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Human impacts on the African Great Lakes*

Richard Ogutu-Ohwayo[1], Robert E. Hecky[2], Andrew S. Cohen[3] & Les Kaufman[4]
[1] *Fisheries Research Institute, P.O. Box 343, Jinja, Uganda*
[2] *Freshwater Institute, Fisheries and Oceans, 501 University Crescent, Winnipeg, Manitoba R3T 2N6, Canada*
[3] *University of Arizona, Tucson, AZ 85721, U.S.A.*
[4] *New England Aquarium, Central Wharf, Boston, MA 02110, U.S.A.*

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Synopsis

The African Great Lakes are important sources of fishes and water for domestic use, are used as avenues of transport, and receive agricultural, domestic and industrial effluents and atmospheric residues. Some of these lakes have speciose fish faunas of great interest to science. The catchment areas of some of the lakes are highly populated and user conflicts have increased the demands on the lakes' resources. There have been drastic reductions in fish stocks in most of the lakes due to overfishing. Introductions of new fish species, though followed by increases in fish catches, have been accompanied by a decline and in some cases extinction of native fish species. Some of the lakes have been invaded by the water hyacinth, *Eichhornia crassipes*. Agricultural activities, deforestation and devegetation of the catchment areas have increased siltation, and led to loss of suitable habitats and biodiversity. There are increased nutrient inputs from agriculture, sewage and industrial discharges and combustion processes which can cause eutrophication. There are also increased threats of toxic pollution from industrial waste discharge, mining, pesticides, and oil residues and spills. Climatic changes may also affect thermal stability of the lakes. These factors threaten availability of dietary protein, clean water and biodiversity. National and international efforts are required to manage the fisheries, guide the introduction of exotics, conserve biodiversity, control the water hyacinth, control eutrophication, reduce input of contaminants and manage climate change.

Introduction

Most of the African Great Lakes (Figure 1) are located in Eastern Africa. They include natural lakes: Lake Victoria (68 000 km^2 – the second largest lake in the world), Lake Tanganyika (33 000 km^2 – the second deepest lake in the world), Lake Malawi (30 000 km^2), Lake Turkana (7200 km^2), Lake Albert (6800 km^2), Lake Kyoga (2700 km^2), Lake Kivu (2700 km^2) and Lake Edward (2325 km^2). Several smaller lakes like George, Nakuru and Naivasha as well as man-made lakes such as Kariba (5250 km^2) and Cabora Bassa (1739 km^2) which are located in the Great Lakes region, have been useful in understanding the processes within the Great Lakes.

The African Great Lakes are an immense source of dietary protein and clean water. They are also avenues of transport, recreation and provide revenue through tourism and fish export. These lakes are critical as sources of food in Africa where al-

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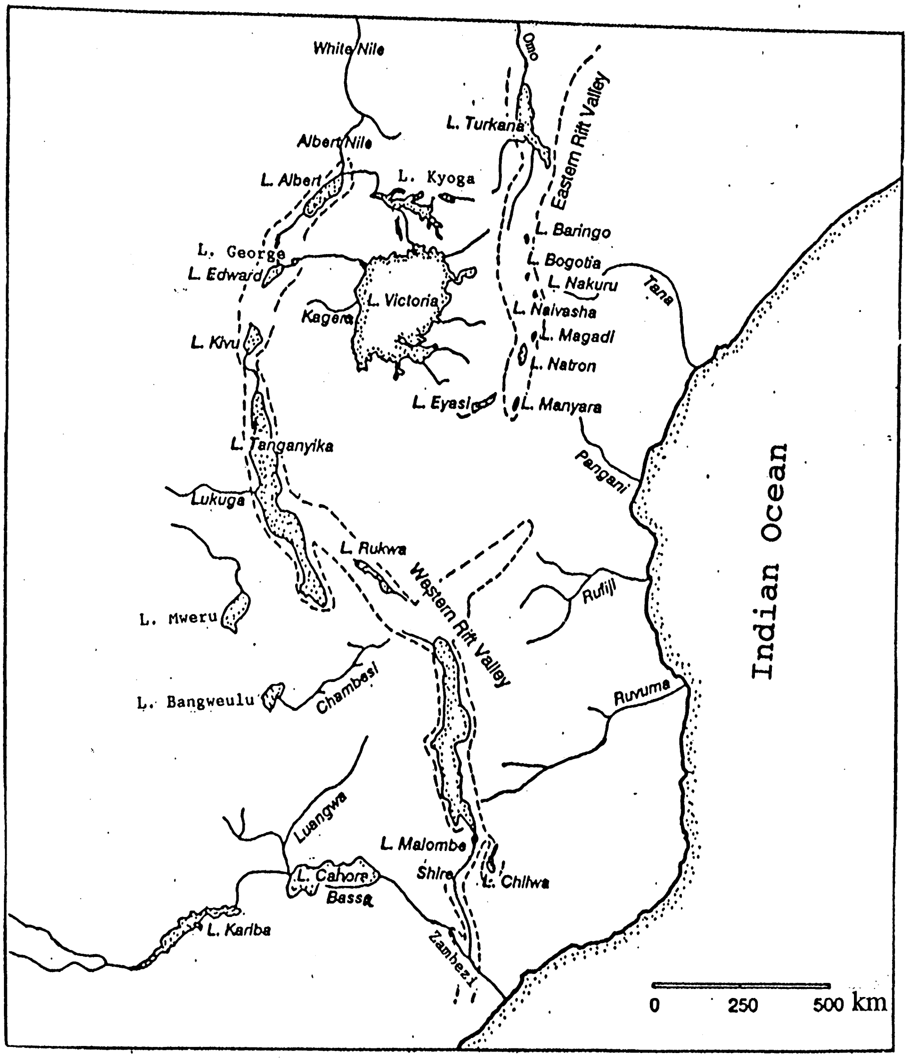

Figure 1. Map of the Great Lakes region of Africa showing the location of the African Great Lakes.

ternative sources of protein such as beef and chicken are either scarce or too expensive for most people. This is in contrast to developed countries where there are many alternative sources of protein and where recreational values for the large lakes are proportionately more important. In Africa there are generally no trash fishes: most types and sizes of fishes are eaten. Fish is normally the cheapest source of animal protein and comprises 50% to 70% of the animal protein consumed by the people within the African Great Lakes' region (Cohen et al. 1993). Most of the inhabitants around the African Great Lakes get water for drinking and other domestic uses directly from the lakes without any prior treatment. Any contamination that would make this water unsuitable for human use would have detrimental social, medical and economic impacts.

