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Lake Victoria fisheries: Outlook and management

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Abstract
The past subsistence of the Lake Victoria fishery was dominated by rich, diverse haplochromine cichlids. This multispecies fishery has undergone a decline over the past four decades, evolving into a commercial fishery consisting mainly of Nile perch (*Lates niloticus*), Nile tilapia (*Oreochromis niloticus*) and cyprinid (*Rastrineobola argentea* species). To better understand Lake Victoria fisheries, studies dating as far back as the 1920s have been carried out to assess the status of the fish stocks. These past studies indicated the lake fisheries were declining because of numerous major challenges, including intense fishing, invasive species, loss of biodiversity, ecological alterations, climate change, inadequate information to inform management and unharmonized policies. Numerous policies and regulations have been developed and implemented over the years to address these issues and manage the fisheries sustainably. Most of the interventions have been sectorial, disjointed and unharmonized and have not reduced the declining fish catch rates. With reestablishment of the East Africa Community (EAC) with several institutions in 1994, the Lake Victoria riparian states initiated an ecosystem approach to manage the Lake Victoria fishery resources in a sustainable manner. This study reviews the development of the Lake Victoria fisheries, outlines major past and present management challenges and provides a set of new strategies to manage the lake's fisheries resources, with emphasis on an ecosystem approach.

KEYWORDS
East Africa community, ecosystem, fishery, Lake Victoria, policies

1 | INTRODUCTION

Lake Victoria is the second largest lake in the world by surface area after the Caspian Sea, covering about 69,000 km^2 in East Africa (Crul, 1995). It has a maximum depth of 84 m, a mean depth of 40 m and a shoreline of about 3,500 km. The lake is shared by Kenya (6% of surface area), Uganda (43%) and Tanzania (51%), with a drainage basin covering about 236,000 km^2 that extends to Rwanda and Burundi. The lake supports a valuable artisanal and commercial fishery and is a source of food, employment and water for domestic, industrial and irrigation use, as well as having a good potential for tourism (Abila, 2000; Njiru, Waithaka, Muchiri, van der Knaap, & Cowx, 2005; Ntiba, Kudoja, & Mukasa, 2001; Odongkara, Abila, & Onyango, 2005). It also is a major transport route within the region, has important aquatic habitat containing a rich biodiversity (Seehausen, van Alphen, & Witte, 1997; Seehausen, Witte, Katunzi, Smits, & Bouton, 1997; Witte, Goldshmidt, Ligtvoet, Oijen, & Wanink, 1992) and modulates the regional climate (Swenson & Wahr, 2009).

An increasing human population and high exploitation rate have threatened the health of Lake Victoria and its resources. From about 1960, the population increased dramatically from about 10 to more than 40 million people within about 100 km from the lake shoreline, with their activities negatively impacting the lake and its resources (PRB 2009; Yongo, Keizire, & Mbilinyi, 2005). Human-oriented activities such as farming, disposal of urban sewage, overexploitation of natural resources and introduction of exotic species have had profound negative physical, chemical, biological and ecological effects on the lake, altering its ecosystems (Kolding, Van Zwieten, Mkumbo, Silsbe, & Hecky, 2008; Lung'ayia, M'Harzi, Tackx, Gichuki, & Symoens, 2000; Mugidde, Gichuki, Rutagemwa, Ndawula, & Matovu, 2005; Witte et al., 1992). These changes have led to a decline in fish catches, changes in the lake biodiversity and threatened the sustainability of the lake's fisheries upon which millions depend on for their economic sustenance and livelihoods. To this end, this study investigated the development of the Lake Victoria fishery, reviews past and current management approaches and outlines the needs for ecosystem approach.

