AFRICAN POLITICAL, ECONOMIC
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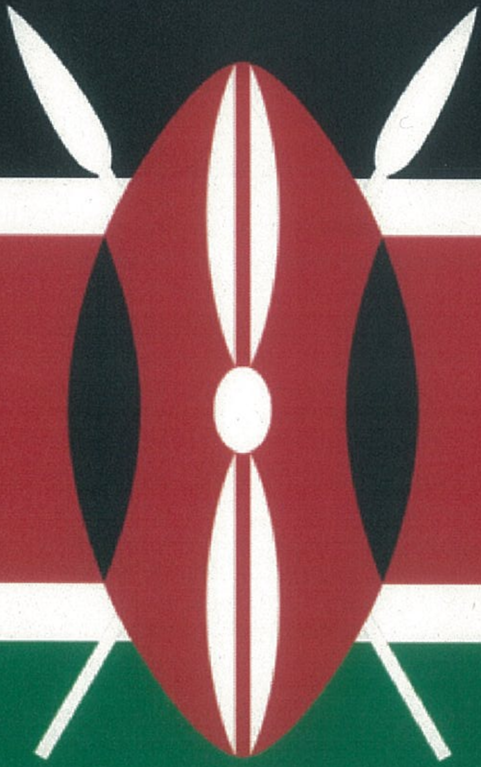
KENYA

Political, Social and Environmental Issues



James W. Adoyo ❖ Cole I. Wangai
Editors

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JAMES W. ADOYO
AND
COLE I. WANGAI
EDITORS

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PREFACE

In this book, the authors examine Kenya's current political, social and environmental issues. Topics discussed in this compilation include the mitigation and impacts of forest degradation in Kenya; fish biomanipulation of Kenyan lakes; the political and social dimensions associated with biotechnology regulation in Kenya; the developmentally disabled population in Kenya; status of Kenya's environmental management and protection challenges; and economic development and food security in Kenya.

Chapter 1 - Kenya covers a total land area of approximately 5.7million km2 between latitude 4°21' North and 4°28' South and longitude 34° and 42° East, bisected horizontally by the equator, and with diverse topography, hydrology and climate. The landforms range from the glaciated mountain peak of Mt. Kenya in central Kenya, which is almost under permanent snow cover, to upland plateaus in western Kenya, the coastal plains, and the vast savannah grasslands that dominate the rest of the country. It is divided by the Great Rift Valley that cuts across East Africa into the eastern part of the country dominated by Mt. Kenya and the Aberdare ranges (altitudes of between 4,000 – 5,200m) and the western region which slopes downwards from the Mau ranges and Mt. Elgon at an altitude of about 4,300m to the Lake Victoria basin at the far west. Within these physiographic areas, the country‟s hydrology is characterized by four major rivers (the Tana, Mara, Yala and Nzoia river basins), all originating from forested water towers (i.e. Mt. Kenya, Mau, Abaderes, Mt. Elgon and Cherangani hills). There are, however, many other smaller rivers that originate from the water towers that directly impact livelihoods of the local communities and the national economy. Kenya‟s rainfall depicts a bimodal regime with the rainfall peaks generally occurring in April/July (long rains) and October/November (short rains)

Chapter 2 - The self-described “social-ecologist”, Peter Drucker, said that what gets measured gets managed; a statement that could have welcomed political and social concepts into environmental matters. A case in point is the fish restocking (a type of fish biomanipulation) in many lakes in the world and with special reference in the tropics. However, due to the increased anthropogenic impacts and eutrophication of the aquatic ecosystem in the tropics (and in particular Kenya) is becoming increasingly apparent; the need for proper management strategies for a sustainable fishery is becoming non-negotiable. Under such a perspective, fish biomanipulation that was coined by Shapiro (1975) could be a self proclamation that the road from basic science to its application could be winding and the process laborious. Despite some positive results of fish biomanipulation in the temperate regions, this management approach seems to elicit ecological debate at political, environmental and social fora since its successes seems to be of short-term need. This paper reviews the fish biomanipulation process and principles, the successes and limitations; thereby highlighting on the need for defining theoretical explanations and their practical implications in the present scientific world. This is because details of the process have to be verified in the light of frequent future applications rather than on political and social undertones that damage the ecological wellbeing.

Chapter 3 - This article is written against the recent lighting episodes that killed over 40 people within a span of one week. Eight members of one family died after lightning struck their grass-thatched house in Mencheiwa village, Keiyo South District in the Rift Valley province of Kenya. Lightning is Kenya"s most underrated weather-related hazard in terms of response, management and research. It's also the most unpredictable and every year, kills over 10 000 people and injures about 100 000. GIS is used to map the spatial distribution of the hazard. This article discusses what makes lightning so dangerous, and compares with other weather hazards? Also presented is a map showing the spatial and temporal distribution of lightning mainly in the Rift Valley, Nyanza and Western provinces and of lately Central province. From this study, it is clear most lightning casualties are rural populations. Sixty six percent of the 47 counties are in the high lightning hazard zones. This paper argues that lightning is so dangerous since it is hard to know just when and where it is likely to strike-or how it will behave when it does. The study recommends a number of management approaches, awareness campaigns, research as well as reinstituting a relevant organisation.