Lakes Malawi, Tanganyika and Victoria, in particular, harbour unique and diverse fish faunas of which most species are endemic. Many of the cichlids have undergone remarkable speciation within individual lakes. Lake Victoria has, or had over 300 haplochromine cichlid species, over 99% of them endemic (Goldschmidt & Witte 1992, Witte & Oijen 1990, Witte et al. 1992a, b). Lake Malawi has perhaps 500 haplochromine species of which only about five are not endemic (Fryer & Iles 1972). Lake Tanganyika has the richest fish fauna on earth (Coulter 1991). Studies of haplochromine cichlids have been useful in understanding speciation.

During this century, the African Great Lakes have experienced declines in fish catches, reductions in fish species diversity and deterioration in water quality. These changes are mainly due to overexploitation of the fishes, introduction of exotic species, degradation of the fish habitat and pollution. The Laurentian Great Lakes of North America went through similar changes and it has cost billions of dollars to reverse or mitigate only a few of the problems; meanwhile new problems due to human activities have continued to crop up. The riparian African states do not have the resources to clean up the lakes: therefore they should prevent conditions in the lakes from deteriorating further while there is still time to act.

Human impacts on lake ecosystems can follow one or all of the following four steps (Hecky & Ogutu-Ohwayo 1990): (1) over-exploitation which leads to a decline in the fish stocks. This can lead to (2) species introduction to maintain fish catches. Increases in human population, intensive land use and industrialization can be followed by (3) eutrophication and rapid contamination of the aquatic system. If steps (1) to (3) are not regulated, they can lead to the final step (4), abandonment. This paper discusses how overexploitation, introduction of non-native species and activities in the catchment area of the African Great Lakes have affected fish catches, led to loss of biodiversity and deterioration in water quality, and suggests measures to reduce or mitigate these processes.

Human population growth

The pressures on the African Great Lakes have been increased by the very high rates of human population growth and that of livestock within the region, especially around the Great Lakes themselves. The rate of population increase of the countries in the Great Lakes' region is between 3 and 4% per annum (Hecky & Bugenyi 1992, Hecky 1993)

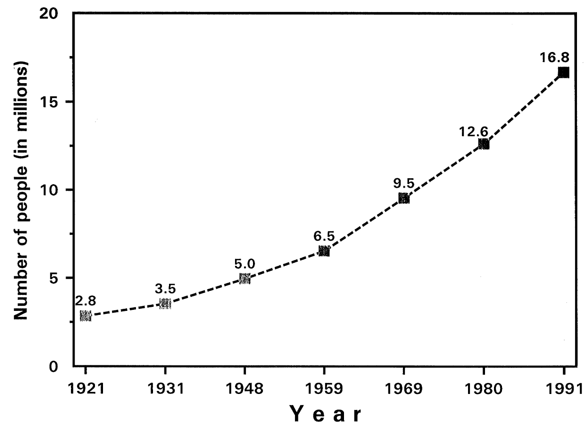

Figure 2. Changes in human population in Uganda between 1921 and 1992.

and is accelerating (Alabaster 1981). For instance, in Uganda, human population increased almost exponentially from 2.8 million in 1921 to 16.8 million in 1991 (Figure 2). This compares with a growth rate of about 0.6% per annum in most developed countries. This rate cannot be sustained even in the short term without severe impacts on the aquatic resources. The total human population of the countries around the Great Lakes with a total surface area of 7 449 000 km^2 was 178 million in 1985 and is expected to reach 287.56 million by the year 2000 (Cohen et al. 1996). In addition, the livestock population around some of the African Great Lakes is close to that of humans (Bootsma & Hecky 1993). Many rapidly growing urban centres are also located along the shores of the Great Lakes, especially Lake Victoria. This high population has increased the demand for agricultural and domestic water supply and increased the discharge of waste, and pollutants into the lakes. It has also increased the demand on land for livestock, agriculture and fuel wood. These have accelerated the rates of devegetation and deforestation thus enhancing erosion, sedimentation, siltation and nutrient loading into the lakes (Hecky 1993, Bootsma & Hecky 1993).

Impact of fishing activities

The best documented impact of man on the African Great Lakes is overexploitation of the fisheries.

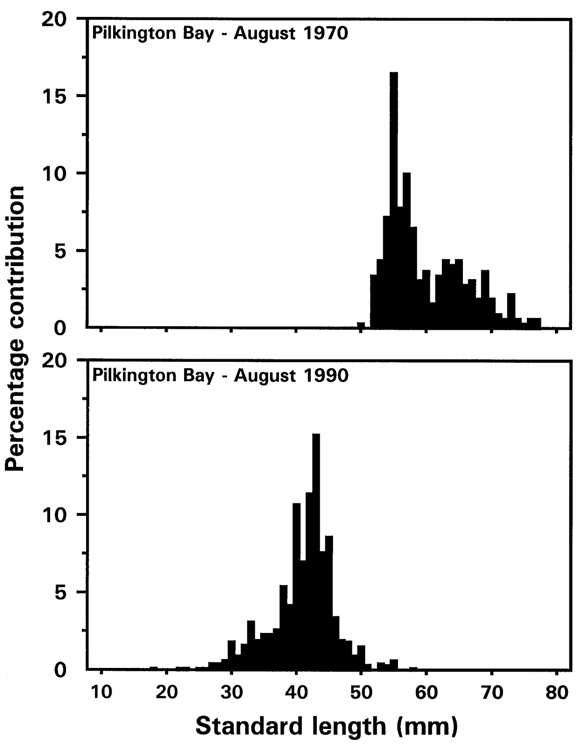

Figure 3. Changes of the population structure of *Rastrineobola argentea* in the northern water of Lake Victoria following human exploitation.