2 | LAKE VICTORIA FISHERIES

2.1 | Past management influences on current approaches

Fish net bear and mesh size regulation were first attempted in 1931 to protect the native *Oreochromis esculentus*, with the use of gillnets of <5 in. (127 mm) being banned in accordance with scientific study recommendations (Graham, 1929). Catches continued to decline, however, resulting in a bid to capture more fish, with synthetic fibre nets replacing the natural fibre nets in the 1950s, as well as the use of outboard engines on canoes in order to travel farther offshore (Mann, 1969). To attempt to capture the smaller *O. variabilis* and mormyrids, the government revoked the minimum mesh size of 5 in. (127 mm) to 4.5 in. (114 mm) in the late-1950s. This measure did not last long, however, being followed by a further decline in fish catches in the 1960s (Fryer & Iles, 1972; Ogutu-Ohwayo, 1990). To increase the diminishing catches, herbivorous Tilapiines, *O. niloticus*, *O. leucostictus*, *Tilapia rendalii* and *T. zillii* and *L. niloticus* were introduced in the late-1950s and early-1960s during the colonial era (Ogutu-Ohwayo, 1990; Welcomme, 1967). Even with the introduction of exotic species, the catches continued to decline in the early-1960s, with fishers further reducing gillnet mesh size to 4 in. (102 mm), followed by a reduction to 3 in. (76 mm), then to 1.8 in. (46 mm) and later to 1.5 in. (38 mm) in order to harvest underexploited species and haplochromines (Fryer & Iles, 1972). To exploit the abundant native *R. argentea*, fishers started using a seine net of 0.4 in. (10 mm) that also captured juveniles of the larger species, thereby affecting their recruitment.

After the riparian states gained independence in the 1960s, the management of fisheries was transferred to the national fisheries departments, thereby losing the existing harmonized coordination mechanism. Lake Victoria fisheries management was additionally affected following the collapse of the East African Community in 1977, wherein each state adopted a different management regime, depending on the fish stock of interest (Van der Knaap, Ntiba, & Cowx, 2002). In an attempt to stop this situation, riparian states with development partners funded several joint lake studies with the goal of better understanding the lake and its ecosystem as a means to inform rational management (Cowx, Van der Knaap, Muhoozi, & Othina, 2003; Njiru et al., 2005). Using information from these studies, attempts were made to implement an annual closed season for *R. argentea* in Kenya for a four-month period, starting in 2001, gear regulation, enforcement of mesh size restriction (5 in. for Nile tilapia; 7 in. for Nile perch) and use slot size to capture Nile perch between 50 and 85 cm TL starting in mid-2000 (Njiru et al., 2005, 2009). These measures were short-lived, however, with the fish catches exhibiting a declining trend (Van der Knaap & Ligtvoet, 2010).

In the 1970s, Lake Victoria had a multispecies fishery dominated by the tilapiines *O. esculentus* and *O. variabilis*, and over 500 species of haplochromine cichlid species (Ogutu-Ohwayo, 1990; Witte et al., 1999). The endemic cyprinid, *R. argentea* (locally known as Mukene—Uganda, Omena—Kenya, dagaa—Tanzania), although available in large quantities was not exploited on a large scale because of its small size. There was also a significant fishery consisting of more than 20 groups of noncichlids fishes, including *Protopterus aethiopicus*, *Bagrus docmak*, *Clarias gariepinus*, *Schilbe intermedius*, Labeo *victorianus*, *various Barbus* species and mormyrids (Kudhogania & Cordone, 1974; Ogutu-Ohwayo, 1990; Taabu-Munyaho et al., 2014; Witte et al., 1999). Experimental trawl surveys conducted on Lake Victoria in 1970, 1981, 1989, 2000, 2004, 2008 and 2016 indicated that the original assemblage of fishes in the lake has considerably declined (Figure 1a). Since 1980, the commercial fishery of Lake Victoria shifted to Nile perch (*Lates niloticus*), Nile tilapia (*Oreochromis niloticus*) and the native cyprinid (*R. argentea)* which together make up 80%–90% of the catch; a major shift from previous observations of 80% haplochromine catches (Figure 1a,b). However,