Chapter 4 - Biotechnology revolution is poised to benefit the world poorest only if controversies associated with safety are regulated

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Chapter 2

FISH-RESTOCKING OF LAKES IN KENYA: SHOULD SOLEMNLY BE AN ENVIRONMENTAL ISSUE

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ABSTRACT

The self-described "social-ecologist", Peter Drucker, said that what gets measured gets managed; a statement that could have welcomed political and social concepts into environmental matters. A case in point is the fish restocking (a type of fish biomanipulation) in many lakes in the world and with special reference in the tropics. However, due to the increased anthropogenic impacts and eutrophication of the aquatic ecosystem in the tropics (and in particular Kenya) is becoming increasingly apparent; the need for proper management strategies for a sustainable fishery is becoming non-negotiable. Under such a perspective, fish biomanipulation that was coined by Shapiro (1975) could be a self proclamation that the road from basic science to its application could be winding and the process laborious. Despite some positive results of fish biomanipulation in the temperate regions, this management approach seems to elicit ecological debate at political, environmental and social fora since its successes seems to be of short-term need. This paper reviews the fish biomanipulation process and principles, the successes and limitations; thereby highlighting on the need for defining theoretical explanations and their practical implications in the present scientific world. This is because details of the process have to be verified in the light of frequent future applications rather than on political and social undertones that damage the ecological wellbeing.

Keywords: lakes, biomanipulation, political, social, ecological, management, Kenya

INTRODUCTION

Biomanipulation is a technique used to restore water quality in eutrophied lakes (Benndorf et al., 2002; Perrow et al., 2002)). Eutrophication is the accumulation of nutrients, particularly phosphorous, in aquatic systems. The process does occur naturally in all water bodies but human activities accelerate the process. Intense nutrient influxes into lakes cause dramatic changes to lake dynamics. Planktivores become abundant and reduce zooplankton (Mehner et al., 2002). Larger sized zooplankton species are diminished leading to dominance by smaller sized species. The ratio of planktivores to piscivores widens, reducing the ability of piscivores to control planktivore populations. Planktivores also recycle phosphorous in lakes through excretion that directly influences algae production (Mehner et al., 2002). High concentrations of phosphorous through external and internal nutrient loading promote algal blooms. Blooms harbour toxins that cause zooplankton and fish death, macrophyte decline, and a decrease in dissolved oxygen when they decay or die. Biomanipulation seeks to control blooms by increasing zooplankton populations to promote heavy grazing of algae (Benndorff et al., 2002). Majority of effort in rehabilitating eutrophication in lakes has been aimed at eliminating nutrient fluxes (Jeppesen et al., 2005). One of the better ways to reverse eutrophication is to reverse activities leading to increase in nutrients flux into the lake especially phosphorous (Benndorff et al., 2002). The method has great success especially with point source pollution, but it is expensive and enriched sediments may act as source rather than sink for phosphorus. With increased number of eutrophied lakes in the world, an alternative less expensive method of controlling eutrophication should be adopted. Little attention has been given to the possibility of restructuring the biological communities of the lakes as a direct approach to combating eutrophication. Benndorf et al (2002) argued that biomanipulation a relatively new technique may be an option to rehabilitation of eutrophied lakes. The concept was formally defined by Shapiro in 1975 (in Benndorff et al., 2002). He explained that Shapiro desired an alternative approach to lake restoration that relied less upon chemicals and engineering. Biomanipulation concept is not entirely new in lakes restorations. Caird in 1940 (in Benndorff et al., 2002) described a situation that occurred in a Connecticut pond; the pond suffered immense algal blooms and required copper sulfate treatments several times per year. The introduction of large-mouth bass into the lake eliminated the need for copper sulfate treatments and further observed the changes in the pond, but it is unclear if he fully understood how the large-mouth bass controlled the algae blooms. Perrow et al (2002) argued that biomanipulation is typically used in lakes that are small, shallow, and closed systems. He affirmed that biomanipulation tends to work well in shallow lakes since organisms are not spatially separated by depth. Also, nutrient levels are more static since losses to the hypolimnion are unlikely and believed that lakes need to be closed systems because organisms entering a lake through connections with other water bodies will inhibit the ability to control lake"s fauna.

EUTROPHICATION OF KENYAN LAKES

Eutrophication of freshwater lakes through the enrichment of water by nutrients (mainly phosphorus and nitrogen), is an increasing problem threatening lakes in Kenya (Mugidde et al., 2005; Kitaka et al., 2002). Lakes in Kenya suffer from point and nonpoint sources, with municipal sewerage and agriculture being the main source of anthropogenic phosphorus and nitrogen (Mugidde et al., 2005; Kitaka et al., 2002). The point source pollution in Kenya unlike most temperate regions has not yet been controlled (Kitaka et al., 2002; Mugidde et al., 2005). Factories and municipals continue to deposit their effluents into the lake unabated. The consequences of eutrophication are both environmental and socio-economical (Mugidde et al., 2005). This has resulted in major changes in the biological structure and dynamics of the lakes and often in a shift from a clear to a turbid state. Enrichment of the water has led to massive blooms of algae especially of the toxic blue-greens (Lung‟ayia et al., 2000; Kitaka et al., 2002; Mugidde et al., 2005).

Ballot et al. (2009) pointed out that the proliferation of the blue-green algae in Lake Naivasha is an indication of eutrophic condition of the lake. Due to continued nutrient enrichment, Lake Naivasha has changed from eutrophic to hyper-trophic (Kitaka et al., 2002). In Lake Victoria, the primary productivity has doubled and the algal biomass has increased 8–10-fold, accompanied by a shift in the algal species composition (Lung‟ayia et al., 2000). The chlorophyll-*a* concentration varies between 2 and 13 mg m^{-3} in the main lake and between 8.8 and 71 mg m^{-3} in the inshore waters (Lung‟ayia et al., 2000), compared to 1.2–5.5 mg m^{-3}and 30 mg m^{-3} in the same waters in 1960 and 1961, respectively (Talling, 1966). The increase in chlorophyll-*a* concentrations and the higher abundance of the buoyant cyanobacteria have resulted in decreased water transparency. The average transparency values (expressed as Secchi depth) have decreased from 7.3–7.9 m for offshore stations and 1.3–1.45 m in Nyanza Gulf in 1927 (Worthington, 1930) to 1.1–1.38 m and 0.58–1.68 m in the same areas, respectively, during 1994–1995 (Lung‟ayia et al., 2000).