Originally, the fisheries of virtually all the African Great Lakes were subsistence in nature and were mainly confined to inshore areas where fishermen used local materials such as seine nets of papyrus, basket traps, harpoons and hooks operated from simple rafts or dugout canoes (Graham 1929, Jackson 1971). The fishing effort was therefore low, and caused little or no damage to the fish stocks.

The catch per unit effort of the most important commercial species started to decline following introduction of more efficient fishing gears and increases in fishing effort (Jackson 1971, Ogutu-Ohwayo 1990a). The biggest problem on virtually all the African Great Lakes is introduction of fishing techniques without assessing their impact on the fisheries and without having a means to control them. Development almost invariably has preceeded research and management. Management practices must be improved and become anticipatory if the fisheries resources are to be sustained or even extended in time.

Lake Victoria

The impact of human activities have become manifest more prominently on Lake Victoria than the other Great Lakes. This is probably because Lake Victoria has the largest catchment area, the highest human population in the catchment area and the biggest number of fast growing cities (Bootsma & Hecky 1993). Although it has the largest surface area, it is the shallowest (mean depth 40 m) and has the smallest volume of the Great Lakes. Therefore, its ability to dilute inputs is limited. The changes that have taken place in Lake Victoria can, therefore, serve as a signal to what may take place in the other African Great Lakes where certain human induced changes have not manifested themselves.

Originally, Lake Victoria had a diverse native fish fauna. About twelve taxa comprised the bulk of commercial catches and there were more than 300 haplochromine species (Witte et al. 1992a, b). *Oreochromis esculentus* was originally the most preferred and important commercial food fish in this lake (Graham 1929). *Labeo victorianus* formed an important fishery in the affluent rivers of Lake Victoria. The haplochromine cichlids and *Rastrineobola argentea* were abundant but because of their small size, were not much exploited when the larger species were still abundant.

The traditional fishing methods which consisted of basket traps, hooks and seine nets of papyrus had little impact on the fish stocks. The fishing effort on Lake Victoria started to increase with the introduction of flax gillnets in 1905. Initially it was possible to catch as many 50–100 *O. esculentus* per net of about 50 m (Jackson 1971). Within 3 years, the catch rate began to decline and there was evidence that *O. esculentus* was being overfished. This led to the first fishery survey of the lake by Graham (1929).

Graham confirmed that the stocks of *O. esculentus* were being overfished and recommended a minimum gillnet mesh size limit of 127 mm. This was imposed in 1931. However, there was no limit to the fishing effort, and this continued to increase along with the human populations, and as new markets for the fish became available due to improved transportation to urban centres. This was followed by a rapid fall in catch per unit effort of *O. esculentus*.

As the catch in the larger mesh nets decreased, the fishermen shifted to smaller mesh gillnets. The catches in the smaller meshes were better than those in the 127 mm mesh, and this made the 127 mm minimum mesh regulation so difficult to enforce that it was repealed in Uganda and Tanzania in 1956 and in Kenya in 1961. This marked the end of a uniform management policy for the lake. Meanwhile, fishing pressure had increased with the replacement of the flax gillnets in 1952 by synthetic fibre gillnets with greater efficiency and longer life span. Transportation on the lake was also improved by introduction of outboard engines in 1953.

Following the depletion of the larger species, fishermen shifted to exploit the smaller species; principally the haplochromines and *R. argentea*. Very small mesh nets of 38 mm to 46 mm were introduced to exploit haplochromines and a fine seine net of 10 mm to exploit *R. argentea*. The seine nets were particularly dangerous because they caught juveniles of the larger species. The dragging of the seine nets destroyed the breeding grounds of many cichlids. Furthermore bottom trawling was initiated in the Tanzanian part of Lake Victoria in the early 1970s to harvest haplochromines and this was followed by a drop in the catch rates and the size of haplochromines landed. However, before the trawl fishery was extended over the entire lake, populations of an introduced predator, the Nile perch, *Lates niloticus*, increased rapidly between 1977 and 1983 and accelerated the depletion of haplochromine stocks (Ogutu-Ohwayo 1990a, Witte et al. 1992a, b).

Stocks of *L. victorianus* which formed the most important fishery of the affluent rivers of Lake Victoria were damaged through intensive fishing at the mouths of rivers at the time that gravid individuals were ascending the rivers to breed (Ogutu-Ohwayo 1990a). *L. victorianus*, is a migratory species which lives in the lake but ascends the rivers to breed during the rainy seasons (Cadwalladr 1965). For this fishery to be conserved, it would have been necessary to limit fishing at the mouths of rivers at the time that the fish were ascending the rivers to breed.

Since the 1980's, the fisheries of lakes Victoria and Kyoga have been dominated by two introduced species, *L. niloticus* and *Oreochromis niloticus* and one native species *R. argentea*. All three species are heavily exploited by gillnets and seine nets. There is evidence that even the current stocks of these three fishes are being overfished. For instance, the size of *R. argentea* landed in Lake Victoria has decreased, apparently due to high fishing pressure and a shift to smaller mesh seine nets (Figure 3). Initially, *R. argentea* was exploited using 10 mm seine nets. However as the larger fishes have been depleted, the fishermen have shifted to smaller mesh seine nets of 5 mm mesh and below. The 5 mm mesh nets crop a lot of immature *R. argentea*.

Overexploitation of the fishery resources similar to that in Lake Victoria has been recorded on the other African Great Lakes.

