 in area, which became a common feature of the Lake (Gaudet & Falconer, 1982; Harper, 1984), must have inhibited to some extent the growth and regrowth of aquatic vegetation, although they are unlikely to have been responsible for the disappearance of Water-lilies. Siddiqui (1977) had implicated the spread of *Salvinia* mats as a factor in the decline of fish catches, but this is unlikey to have been true in the 1970s because of the dominant effect of overfishing due to the use of small-mesh nets. However, it may have been true for the period after the spread of mats and 'islands', because there was a rapid decline in catches in 1981–82, followed by a recovery as the floating vegetation became grounded.

From 1984 and onwards, aquatic vegetation returned to the littoral zone during a period of continued decline of water-level. The abundance of submerged plants in 1979 following a period of rapid water-level rise, and then again in 1984–87 during a period of water-level decline, suggests that the aquatic plant species are able to adapt rapidly to water-level changes. The reappearance of both submerged vegetation and Water-lilies after a period of up to ten years' absence from the Lake, is almost certainly a result of the disappearance of Coypu and the population decline of Crayfish; in 1987 Crayfish density was found to be below 0.25 per m^2 (measured in 50 random 1 m^2 frame-samples in the littoral zone).

For the last four years *Tilapia* catches, although low, have been stable at around 200 metric tons; this may be because there was a zone of littoral submerged vegetation which provides food and shelter, even though the Lake's level continued to decline. The drop in Bass catches was most likely a consequence of the earlier decline in *Tilapia* and Crayfish, with Bass seeking alternative, less-accessible food such as amphibians and their own young, or maintaining an invertebrate diet beyond the size at which they would normally become piscivorous.

The loss of Papyrus between 1983 and 1988 has been due solely to clearance for both large-scale and subsistence agriculture as Lake levels have declined. The land thus reclaimed is flat and fertile; almost all is used for arable crops. It is inevitable that this process will have increased the nutrient levels in the Lake, both through leaching and runoff directly from the farmed areas (Njuguna, 1985) and through loss of the swamp's buffering effect in the inflowing river deltas (Viner, 1975; Gaudet, 1980). Nutrient concentrations measured in the Lake had approximately doubled between August 1984 and August 1988, *e.g.* from a median of 45 to 125 mg per m^3 of soluble nitrogen and from 5 to 12 mg per m^3 of soluble phosphorus. These are still fairly low by temperate shallow-lake standards but indicate a worrying increase; studies are now under way to calculate nutrient budgets on the Lake and identify major sources and nutrient sinks.

It could be argued that Lake Naivasha experienced low levels for more than a decade earlier in this century, and that the present phase is merely a repeat episode about which little needs to be done. However, during this earlier period there was little agricultural activity and dense Papyrus swamps developed. Now, there are only two small areas in the west and in the north of the Lake where natural vegetation is able to colonize the draw-down zone; 12 km^2 of Papyrus swamp was reduced to 2 km^2 (Anon., 1986). The loss of so much swamp may make recovery, when once the Lake-level rises, slow and incomplete.

MANAGEMENT OF THE LAKE SYSTEM

Two bodies have a direct control over some aspects of Lake Naivasha. The Department of Fisheries manages the fishery by the issue of licences and enforcement of the mesh-size regulations. The Ministry of Water Development issues licences for the abstraction of water for irrigation. Several other bodies have interests in the Lake — the local government agencies at Provincial, District, and Town Council, levels; national bodies such as the President's Commission on Soil Conservation and Afforestation, and local bodies such as the Lake Naivasha Riparian Owners' Association, are the main ones. The Department of Wildlife Conservation and Management now has an increasing local interest as two areas adjacent to the Lake — Longonot Volcano and Njorowa Gorge (Hell's Gate) — were declared National Parks in 1983.

Many people would like to see the Naivasha lakes and their catchment areas managed under some kind of unified authority similar to that of a National Park or National Reserve (Njuguna, 1982), although with so many people and so much money involved in intensive agriculture around the shoreline, this might prove difficult. It is essential, however, to draw up and operate some kind of whole-lake management plan, measuring and controlling land-use changes and water-uses. The most immediate threat comes from further agricultural clearance of lake-edge vegetation and the development of a serious imbalance between water-use (for irrigation and public water-supply) and water input coupled with storage capacity.