Massive blooms of algae, especially the toxic blue-greens, are now a common occurrence in the Kenyan lakes. In lakes Victoria and Naivasha, anoxic water attributed to the use of oxygen by decaying flora is attributed to occasional fish kills (Ochumba, 1990). Increases in hypoxia might reflect a combination of increased nutrient levels and losses of phytoplaktivorous/detritivorous haplochromine cichlids (Lung‟ayia et al., 2000; Kitaka et al., 2000; Ballot et al., 2009). Continued eutrophication and dominance by toxic cyanobacterial blooms may further lead to decline in aquatic communities including zooplanktons. It is estimated that about 30–50% of the oxygenated waters volume has been lost in Lake Victoria since the 1960s, which has reduced the fish habitat (Mugidde et al., 2005).

Tropical lake communities are dominated by zooplanktivorous fish communities such as cyprinids which increase with increase in abundant with increasing eutrophication, leading to a decrease in biodiversity (Jeppesen et al., 2005). Increase in cyprinids abundance not only further enhances the eutrophication of lakes by increased planktivory and recycling of nutrients from the sediments, but also decreases the resource value of the lake. Lake Victoria is now dominated by a pelagic cyprinid, *R. argentea* (Njiru et al., 2008; 2010).

ZOOPLANKTON COMMUNITY STRUCTURE

Most likely due to high predation by fish, the zooplankton communities in tropical and subtropical lakes are frequently dominated by small cladocerans (like *Diaphanosoma, Ceriodaphnia* and *Bosmina*), rotifers, juveniles and small copepodites among the copepods (Branco et al., 2002; Garcia et al., 2002).

Zooplankton communities in Kenyan lakes are dominated by small cyclopoid, cladocerans and rotifers (Mergeay et al., 2004; Mwebaza-Ndawula et al., 2005; Masai and Omondi, 2005). In Lake Victoria for example, copepods consist mainly of *Thermocyclops, Mesocyclops* and *Thermodiaptomus,* cladoecera comprise of *Diaphanasoma, Daphnia and Ceriodaphnia.* There has been a decline in large-bodied cladocera such as daphnids associated with increase fish predation which coincides with changes in fish compositions in the lake. There is noticeable seasonal zooplankton abundance in Lake Victoria, related to peaks and predation impacts of planktivorous fishes including *R. argentea* and juvenile fishes (Mwebaza-Ndawula et al., 2005). Low zooplankton densities coincide with high stocks of larval *R. argentea* during the month of July while in the deep offshore waters where pelagic densities are low, high zooplankton abundance occur (Mwebaza-Ndawula et al., 2005). Large bodied daphnia such as *Daphnia lumholtzi* is confined to the deep offshore waters where planktivorous fish densities are low (Mwebaza-Ndawula et al., 2005).

Lake Naivasha is devoid of specialised zooplanktivorous fish, and is therefore considered to have an incomplete aquatic food web (Mavuti, 1990; Hickley et al., 2002). The fish species introduced to Lake Naivasha are thought to have little impact on the large zooplankton (Mavuti, 1990) because of their mainly herbivorous, omnivorous or piscivorous diets. This view on the food web of Lake Naivasha contrasts with the long-term perspective offered by Mergeay et al. (2004), which suggested a significant influence of fish predation on Daphnia community history in the lake. The juveniles, of these fishes are zooplanktivorous. For example, *Daphnia magna* was common in Lake Naivasha throughout the 19th and early 20th centuries, but disappeared (or was decimated beyond detection) within a few years after introduction of largemouth bass and cichlid fishes in the late 1920s. Because of its large size (2–5 mm), *D. magna* is especially prone to visual predation by fish. Whether fish stocking was the principal reason for the population collapse of *D. magna* in Lake Naivasha is uncertain, but it probably accelerated the process.

Mergeay et al. (2004) argued that both turbidity and macrophytes provide a refuge for Daphnia against fish predation, because of decreased visibility. Turbidity can also impact Daphnia negatively because of obstruction of the filter apparatus and the resulting decrease in feeding efficiency.

The recent reappearance of large-bodied Daphnia species (*D. magna, D. barbata, D. lumholtzi, Daphnia* sp. nov. type Limuru) after 20–110 years of absence can be explained by their release from fish predation, following a dramatic increase in turbidity caused by excess clastic sediment input from eroded catchment soils (Mergeay et al., 2004). The small-bodied species *D. laevis* has fared less well recently, presumably because the benefit of lowered predation pressure is counteracted by more pronounced negative effects of increased turbidity on this species and loss of submerged macrophyte beds which formerly served as predation refuge.

FISH BIOMANIPULATION APPROACHES

Radke et al (2002) noted that the premise behind biomanipulation is the manipulation of biotic components of a lake as opposed to conventional nutrient management. They added that the goal of water quality improvement is achieved through the manipulation of higher level consumers of a lake. They suggested two general biomanipulation approaches used to increase zooplankton populations: One method to increase zooplankton populations is to remove planktivores through a fish kill or removal. Rotenone, a powdered form of derris root in 5% formulation, is an effective piscicide used to restructure or eliminate certain fish communities.