Lake Tanganyika

The fishery of Lake Tanganyika was originally dominated by four *Lates* spp.; *L. mariae, L. angustifrons, L. microlepis* and *L. stappersi* and two clupeids; *Limnothrissa miodon* and *Stolothrissa tanganicae*. These species contributed over 90% of the landings (Bayona 1988). The original fishing methods which consisted of attracting fishes using burning bundles of reeds operated from simple canoes and then scooping the fish did not have much effect on the fishes. This practice and the limited demand for fishes made the fishery sustainable. The fishing effort on Lake Tanganyika increased in the 1950's with the introduction of an industrial fishery which used boats with engines and more powerful pressure lamps, in conjunction with purse seines and lift nets. Before the industrial fishery, *Lates* species contributed up to 57% of the fish catch (Cohen et al. 1996). After commencement of the industrial fishery, populations of the three largest *Lates* species dropped to very low levels. The fishery then shifted to the smallest *Lates* species, *L. stappersi*, and the two clupeids.

Populations of the two clupeids have been oscillating out of phase with their main predator, *L. stappersi*, presumably due to predator-prey interactions (Roest 1992). During this period, the total fish catch from the lake has decreased to the extent that the industrial fishery has in some case been abandoned.

There is also beach seining in some inshore areas of Lake Tanganyika, using fine mosquito seine nets. These, as for Lake Victoria, are harmful to the fishery.

Lake Malawi

The traditional fishing methods on Lake Malawi consisted of traps and beach seines operated from dugout canoes and small plank boats (Cohen et al. 1996). Fishing was originally artisanal using small craft, open water seines (chirimila), and gillnets. The fisheries consisted of *Oreochromis* spp. (chambo), the catfishes especially *Bagrus meridionalis*, the small pelagic cyprinid *Engraulicypris sardella* and small zooplanktivorous cichlid species (utaka). *Labeo mesops* was the most important riverine fishery and was originally second only to the chambo fishery. Ringnets were introduced in 1943, initially for catching *Oreochromis* species, and later to catch small pelagic species such as *E. sardella* (usipa) and small, zooplanktivorous haplochromine cichlids (utaka).

The cyprinid *L. mesops* which was the most important riverine species was, as in the case of the Lake Victoria *L. victorianus* (Ogutu-Ohwayo 1990a), depleted due to intensive gillnetting of gravid individuals on breeding migrations (Cohen et al 1993). In addition, degradation of the spawning grounds due to excessive siltation following deforestation and devegatation of the catchment area may have affected *L. mesops* (Cohen et al. 1996).

An industrial trawl fishery which was introduced on Lake Malawi during the 1970's to harvest small cichlids (Turner 1977a, b), accelerated the decline in stocks of certain species in the lake. The size and the number of cichlid species caught was reduced by up to 20% in some parts of the lake. The small meshsize nets used in the trawls also depleted the stocks of the larger species especially the catfishes and cyprinids through cropping juveniles (Alimoso et al. 1990).

On lakes Malawi and Tanganyika, cichlids are collected for ornamental fish trade. Many of these species are of limited distribution and their collection can reduce fish species diversity. Species translocated from their native range by aquarists can disrupt indigenous stocks (Ribbink et al. 1983).

Lake Turkana

Of all the African Great Lakes, Lake Turkana probably has the lowest human population around it. This is due to its location in an arid region. But even here, considerable changes in fish species composition have been recorded due to alterations in fishing practices (Bayley 1977, Hopson 1982, Kolding 1992).

There was minimal fishing on Lake Turkana prior to 1950's. Beach seining in the shallow and more productive Ferguson's Gulf started in the early 1950s. Gillnets were also introduced in the same area in the 1960s. Introduction of this fishing gear resulted in an increase in fish catches which reached a maximum in 1976. The high catches justified construction of a fish processing factory. The ready market provided by the factory fuelled an increase fishing effort which led to overfishing, and consequently to a decline in the stocks. High fish catches could not be sustained and the fish processing plant was abandoned only a year after its construction. However, the changes in the fish stocks in Lake Turkana have also been linked to environmental changes especially in lake level (Kolding 1992).

Management of the fisheries

It is clear that depletion in fish stocks in many of the African Great Lakes has been caused by introduction of more efficient fishing methods without having a means of regulating either their deployment or the overall fishing effort.

For stocks to be sustainable, it would be necessary to control the fishing effort. However on most of the African Great Lakes, controlling the number of fishermen, boats, or nets is challenging because, historically, most of these fisheries have been open for all. The management measures that have been introduced on some of the lakes have involved controlling only the type and mesh size of the gears used. The open access policy to the fisheries of the

African Great Lakes needs to be evaluated and the fishing effort controlled.

Fish stocks, especially the cichlids, are particularly susceptible to dragged gear such as beach seines and bottom trawls. Use of active gear such as seines and trawls which are dragged on lake bottom should only be permitted where there is scientific evidence of it causing no harm. Other active fishing methods such as lift nets and driving of fish into the nets by beating water are also becoming widespread on many of the African Great Lakes. These should be examined and where found detrimental banned.

Fish species introductions

The purpose of fish introductions

Another impact of man on the African Great Lakes has been the introduction of exotic fish species. Most of the introductions have been aimed at increasing fish catches from water bodies where native fish species had been depleted or where there were no commercially important food fishes. Fish have also been introduced into the African Great Lakes' region for aquaculture, to create sport fisheries for recreation and to control disease vectors and weeds (Ogutu-Ohwayo & Hecky 1991, Ogutu-Ohwayo 1992). The most outstanding examples of fish introduction into the African Great Lakes are those of lakes Victoria, Kyoga, Nabugabo, Kivu, Naivasha, and the man-made lakes Kariba and Cabora Bassa.

Nile perch and four tilapiine species *O. niloticus*, *O. leucostictus*, *Tilapia zilli*, and *T. rendalli*, were introduced or accidentally gained access to lakes Victoria, Kyoga and Nabugabo in the mid 1950s and early 1960 (Gee 1964, Welcomme 1964, 1966). Nile perch was expected to feed on haplochromines and convert them into a larger fish of greater commercial and recreational value (Anderson 1961). *O. niloticus* and *O. leucostictus* were introduced to supplement the stocks of the native tilapiines which had declined due to overfishing. *T. zilli* were introduced to feed on macrophytes which were not being utillized by any other commercially important species. *T. rendalli* appears to have been introduced accidentally from fish ponds (Lowe McConnell personal communication).