The vegetation — particularly the Papyrus swamps — is the key to the ecological health of the Naivasha Lake-system. The buffering effect of Papyrus is well documented, both for the former North Swamp area (Gaudet, 1980) and for other wetlands (Mavuti, 1981; Symoens *et al.*, 1981; Howard-Williams & Thompson, 1985). The importance of Papyrus and other aquatic vegetation-types at Naivasha extends far beyond their role in water chemistry. They are a vital component of the habitat requirements of many bird and mammal species of the Lake. Surveys have shown, for example, that the highest species-richness of birds in the Lake environs in 1987 occurred in marshland, submerged macrophyte, and Papyrus zones (Henderson, 1988). Fish Eagles (*Haliaetus vociter*) were more abundant in areas of Lake-shore fringed with Papyrus and *Acacia* trees and less abundant where such vegetation had been cleared (Smart, 1988*a*). Hippopotamus numbers (*Hippopotamus amphibius*) and group-sizes were highest in the western and southern areas of the Lake where Papyrus and natural vegetation zones (*Acacia–Cassia* scrub) were most extensive (Smart, 1988*b*).

Four immediate management etc. needs for the Lake can be identified which, together, seek to protect its semi-natural ecosystems while maintaining its health for long-term human exploitation. These are:

A. Some kind of continuous 'buffer-zone' at least 50-m wide is needed between areas of cultivation and the water's edge, in order to utilize the nutrient-retention properties of Papyrus swamp and retain a natural 'reservoir' of drawdown species. This essential beginning has already been voluntarily incorporated into guidelines which are being drawn up by the Riparian Owners' Association.

B. A management plan for the Lake, including the hinterland vegetation zones and major human uses in the catchment area, should be drawn up and followed. Essential components in this plan will be:

1) Establishment of the hydrological cycle of the Lake and its feeder streams, balancing human requirements for water supplies against both human and wildlife needs for maintenance of the Lake's ecosystems;

2) Management of the vegetation and land-use within the areas of the Lake's edge that are actually or potentially irrigated, balancing conservation of the natural vegetation-zones with the needs of human food and cash-crop cultivation;

3) Management of the overall pattern of agriculture in the catchment — to prevent erosion, nutrient losses, and disruption of the runoff patterns, in the higher-altitude areas where rainfall is greatest;

4) Planning of ecological and agricultural advice and incentive schemes to enable successful implementation of the above; and

5) Continuation of existing fisheries' policies which include licensing, mesh-size enforcement, poaching control, and maintenance of conservation zones for fish-spawning.

C. The establishment of a detailed ecological and hydrological monitoring programme to feed-in the information necessary for decisions on the management plan. The Government of Kenya has already established other lake-basin and river-catchment development authorities, as well as special bodies such as the Presidential Commission on Soil Erosion; perhaps a new but similar body is required now to encompass the specific needs of the Naivasha Lake-system. A start has been made in this direction by the establishment of a Lake Naivasha Environment Committee by the local District Commissioner.

D. The establishment of a programme of education on environmental and water conservation needs and their scientific basis — for administrators, farmers, and the public at large. Starts have been made at the Naivasha Wildlife and Fisheries Training Institute and the Elsamere Conservation Centre.

In the longer term, however, the range of natural habitats that are represented in the Lake and its terrestrial environs, can only be fully protected by integrated management which includes long-term conservation needs, or, as a last resort, by conservation-body ownership and administration of crucial areas. The western side of the Lake is the least developed and provides the only realistic area for some kind of conservation control-zone extending all the way from open water back through to the *Acacia* scrubland.

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Summary

Lake Naivasha is an important freshwater resource for Kenya's foreign-currency-earning agriculture and tourism, and for water-supply. It has always experienced extensive water-level fluctuations as a consequence of irregular rainfall patterns that are affected by continental-scale climatic events, and its communities — particularly of aquatic plants — were adapted to these changes.

Introductions of the Crayfish *Procambarus clarkii* to the Lake, together with the accidental arrival of Coypu (*Myocastor coypus*) and the floating water-fern *Salvinia molesta* in the 1960s and 1970s, have combined to produ-

ce dramatic effects; the latest decade, during which the native aquatic flora was severely reduced, is just ending. A potentially serious threat is now posed by rapid agricultural expansion and swamp clearance during the present phase of declining Lake-levels — particularly as there is no overall management authority for the Lake.

Four main steps are proposed towards developing sustainable management of the Lake for all its uses. The first is that a 'buffer' of natural vegetation be maintained around the Lake-margin. The second step is that an overall management plan be drawn up, paying attention to: (1) the balance between human water-use and maintenance of the Lake; (2) the balance between agriculture and wildlife conservation in the irrigated zone around the Lake; (3) the overall pattern of land-use within the Lake catchment; (4) the provision of an agricultural advice and incentives scheme to cover the above; and (5) continued careful management of the Lake fishery. The third step is that a full-time ecological and hydrological monitoring programme be implemented, to provide the accurate information necessary for implementation of the management plan. The fourth step is the establishment of an effective programme of education on environmental and water conservation needs and their scientific bases.

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