Radke et al (2002) described that all fish are susceptible to its impacts but planktivores and benthivores are the main target. A dose of 1.0 mg 1^{-1} will achieve a complete fish kill. They noted that the dose can be altered to fit the level of fish kill desired. They cautioned that Rotenone application is mostly effective in warm weather (optimal water temperature of 20°C or above), but it remains toxic in the lake for long periods of time in cold weather. However, they believed that fish removal can be accomplished through intense seining. Benndorff et al (2002) pointed out that Rotenone may produce undesirable side effects in the ecosystem and may affect untargeted fauna. This means that zooplanktons are killed and may not rebound for several months, causing a decrease in algae grazing rates. Benndorff et al (2002) believed that application prior to spawning of desired species will enhance the success of Rotenone use. For example, Rotenone should be applied in spring prior to large-mouth bass spawning. On the other hand, they argued that seining activities produce little success. Benndorff et al (2002) implied that seining may only be performed in shallow lakes with smooth bottoms. But, most lakes do not have smooth bottoms which lead to partial harvesting and tearing of the net. The technique is also costly since it is labor intensive.

Radke et al (2002) suggested the second method to increase zooplankton to be the direct stocking of faunal components of a lake. Piscivore stocking increases predation of planktivores. A decrease of planktivores leads to reduced predation of zooplankton and an increase in large filter-feeding zooplankton which exert a higher grazing pressure on phytoplankton. Larger zooplanktons are able to consume a wider range of algae types compared to smaller zooplankton (Starling et al., 2002). Reduction in algae and the resultant decline in nutrients improve water transparency and may allow growth of submerged vegetation. The vegetation further acts as filter of nutrients entering the lake and increase water quality. The macrophytes may also act as refuges for zooplankton increasing their populations (Helminen et al. 2002).

In their study, Meijer et al. (1999) found that when more than 25% of the lake surface is covered with submerged macrophytes the algal biomass is repressed by the macrophytes and water clarity increased. Nonetheless, the species composition of the macrophytes community may be important. Van Donk and Gulati (1995) found *Chara* can keep the water clear for a long period during the year, but *Potamogeton berchtoldii* may die off early in the summer increasing water turbidity. However, in practice it is difficult to unravel the specific mechanisms involved in clearing the water, since several processes occur simultaneously, and data-sets are frequently not detailed enough to sort between the alternative hypotheses (Meijer et al., 1999).

The desired fish composition is 30-40% piscivores which corresponds to a biomass ratio of 0.28 to 0.66 piscivores to planktivores. The average stocking rates of zooplankton are 4 million individuals (Benndorff et al., 2002).

Helminen et al (2002) noted that the success of piscivore stocking is limited. When used as the sole technique, stocking does not appear to provide long term effectiveness. One problem is the inability to stock the number of fish required to control abundant planktivore populations. Another problem to be related to is the nonexistence of spawning grounds and habitat requirements of piscivores in eutrophied lakes. Hence the way to increase the success of stocking is to perform a fish kill or removal prior to stocking to decrease planktivores.

BIOMANIPULATION IN KENYAN LAKES

Though extreme inputs of nutrients can nowadays be reduced and controlled, additional measures to reverse eutrophication may be needed. According to Mehner et al. (2002), biomanipulation is a widely accepted and frequently applied ecotechnology to improve the environmental and ecological quality of standing waters. These often involve biomanipulation, typically mass removal of zooplanktivorous fish- like the cyprinids. However, the success of biomanipulation has many times been limited or short lived mostly because the more subtle impacts of biomanipulation on the ecosystem-wide processes of lakes have not been thoroughly studied (Syväranta, 2008).

Introductions of fish species into an aquatic system is a type of “fish biomanipulation.” A case in point is lakes Victoria and Naivasha in Kenya (Figure 1). In Lake Victoria, Nile perch, *Lates niloticus* (L), *Oreochromis niloticus* (L), *Oreochromis leucostictus* (Trewavas), *Tilapia zillii* (Gervais) and *Tilapia rendalli* (Boulenger) were introduced into the lake in 1950s and 1960s (Welcomme, 1967; Ogutu-Ohwayo, 1990). In Lake Naivasha, introduced species were largemouth bass, *Micropterus salmoides* Lacépède, blue spotted tilapia, *Oreochromis leucostictus* (Trewavas), Redbelly tilapia, *Tilapia zillii* (Gervais), common carp, *Cyprinus carpio* Linnaeus , straightfin barb, *Barbus paludinosus Peters, guppy, Poecelia reticulata* Peters and a crustacean, red-swamp crayfish, *Procambrus clarkii* (Girard) (Ojuok et al., 2008; Kundu et al., 2010).

Lakes Victoria and Naivasha scenarios offer the need to look at limitations and the successes of fish biomanipulation in the tropics and Kenya in particular.

Fish restocking is mainly done to improve production and conditions of the lakes based on decisions agreed upon by the social, environmental and political spheres without considering the ecological consequences of such habitats. In Lake Naivasha, fish were introduced for commercial purpose and to fill vacant niches left by the extinction of endemic species (Britton et al., 2007; Ojuok et al., 2008).