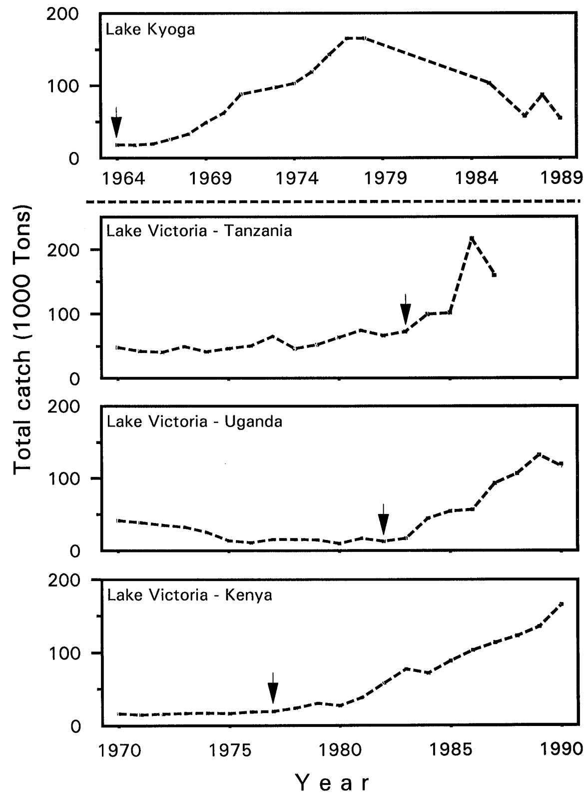

Figure 4. Changes in total fishery catch in the Lake Victoria and Lake Kyoga following fish species introductions. The arrows show the time when landings of Nile perch started increasing rapidly.

The Lake Tanganyika clupeids, *L. miodon* and *S. tanganicae*, were introduced into Lake Kivu in 1958 and 1960 and into Lake Kariba during 1967 and 1968 (Balon 1974, Spliethoff et al. 1983, Marshall 1988, Ogutu-Ohwayo & Hecky 1991, Ogutu-Ohwayo 1992) to create an open water pelagic fishery. Of the two clupeid species, only *L. miodon* was successful in establishing itself in lakes Kariba and Kivu. *L. miodon* from Lake Kariba spread down the Zambezi and became established in Cabora Bassa Reservoir.

Oreochromis spilurus was introduced into Lake Naivasha in 1925. This was followed by introduction of the black bass, *Micropterus salmoides* in 1929, and *O. leucostictus* and *T. zilli* in 1956 (Sidiqui 1977). Other fish species which have been introduced to the African Great Lakes' region are listed by Ogutu-Ohwayo (1992). They include the common carp, *Cyprinus carpio*, and the rainbow trout, *Oncorynchus mykiss*, which were introduced for aquaculture, the mosquito fish, *Gambusia affinis*, and the guppy, *Poecilia reticulata*, which were introduced to control mosquitoes, and the haplochromine cichlid, *Astatorheochromis alluaudi* to control snail vectors of bilharzia.

The introduction of the Nile perch and non-native tilapiines into lakes Victoria, Kyoga and Nabugabo, that of the black bass and several tilapiines into Lake Naivasha and that of the clupeids into lakes Kivu, Kariba and Cabora Bassa have had both positive and negative effects.

Beneficial outcomes of the introductions

The quantity of fish landed from Lake Kyoga increased about ten times and that landed in the Ugandan, Kenyan and Tanzanian region of Lake Victoria about two to six times following establishment of the introduced species (Figure 4). At least 80% of this catch was contributed by the two introduced species; Nile perch and Nile tilapia. These increases in fish catches have resulted in increases in the amount of fish available for food and in local and foreign earnings to the people in the region. As a result, many fish processing factories have been built around Lake Victoria to fillet Nile perch mainly for export. Although this has the positive effect of providing the hard currency which is much needed by the countries around Lake Victoria, it has a negative impact of depriving the local people of their cheapest source of animal protein because prices are now set by the international market. Also, the incentive created by the availability of a ready market has resulted in rapid increases in fishing pressure. Statistics of the Uganda Fisheries Department show that the number of fishing canoes in the Ugandan region of Lake Victoria more than doubled from 3264 boats in 1971 to 8674 boats in 1990. This over-capitalization of the fishery should be regulated as it will surely lead to depletion of the stocks.

The introduction of *L. miodon* into Lake Kivu and Lake Kariba and that which spread from Lake Kariba to the Cabora Bassa Reservoir resulted into an increase of fish catches (Ogutu-Ohwayo & Hecky 1991, Ogutu-Ohwayo 1992). The quantity of fish landed on Lake Kariba increased from 1000 tons in 1974 to about 24 000 tons by 1985 (Marshall 1988) of which *L. miodon* now contributes about 80%. The potential fish yield from Cabora Bassa Reservoir was estimated at 8000 tons and that from Lake Kivu at 10 300 tons (Petr & Kapetsky 1983).

Negative consequences of fish introductions

Increases in the populations of the Nile perch and the Nile tilapia were accompanied by a reduction and in some cases total disappearance of many native species from lakes Victoria and Kyoga (Ogutu-Ohwayo 1990a, 1992, Witte et al. 1992a, b). Although the stocks of many of the native species had declined due to overfishing, none had completely disappeared. Predation by the Nile perch and competition with the introduced tilapiines contributed to the final extermination of many native species (Hamblyn 1966, Gee 1969, Okedi 1971, Ogutu-Ohwayo 1985, 1990a, b, Witte et al. 1992a, b).