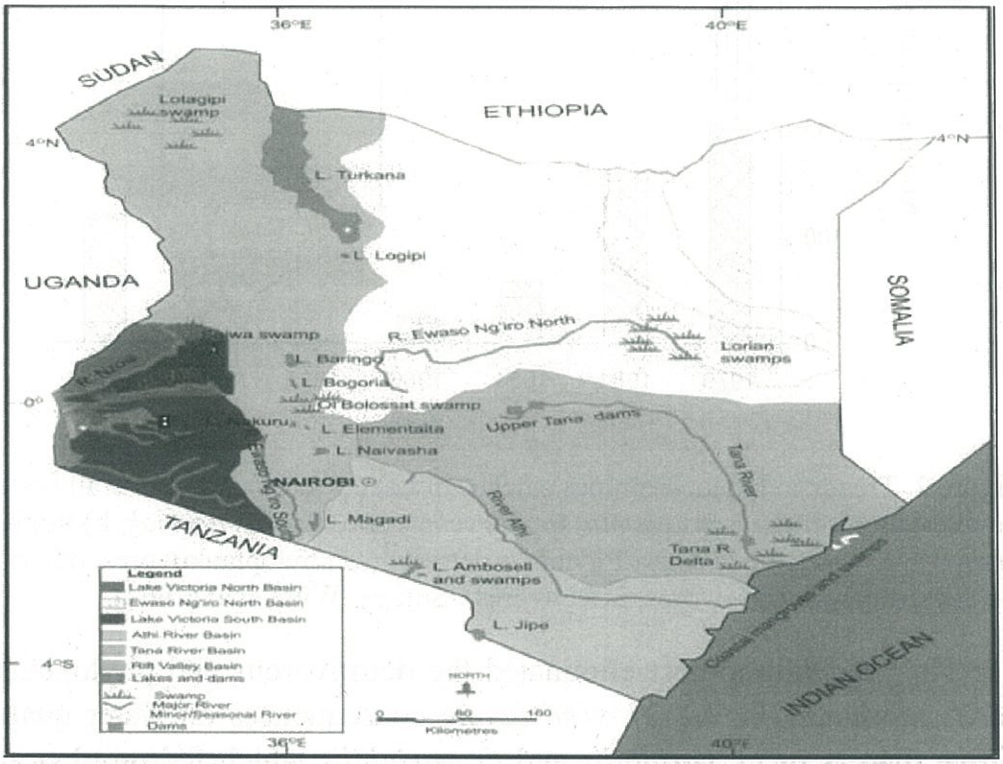

Figure 1. The location of Lakes Victoria and Naivasha in relation to other Kenyan lakes. Lake Victoria is the largest and borders Kenya, Uganda and Tanzania. Lake Naivasha is one of the Rift Valley lakes, near L. Elementaita.

Crayfish and common carp have greatly influenced the lake"s water quality due to their feeding habits (Smart et al., 2002). Crayfish feeds on the macrophytes, while feeding behaviour of common carp stirs sediments and uproots macrophytes (Smart et al., 2002)

Nile perch introduced into Lake Victoria was mainly to convert the small bony but abundant haplochromines to suitable table fish (Ogutu-Ohwayo, 1990). The exotic tilapias were introduced to compensate for the decreasing catches of native tilapiines of *Oreochromis variabilis* and *O. esculentus rendalli* (Boulenger) (Welcomme, 1967). Introduction of Nile perch contributed to the decline of haplochromines biomass from >80% during the 1970s to <1% by the late 1980s, whereas the other native species were occasionally recorded in fish landings (Ogutu-Ohwayo, 1990; Njiru et al., 2010). Nile perch fed mainly on haplochromines (Witte et al., 2007).

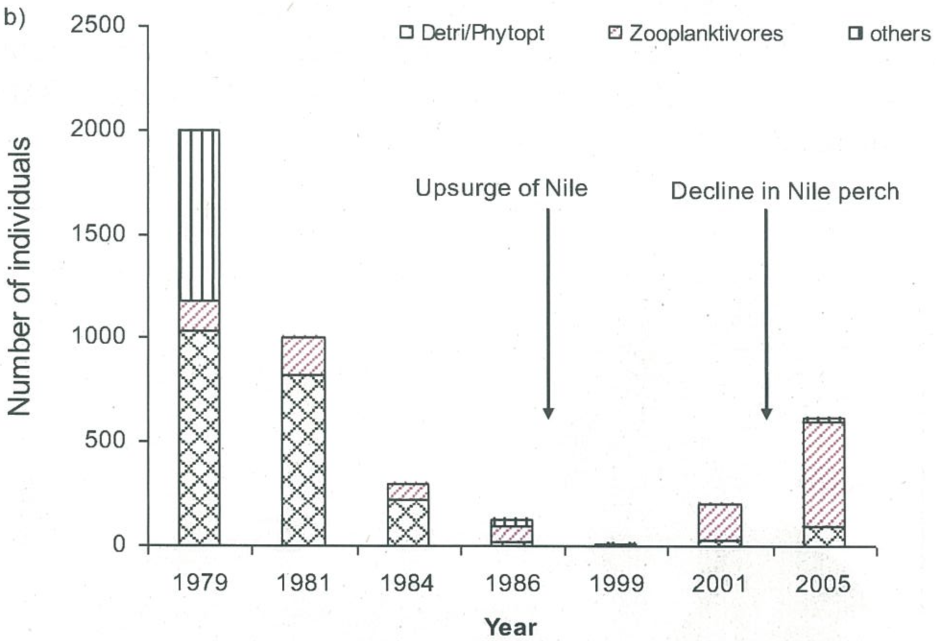

Figure 2. Trends in haplochromines catches in Lake Victoria, a) in overall bottom trawl catches. others = *Synodontis* spp, *Brycinus spp, Bagrus docmak,* b) trophic groups in Mwanza Gulf, Detri/Phytopt = detritivores/phytoplanktivores. others = trophic groupings (piscivores, insectivores). Source: Witte et al (2007).

The predation almost eliminated the detritivorous and phytoplanktivours haplochromines (Figure 2), with severe consequences on water quality. The native tilapias of *O. variabilis* and *O. variabilis* which fed on phytoplankton were also out competed by the more diversified feeder, *O. niloticus* (Welcomme, 1967; Njiru et al., 2010). Nile tilapia diet consists of a variety of food items including algae, fish and detritus (Njiru et al., 2004). The algal composition in the lake has also changed towards toxic and unpalatable cyanobacteria (Lung"ayia et al., 2000).