At the time of the establishment of Nile perch, haplochromines were the most abundant species in Lake Victoria (Kudhongania & Cordone 1974, Okaronon et al. 1985) and formed at least 80% by weight of the demersal fish stocks in the lake. Haplochromines were also abundant in Lake Kyoga (Worthington 1929) and in Lake Nabugabo (Ogutu-Ohwayo 1993). These haplochromines were the main prey of the Nile perch soon after its establishment in lakes Victoria, Kyoga and Nabugabo (Hamblyn 1966, Gee 1969, Okedi 1971, Ogutu-Ohwayo 1993). As the stocks of the Nile perch increased, those of the haplochromines decreased and became very rare. About 200 of the more than 300 species of haplochromines, are feared to have become extinct since Nile perch became abundant in Lake Victoria (Witte et al. 1992a, b) and a similar fate has befallen those of lakes Kyoga and Nabugabo (Ogutu-Ohwayo 1985, 1990a, b, 1993).

Introduction of the black bass into Lake Naivasha also resulted in a reduction in the number of fish species (Siddiqui 1977, Ogutu-Ohwayo 1992).

Although many of the other introduced species which have been introduced into the Great Lake's region have not been reported in the lakes themselves, some of them may over time enter the lakes. For instance, the black bass was recently reported to have entered Lake Victoria from fish culture facilities in the catchment area (Ochumba personal communication).

Mixing of species, especially tilapiines which are similar in ecological requirements and are closely related genetically has also contributed to elimination of some of the native species through competition and/or hybridization between native and introduced forms (Ogutu-Ohwayo 1990a, 1992, Ogutu-Ohwayo & Hecky 1991).

In contrast to the introduction of the Nile perch and the tilapiines into the diverse fish faunas of lakes Victoria and Kyoga, the establishment of *L. miodon* in lakes Kivu and Kariba did not have much detrimental effect. Lake Kivu had an impoverished fish fauna perhaps as a result of catastrophic fish kills due to volcanic activity. The original fish fauna of Lake Kariba was of riverine origin, thus the introduced clupeid did not encounter many fishes that were adapted to inhabit the pelagic zone of the man-made lake (but see Balon 1974, 1978, Balon & Bouton 1986).

Introduction of clupeids into other lakes

Following the success of *L. miodon* in lakes Kivu, Kariba and Cabora Bassa, it was suggested that the clupeid be introduced into Lake Malawi so that it could utilize the cladocerans and chaoborids which are abundant in the open water pelagic zone, and convert these into harvestable food fish (Turner 1982). This proposal was based on the observation that in Lake Tanganyika, where clupeids are abundant, cladocerans and chaoborid larvae are absent whereas in Lake Malawi, where clupeids are absent both chaoborids larvae and cladocerans are abundant. The native species of Lake Malawi were not efficient in converting pelagic zooplankton into harvestable fish (Turner 1982, Hecky 1984, Bootsma & Hecky 1993). However, unlike the impoverished fish fauna of lakes Kivu, Kariba and Cabora Bassa, Lake Malawi already has a complex fish community including a rich assemblage of endemic zooplanktivores. The effects of introducting the clupeid into such a system would be difficult to predict. It could compete with the Lake Malawi pelagic species and disrupt it as in the case of lakes Victoria, Kyoga and cause losses in fish species diversity.

Management of fish species introductions

From the above account, it is clear that fish species introductions can be either beneficial or hazardous (Balon & Bruton 1986). Therefore, clear guidelines governing proposed introduction should be developed specifically for the African Great Lakes region. The safest course, and likely the most advisable, is to restrict introductions to fishless lakes or those with an impoverished fish fauna.

Invasion by the water hyacinth

Some of the Great Lakes of Africa have been invaded by a weed, the water hyacinth, *Eichhornia crassipes*. The water hyacinth is native to South America. Because of its attractive appearance, it has been moved by man to many parts of the world as an ornamental plant (Harley 1990). Its first appearance in Africa was recorded in Egypt between 1879 and 1892. Since then it has spread to other parts of Africa including the Great Lakes region. It was reported in South Africa around 1910 from where it spread to Zimbabwe in 1937 and to Mozambique in 1942. The weed was reported on River Sigi near Tanga in Tanzania in 1955, and in River Pangani in 1959 (Harley 1991). The water hyacinth was reported in lakes Naivasha and Kyoga in 1988, Lake Victoria in 1990 and Lake Albert by 1991 (Harley 1991, Twongo 1993). It is believed to have invaded Lake Victoria via River Kagera, which enters the lake from Rwanda (Twongo 1993). The hyacinth is already present in River Shire (Tweddle 1992) and in Lake Malawi (A.J. Ribbink personal communication). If nothing is done to stop its spread, it may enter Lake Tanganyika since it is already present in the Great Lake's region and there is increasing commerce among the lakes.

The water hyacinth tends to invade water bodies where hydrological conditions have been altered by the activities of man or where nutrient levels in the water have increased (Harley 1990). For instance, hyacinth is frequently a problem in new reservoirs soon after their formation when nutrient concentrations are still elevated. The concurrent appearance of the water hyacinth in several lakes in Eastern Africa could have been stimulated by regional environmental changes, increased nutrient levels such as those recorded in Lake Victoria (Hecky 1993, Bootsma & Hecky 1993).

The water hyacinth is the world's worst aquatic weed (Harley 1990). It multiplies and spreads very fast. A single plant can produce 140 million daughter plants every year, enough to cover 140 hectares with a fresh weight of 28 000 tons. The spread of the water hyacinth along the inshore areas of Lake Naivasha took only three years (Harley 1991). Its spread into lakes Victoria, Kyoga and down the Nile into Lake Albert took about three years (Twongo 1993). The weed also produces seeds which can survive in mud for about 30 years, posing severe reinfestation problems.

The water hyacinth thrives in the shallow, sheltered bays which are also the most suitable breeding and nursery grounds for many fish species. It can, therefore affect breeding and juvenile feeding of many fishes. It forms dense mats which impede boat traffic, block irrigation channels and interfere with hydro-electric generation and with water treatment plants; the plants foul screens to the turbines and filters of urban water supplies. Water hyacinth provide breeding places for animal vectors that transmit human and animal diseases, such as the mosquitoes which act as intermediate hosts for the malaria parasites, and snails which act as intermediate hosts for schistosomes. The area below extensive mats of the water hyacinth is low in oxygen, which reduces habitable space for aerobic organisms. The loss of water by evapotranspiration by the water hyacinth is 3.5 times to that of free water surface. The rapid loss of water affects production and water balance. Along the Nile, where water is a very valuable asset for irrigation, it has been estimated that one tenth of the average annual yield was at one time lost due to hyacinth infestation (Harley 1990).

However, invasion by the water hyacinth may have some benefits to the fishery. Since its invasion of Lake Kyoga, and apparently Lake Victoria, populations of haplochromine cichlids which had been depleted by Nile perch predation (Ogutu-Ohwayo 1985) have improved (Ogutu-Ohwayo 1994). It is not possible to say exactly whether this is due to the spread of the water hyacinth, but the formation of continuous water hyacinth mats along the lake margins may have allowed isolated populations of haplochromines to spread from the more limited areas where they had formerly taken refuge and allowed them to establish breeding stocks. The hyacinth mats also provide some refuge from predation by the Nile perch, and floating mats of water hyacinth may act as dispersers of fish from one area to another.

The presence of the water hyacinth along the shores may reduce the effectiveness of beach seining and this could ironically help to maintain fish populations. Research is required to assess both the positive and negative impacts of hyacinth infestation.

Despite the possible positive effects such as those quoted above, the available information suggests that the water hyacinth is, on the whole, a serious environmental problem. Its spread should therefore be contained and it should be controlled in those areas where it is established. This can be achieved through manual or mechanical removal, chemical control and biological control (Harley 1990). Chemical control using herbicides may not be environmentally safe as the herbicides may affect fish and other aquatic organisms and make the water unsuitable for human and livestock consumption. Biological control using weevils and viruses has been used with success in many parts of the world (Harley 1990). However, the effects of an introduced organism cannot be predicted with certainty and this could under certain environmental conditions be harmful. Manual and mechanical removal is the only environmentally safe method. Since the water hyacinth is a new invader on most of the African Great Lakes, and since weevils may, if introduced, take long to establish themselves, manual removal should be initiated as soon as the weed is detected. This could be done by mobilizing the local community. The water hyacinth control within the African Great Lakes region will, however, need a regional effort as it affects waters shared by more than one country and it can be easily moved from one place to another.

Watershed activities: eutrophication and pollution

Until the 1970's, pollution and eutrophication were not thought to be threats to the African Great Lakes (Jackson 1973). However, Fryer (1972a, b) warned that although production and utilization of organic pollutants within Africa was low, due to low industrialization and little use of agricultural fertilizers, any pollutant entering one of the African Great Lakes would have worse effects than in a similar temperate lake. This is because tropical lakes are saturated at low oxygen concentration and yet oxygen consumption rates are high because of the high temperatures. Oxygen can therefore be depleted very quickly should the demand rise suddenly due to pollution and eutrophication. Because of their large surface area, immense volume, and high temperatures, the rate of water loss through evaporation is very high but the residence time for the water is long (Hecky & Bugenyi 1992, Bootsma & Hecky 1993). This means that pollutants entering a lake from the watershed or atmosphere can become concentrated relative to the source water.

Eutrophication and pollution of the African Great Lakes has and is likely to occur due to nutrient enrichment from human activities in the catchment area, industrial and domestic sewage and waste discharge, and from pesticides, mining, oil residues and oil spills.

Eutrophication

The risk of water pollution and eutrophication increases with increases in human population density and growth (Alabaster 1981) and with increasing urbanization. Of all the African Great Lakes, the catchment area of Lake Victoria has the highest population density (Bootsma & Hecky 1993) with several fast growing urban centres. That eutrophication can and in fact is already taking place in some of the African Great Lakes can be seen from the changes that have taken place in Lake Victoria.

A comparison of observations made in the 1960s by Talling (1965, 1966) with those made in the late 1980s and early 1990s (Ochumba & Kibara 1989, Hecky & Bugenyi 1992, Hecky 1993) provide strong evidence of eutrophication in Lake Victoria. Changes have been recorded in physico-chemical and biological parameters of the lake over the past three decades. Water transparency has decreased and is four times lower than during the 1960s. Oxygen concentration in the hypolimnion during the period of stratification has decreased and anoxia now occurs for longer periods and is more elevated in the water column (Hecky et al. 1994). The concentration of vital nutrients such as N and Si have considerably changed. Si concentration in the lake has decreased by a factor of 10. Algal biomass is 4 to 5 times higher than the mean value of the 1960s and phytoplankton production has doubled (Mugidde 1993, Hecky 1993).

The composition of aquatic invertebrates has also changed. Zooplankton composition has changed from a predominance of calanoid copepods to a dominance of cyclopoid copepods (Mwebaza-Ndawula 1993). The benthic invertebrates are dominated by taxa like chironomids, chaoborids and *Caridina nilotica*, which can tolerate low oxygen tensions.

The increases in eutrophication in Lake Victoria are due to direct and indirect human activities which include: (1) increased nutrient inputs from atmospheric sources and from changes in land use in the catchment area (Bootsma & Hecky 1993) which have increased nutrient loading and stimulated algal production, (2) introduction of the Nile perch which has disrupted the indigenous foodweb and caused biological production to accumulate at lower trophic levels, rather than as fish biomass and (3) changes in regional climate which may have altered the patterns of physical mixing and density stability, thus permitting prolonged periods of stratification and promoting deoxygenation and success of different algal taxa and other organisms.