LESSONS FROM TEMPERATE LAKES

Several lakes respond rapidly and positively to loading reductions; nuisance algal blooming and planktibenthivorous fish abundance decrease, while the percentage of piscivores increases as do water clarity and submerged macrophyte abundance. A study of 14 recovering lakes in Denmark (Jeppesen et al., 2005) showed that the phytoplankton and fish biomass generally declined, leading to an overall higher zooplankton:phytoplankton ratio, which suggests that enhanced grazing pressure on phytoplankton results in clearer water.

Moreover, the biomass of planktivorous fish declined and the share of potential piscivores increased, most likely resulting in a stronger control by piscivores of planktivores. Accordingly, in most lakes the share of the large-bodied zooplankton *Daphnia* spp., which is particularly sensitive to predation by zooplanktivorous fish, and the body weight of *Daphnia* spp. and other cladocerans generally increased, further enhancing the grazer control of phytoplankton.

The improvements in lake water clarity are therefore a result of higher resource control of phytoplankton (lower availability of nutrients) as well as of enhanced predator control of planktivorous fish, cascading to the phytoplankton level via increased grazer control by large-bodied zooplankton. Several other lakes have exhibited a fast response to nutrient loading reduction (Perrow et al., 2002). However, positive effects cannot always be expected to occur, many lakes have proven to be highly resistant to loading reductions and have shown only little improvement (Jeppesen et al., 2005). For some lakes this reflects insufficient reduction of the nutrient input to trigger a shift to the clear water state. For example, significant and sustaining changes in the biological community and water transparency of shallow temperate freshwater lakes cannot be expected to appear unless the TP concentration has been reduced to a level below 0.05-0.1 mg P l^{-1} (Jeppesen et al., 2005), or for deep lakes below 0.02-0.03 mg P l^{-1} (Jeppesen et al., 2005). Even when the P loading has been sufficiently reduced, resistance to improvement is often observed. This resistance may be "chemical": P concentrations remain high because of P release from the sediment pool accumulated when loading was high (Jeppesen et al., 2005). Many years may pass before the surplus pool is released or permanently buried. The duration of this transitional period depends on, for instance, the duration of the period with high TP loading, the residence time and the phosphorus binding sites (like iron) supplied from the surroundings. In some cases this transient phase towards a new equilibrium has spanned several decades (Jeppesen et al., 2005).

Various methods have been used to reduce the internal loading of phosphorus (Jeppesen et al., 2005), including sediment removal and chemical treatment of the sediment with aluminum or iron salts. In stratified lakes also injections with oxygen or nitrate to the bottom layer or destabilization of the thermocline have been used. The resistance may also be "biological". In particular planktivorous and benthivorous fish contribute to biological resistance in shallow eutrophic lakes (Perrow et al., 2002). A continuously high fish predation pressure prevents both the appearance of large herbivorous zooplanktons that would otherwise clear the water as well as diminishes the number of benthic animals stabilizing and oxidizing the sediment. Moreover, excretion of nutrients to overlaying waters from benthic-feeding fish or fish bioturbation of surface sediment may also play a role (Perrow et al., 2002).

To overcome the biological resistance by fish, various fish manipulation methods have been developed (Benndorf et al., 2002). One such method is the enhancement of top-down control of phytoplankton by selective removal of planktivorous fish; a method employed world-wide in the temperate zone. Removal of 75-80 % of the planktivorous and benthivorous fishstock during a 1-2 year period is recommended to avoid regrowth and to stimulate the growth of potentially piscivorous perch (Perrow et al., 2002; Meijer et al., 1999). An alternative or supplementary method to fish removal is ample stocking of 0+ pike (>1000 ha-1) to control newly hatched plankti-benthivorous roach and bream (Perrow et al., 2002). Others have used stocking of pikeperch (*Stizostedion lucioperca*), walleye (*Stizostedion vitreum*) and largemouth bass (*Micropterus salmoides*) (Benndorf et al., 2002). Opposite to the above-mentioned physico-chemical methods, fish manipulation is often cheap (Jeppesen et al., 2005) and therefore attractive, though its long-term stability is uncertain. The findings to date indicate that fish manipulation may have a long-term effect in shallow temperate lakes provided that the nutrient loading is reduced to a TP level below 0.05-0.1 mg P l^{-1} in the future state of equilibrium. However, if the nitrogen loading is low, fish manipulation may sometimes have a positive impact at higher TP concentrations (Jeppesen et al., 2005). The 0.05-0.1 mg P l^{-1} threshold is in accordance with the empirical data appearing in this range. However, temporary effects of fish manipulation can be obtained in lakes with high nutrient concentrations, but it seems unlikely that the effect will prevail in such lakes in the long term unless the abundance of planktivorous fish is repeatedly reduced. The TP threshold for positive effects to occur is most likely lower for deep lakes, but an accurate threshold has to be defined.

LIMITATIONS

Several factors indicate that fish stock manipulations would not have the same positive effect on the environmental state in tropical lakes as in temperate lakes. The fish stock in tropical lakes is often dominated by omnivorous species that feed on zooplankton but also consume phytoplankton, periphyton, benthic invertebrates, and detritus. (Branco et al., 2000). Few piscivorous species are present and omnivorous fish generally dominate independently of trophic state. For example, Lake Victoria is dominated by *R. argentea*, feeding mainly on zooplanktons and several hundreds omnivorous cichlids occur. Lake Naivasha is dominated by omnivorous *C. carpio* which uproots macrophytes while feeding and *P. clarkii* which feeds on macrophytes (Ojuok et al., 2008).

In Lake Victoria, freshwater shrimps, *Caradina nilotica* (Roux) has increased tremendously in the last few decades (Mwebaza-Ndawula et al., 2005). The increase in low-oxygen tolerant *C. nilotica* indicate deterioration of the water quality and changes in food-web dynamics (Muggide et al., 2005). Increase in *C. nilotica* could prevent large herbivorous zooplankton from developing and this could partly explain the success of rotifers, and the high density of copepod nauplii in the lake (Mwebaza-Ndawula et al., 2005). Branco et al. (2000) observed similar changes in zooplankton composition in a coastal lagoon in Brazil. This predation pressure on zooplankton by invertebrates may represent a further limitation of the usefulness of biomanipulation in tropical and subtropical lakes.

In the temperate lakes, commercial and recreational fisheries target piscivores thus it possible to control their fishing to enhance their predation on zooplanktivorous fish. Fish species richness is often higher in tropical and subtropical lakes than the temperate ones. Lake Victoria has over 300 cichlid fish species and over 20 non cichlids (Njiru et al., 2008). The artisanal fishing in the tropics which targets the multi-species fishery instead of a few species renders biomanipulation difficult.

Fish reproduction, which in temperate freshwater lakes takes place once a year, occurs throughout the year in many subtropical and tropical lakes (Lowe-McConnell, 1991). As small fishes are more zooplanktivorous and have a much higher energy demand per unit of biomass than large fish (Kalff, 2002), the dominance of small fish in such high abundances leads to a higher predation pressure on zooplankton than in temperate lakes, where the effect of juvenile fish is typically strong mainly in mid-late summer (Jeppesen et al., 2005).

In addition, because recent biomanipulations have failed to prove that the simple fish–zooplankton–algae food chain is the only process involved in biomanipulation, the exclusive use of food-chain theory for explaining observed patterns has been drastically criticized: „„To some extent, the original idea of biomanipulation (increased zooplankton grazing rate as a tool for controlling nuisance algae) has become a burden“““ (Mehner et al., 2002).

Removal of planktivorous fish or addition of piscivorous fish to a lake clearly affects lower trophic levels, but the effects may not necessarily be the ones predicted by the simple and appealing food-chain theory. The importance of other processes besides pure food-chain dynamics have been demonstrated mainly in shallow lakes since organisms are not spatially separated by depth (Mehner et al., 2002). Theoretical development has progressed in closer cooperation with lake managers than in the case of deeper lakes. Hence, the current issue of concern is to provide a useful guide for lake managers on applications, synthesis and connections between basic and applied research in fish biomanipulations, in relation to understanding the trophic cascade model (Benndorf et al., 2002).

Helminen et al. (2002) argued that the success of piscivore stocking is limited. When used as the sole technique, stocking does not appear to provide long term effectiveness; a case in point being the introduction of Nile perch in Lake Victoria in the 1960s (Njiru et al., 2008) and the fish introductions in Lake Naivasha (Litterick et al., 1979; Muchiri and Hickley, 1991; Britton et al., 2007). One problem is the inability to stock the number of fish required to control abundant planktivore populations. Helminen et al. (2002) gave another problem to be related to the nonexistence of spawning grounds and habitat requirements of piscivores in eutrophied lakes. He concludes that a way to increase the success of stocking is to perform a fish kill or removal prior to stocking to decrease planktivores; a phenomenon that still requires scientific verification since the underlying consequences could damage the environment ecologically.

According to Van de Bund and Van Donk (2001), the overall success of biomanipulation is debatable. They argue that some sources proclaim the approach as successful while others question its reliability (Welcomme, 2001). They believe that the relative young age of the concept makes it difficult to study long term effectiveness. They note that the experiments are typically less than five years and are not long enough in duration to determine dominant trends or causal relationships among the variables being manipulated. For example, they reaffirm that the loss of fish populations by a fish kill or removal will effectively increase macrophyte populations as well as zooplankton. Thus, through nutrient competition, abundant macrophyte populations are able to reduce algae growth. Therefore, they point out that the determination of whether phytoplankton is controlled by zooplankton or macrophytes is difficult to ascertain.

On the other hand, biomanipulation may produce positive results early in the study but may not five or ten years later. In a case study of Round Lake in

Minnesota, biomanipulation did produce the desired results for the first two years with improvement in each successive year but during the third year the lake began to digress to its previous denuded state (Mehner et al., 2002). Lastly, an argument is raised concerning zooplankton grazing rates of blue-green algae. Blue-green algae are a major problem in eutrophied lakes and it is questionable whether zooplanktons are able to use blue-green algae as a food source. Filtering of the algae may be impeded by its size and shape and may even clog the filtering apparatus of zooplankton (Mehner et al., 2002).

SUCCESSES

Nevertheless, biomanipulation was designed to be an alternative to nutrient management and may provide the long term effectiveness that nutrient management has failed to do in eutrophied lakes (Kalff, 2003). Nutrient management techniques ignore the biological interactions occurring in a lake which may be the primary cause of algae blooms and internal nutrient release (Mehner et al., 2002). Nutrient management approaches are ineffective in shallow lake environments due to internal nutrient loading and the impossibility to successfully reduce the external nutrient loads (Mehner et al., 2002). Phosphorous accumulates in sediments and is released through bioturbation, the churning of sediments by organisms, and during low oxygen levels (Kalff, 2003). Nutrient management techniques tend to work best in deep lake environments since nutrient loading is not a major factor (Mehner et al., 2002). Nutrient management techniques seek to control nutrient loading and nutrient levels.

Even though the arguments against biomanipulation are extensive, it is a relatively effective method of lake restoration in shallow lakes compared to nutrient management. Nutrient management techniques have to be repeatedly performed and are not final solutions to eutrophication problems in shallow lakes (Welcomme, 2001). Biomanipulation appears to produce desirable results in most instances. Unfortunately, the success in some cases is short term. Further research is necessary to enhance the stability of biomanipulation (Benndorff et al., 2002).