Nutrient inputs

The possible sources of nutrient inputs are: atmospheric sources, industrial and domestic sewage, agricultural run off and soil erosion. Atmospheric inputs of nutrients appears to come mainly from combustion processes (Hecky 1993) and wind erosion. The main source of household energy within the Great Lake's region is wood and charcoal. Grasslands and forests are burnt as a cheap way of clearing land for agriculture. These processes have greatly enhanced nutrient loading to the atmosphere which is subsequently transported to the lakes by rain or as dry fall. Rainfall seems to be a primary source of fixed nitrogen and phosphorus not only in Lake Victoria but also in lakes Tanganyika and Malawi (Hecky 1993, Hecky & Bugenyi 1992, Bootsma & Hecky 1993). The concentration of P in rainfall and P deposition within Lake Victoria has increased over the past three decades while biological nitrogen fixation by blue green algae is now comparable to the input of N from the rain (Hecky 1993, Bootsma & Hecky 1993). Increased nutrient loading enhances algal growth which deoxygenates the water column as it decays. The rapid decrease in Si in Lake Victoria could be due to increased P inputs as was the case following eutrophication of the Laurentian Great Lakes (Schelske 1983). Since nutrient inputs from the catchment area appear to be a major cause of eutrophication in Lake Victoria and therefore a potential sources of eutrophication of the other Great Lakes, management of activities in the catchment area holds one of the keys to arresting eutrophication.

Clearing of vast areas of land within the Great Lakes' region has increased sedimentation and siltation of the lakes following soil erosion. Excess sedimentation increases turbidity and reduces light penetration which affects the rates of photosynthesis (Alabaster 1981) and can lead to algal succession. It can increase nutrient loading through release of nutrients from soil particles or reduction of nutrient concentration through adsorption of nutrients from the water column. In Lake Tanganyika, excess sedimentation has resulted in local reduction in species diversity. A comparison in species diversity of ostracod crustaceans between areas which have been undisturbed, moderately disturbed and highly disturbed by sedimentation shows that species richness in highly disturbed areas is lower than in undisturbed areas. There are also reductions in fish species diversity in between highly disturbed and undisturbed areas (Cohen et al. 1996).

Changes in the foodweb

The increase in algal biomass could in part, be due to the disruption of the food web by Nile perch predation. When the Nile perch was getting established, at least 80% of the demersal fish biomass by weight in Lake Victoria consisted of haplochromine species (Kudhongania & Cordone 1974). These species occupied virtually all trophic levels, including phytoplanktivores, zooplanktivores, insectivores, molluscivores, detritivores, piscivores (Witte et al 1992a, b). It is reasonable to assume that haplochromines maintained an efficient flow of organic matter in the system. Human exploitation and predation by the Nile perch depleted the various trophic groups of haplochromines (Witte et al. 1992a, b). The loss of phytoplanktivores has left much of the excess algal biomass produced due to increased nutrient accumulation unconsumed. Whatever the reduced phytoplanktivory by fishes, sedimentary P deposition has increased in Lake Victoria and paleolimnological studies indicate that changes in algal communities preceded the dramatic alterations of the fish communities (Hecky 1993). This indicates that changes other than Nile perch introduction are important.

Thermal stability due to climate change

The changes in physico-chemical characteristics of Lake Victoria could be due to increased thermal stability of the water column induced by climate change. The climate of the African Great Lakes region seems to be warming up as a result of human induced global and regional climatic changes (Hastenrath & Kruss 1992) and this may be manifesting itself in Lake Victoria. Higher temperatures were recorded in Lake Victoria in 1989/1990 than was the case about 30 years ago (Talling 1965, 1966, Hecky 1993, Hecky et al. 1994). This would make the lake more stable and less able to mix effectively (Hecky 1993) and could be contributing to the persistence of anoxia (Ochumba & Kibara 1989).

Pollution

Many of the fast growing urban and industrial centres within the African Great Lake's region are located on shores of the lakes. Many of the industries in these cities have no pollution control systems and some of them have very little or no waste treatment capacity and release their wastes directly into the lakes.

Industrial and urban wastes can contain also oil residues, heavy metals, such as copper and mercury, which are toxic to life. For instance, untreated wastes from tannery mills contain chromium, and wastes from pulp and paper mills contain copper. Wastes from mining activities also contain toxic heavy metals. Although concentrations of heavy metals can initially be small, some heavy metals are biologically concentrated at different trophic levels. Koeman et al. (1972) have recorded residues of various heavy metals such as arsenic, copper, tin, cadmium, zinc, and mercury in tissues of birds and in fishes from Lake Nakuru. These are likely to have come from industrial waste from Nakuru town. Deelstra et al. (1976) also detected significant quantities of heavy metals, arsenic, cadmium, lead, zinc and mercury in tissues of fishes from Lake Tanganyika. In Uganda, copper and cadmium from Kilembe mines have been detected in lakes Edward and George (Bugenyi 1979). Treatment of industrial wastes should be part of the planning process of the industries.

Pesticides can also be washed into the lakes. Contamination of the water by pesticides and other chemical pollutants may make it unpotable, kill the fish, or biomagnify to both reduce productivity and make the fishes unsuitable for human consumption. Pesticide residues have been recorded in both water birds and fishes such as *Oreochromis* spp., *Alestes* spp., and *Clarias* spp. in Lake Victoria (Cohen et al. 1996). Although these pesticides have not become a toxicity problem, some of the pesticides which have been encountered, such as dieldrin and aldrin, are persistent toxic compounds and may in future become hazardous. Unfortunately, some of these pesticides, although banned in developed countries because of their known toxicity, are freely sold and used in some parts of the Great Lakes region. There is therefore need to asses the impact of pesticides before they are used. Importation of pesticides which have been banned in other countries should not be allowed.

Petroleum wastes and oil spills are also becoming a threat as pollutants of the African Great Lakes and measures should be sought to avoid them. Petroleum exploration has been carried out in and around lakes Tanganyika and Albert (Cohen et al. 1996). Oil spills can occur if oil exploitation and production begins. Lake transport is important on some of the Great lakes, especially Lake Tanganyika. Boats going up and down these lakes discharge oil residues into the lakes.

Management of eutrophication and pollution

The quality of the water is affected by the input of nutrients and contaminants from the watersheds and airsheds. In order to minimise these, it will be necessary to: (1) establish a boundary of uncleared land along the shores of the lakes and associated rivers so as to reduce sedimentation and regulate the flow of nutrients and contaminants into the lakes, (2) ensure that industrial and municipal establishments have effective effluent treatment plants and that there are limits to the levels of effluents discharged into the lakes, and (3) minimise atmospheric pollution by industries and by extensive bush fires.

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