Starling et al. (2002) believes that a current restoration trend that may improve the reliability of biomanipulation is its integration with nutrient management. Hence, controlling nutrient levels along with food-web manipulation has the potential to create long lasting results because neither food-web interactions nor nutrients are the sole regulators of phytoplankton.

For example, controlling high phosphorous concentrations in shallow lakes will increase the success of piscivore stocking. He points out that in lakes with phosphorous levels above *ca.* 100 g. p l^{-1}, it is nearly impossible to alter piscivore rates. He affirms that a decrease in phosphorous levels through phosphorous inactivation or sediment removal prior to piscivore stocking will increase the survival of piscivores. Thus, combining the efforts of biomanipulation and nutrient management techniques may prove to be the future solution to eutrophication problems in shallow lakes in the tropics and in Kenya in particular.

WAY FORWARD IN KENYAN LAKES

Based on the differences in fish-zooplankton-macrophyte interactions in the tropics and in the temperate regions, it seems more difficult to provoke and not least maintain a trophic cascade effect in subtropical and tropical lakes than in temperate lakes, for which the concept of biomanipulation as a restoration tool was developed. Supporting this view, Nagdali and Gupta (2002) found positive, but only short-term cascading effects of a massive (>80%) kill (due to fungal infection) of the most abundant planktivorous mosquito fish (*Gambusia affinis*) in Lake Naini Tal, India. Zooplankton abundance increased significantly, phytoplankton biomass and productivity declined as did nutrient concentrations, resulting in higher water transparency. However, only 4 months later the abundance of mosquito fish, plankton and nutrients had returned to the level recorded in the previous year! In a study performed by Scasso et al. (2001), a slowly increasing abundance of larger species was observed after two years of biomanipulation involving removal of small planktivorous fish, without, however, inducing cascading effects leading to clear-water conditions.

Yet, only few studies have investigated the applicability of the biomanipulation theory to the tropical and subtropical freshwater ecosystems, and most of the existing ones have examined food interactions in eutrophic lakes and reservoirs with the aim to control cyanobacterial blooms via enhanced grazing by omnivorous fish such as silver carp (Starling et al., 2002). The results obtained indicate that omnivory and strong shifts in fish diet and in the fish and zooplankton composition jeopardize successful biomanipulation (Branco et al., 2000; Boulton and Brock, 2001), but more information on phytoplankton-zooplankton interactions in the tropics and in Kenya is needed before its potential can be fully elucidated. Moreover, the absence of a native piscivorous fish culture in many tropical countries precludes the application of biomanipulation. There is a huge richness of fish species potentially useful for this purpose, but mass production for biomanipulation purposes has not yet been considered. Generally, aquaculture has so far focused on exotic species (i.e. common carp and grass carp) that have negative effects on water quality and biodiversity.

In many of the experiments undertaken in the temperate zone, an improvement in environmental state has, however, been recorded without the occurrence of a trophic cascade, i.e. without changes in the zooplankton species composition towards higher dominance of large-sized individuals and with it a higher grazing pressure on phytoplankton (Starling et al., 2002). Even without such a trophic cascade, a significant reduction has been observed in the occurrence of cyanobacteria, total phosphorus has declined and water clarity increased. These phenomena have been ascribed to reduced release of phosphorus from the sediment, not least due to the lower rate of fish foraging in the sediment following biomanipulation (Scasso et al., 2001). Biomanipulation may therefore potentially also reduce the nutrient release from the sediment in tropical lakes, but the dominance of small fish species and the improved growth conditions for cyanobacteria suggest that the effect might not be long-lasting. Therefore, a drastic reduction of the external nutrient loading seems to be the best way forward for restoring lakes also in the tropics, but clearly the scientific basis (e.g. nutrient threshold levels) on which to make decisions is yet too limited, suggesting the strong need for more research.

CONCLUSION

Generally, biomanipulation can be a very effective method for increasing the transparency of the water in a lake. Many biomanipulations have resulted in increased water transparency. However, basing on the above scientific piece of evidence, a generally better understanding of the complexity of lake food webs and the frequent application of biomanipulation as a lake restoration technique have emerged from the recent developments in biomanipulation research that solemnly make such work an environmental issue. As this type of research is not easily funded in most countries because of political and social conflicts, the results from public lake management programmes can help collect the necessary data. As it is today, many subtropical and tropical lakes such as those in Kenya are heavily eutrophied and biodiversity has declined, and in the years to come it is to be feared that many other lakes in these regions will follow the same negative developmental pattern both as a consequence of the future economical development and climate change.

A point worth mentioning is that details have to be verified in the light of frequent future applications of fish biomanipulation in the tropics with examples being the Kenyan lakes. This could be because all relevant features may have not been adequately considered since not enough is known about the role of habitat heterogeneity (e.g. the ratio of littoral to pelagic habitats) or proportions of species in the fish community for long-term stability of manipulated systems (Mehner et al., 2002). Hence, a successful combination of biomanipulation and fisheries management could be based on four main steps that include: the definition of the main goals and a principal stakeholder analysis; an analysis of the nutrient situation (external load and internal concentration); planning and performing of the manipulation measures considering characteristics of the fish stock and management aspects (e.g. technical feasibility of mass removal, interests of fisheries, stocking measures, catch restrictions); and maintenance (adaptive management). If the respective targets and thresholds in fish biomass can be achieved in fish biomanipulation in the tropics and Kenya in particular, then improvements of water quality and satisfaction of fisheries stakeholders are very likely.

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