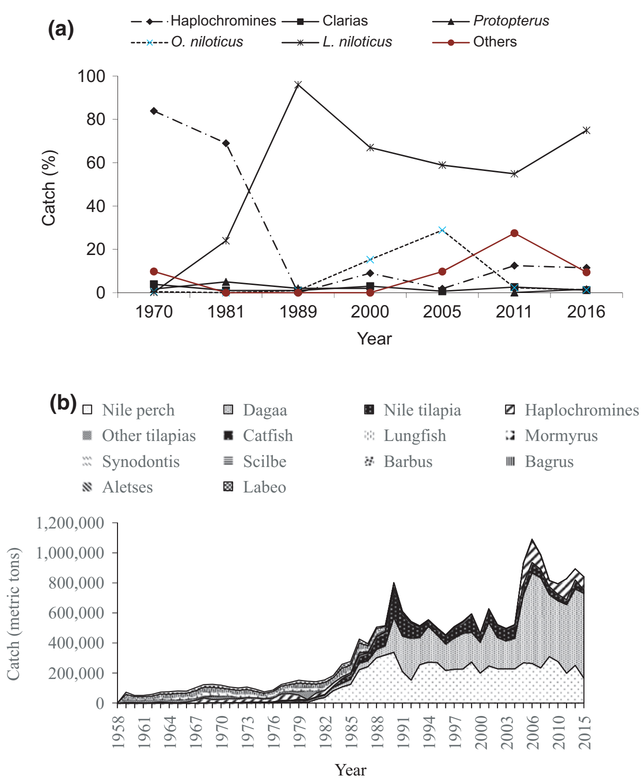

FIGURE 1 Contribution of the major fish species in Lake Victoria (a) percent trawl catches; others include *Synodontis*, *Brycinus*, *Bagrus and Schilbe* species (adapted from Njiru, Nyamweya, Gichuki et al., 2012; KMFRI unpublished data); (b) commercial catches in entire lake (KMFRI and LVFO unpublished data)

in last two decades, catches have seen a resurgence of native species of Haplochromines as demand for fish protein increases (Witte et al., 2007), and Haplochromine species become more prevalent as Nile perch populations decline as a result of high fishing effort (Frame survey, 2016; LVFO, 2014; Njiru et al., 2014).

2.2 | Economy

Up to the 1970s, the Lake Victoria fishery mainly met the subsistence needs for the local riparian communities. The scenario changed to an international multimillion-dollar commercial fishery, with the introduction of the Nile perch fishery. By the 1990s, Nile perch accounted for 90% of the exported in the three riparian countries of Kenya, Uganda and Tanzania (Odongkara et al., 2005; Yongo et al., 2005). Statistics indicated that about 75% of the Nile perch catch was exported to Europe, the USA and the Middle East between 1992 and 2010. The total export of Nile perch was about 20,000 mt valued at USD 27 million in 1992, increasing to 92,000 mt in 2005 valued at USD 322 million, but decreased to 51,000 mt valued at USD 265 million in 2010 (Odongkara et al., 2005; Weston, 2015). The total lake production in 2014 was estimated at USD 650 million worth of fish a year (LVFO unpublished, Weston, 2015). The earnings from the lake fisheries are a major contributor to economic growth around the riparian states. Beginning in the 1980s, the shift towards the Nile fishery resulted in growth in the sectors of fish processing, net manufacturing, boat building, fish marketing, packing and air commerce. The Lake Victoria fishery currently supports more than 200,000 fishers (Lake Victoria Fisheries Organisation (LVFO), 2014), with an estimated 35 million people dependent directly or indirectly on it for a living (Weston, 2015). The Lake Victoria fisheries contribution to the GDP in terms of food, income, employment and foreign exchange earnings, as follows: 0.5% in Kenya; 2.5% in Tanzania; and 2.8% in Uganda (FAO 2015; Gordon & Ssebisubi, 2012).

2.3 | Management challenges

Management of Lake Victoria fisheries has faced myriad challenges emanating from within and outside the fishery sector, including intensive fishing and overfishing, invasive species, loss of biodiversity, ownership issues, ecological changes, climate change, inadequate information to inform management and unharmonized policies. To this end, the Lake Victoria management challenges that persist today can be traced to past management efforts, changes in fish species and their values, and increased human population (Figure 2).

2.4 | Intensive fishing and overfishing

The Lake Victoria fishery allows entry to fishing after paying of a nominal access fee to acquire a fishing permit. Commercial fishing began in the early 20th Century, with stocks of the most important species (endemic tilapias *Oreochromis esculentus*; *O. variabilis*) having collapsed by 1940 because of overfishing (Njiru et al., 2014). Although attempts were made in the 1950s and 1960s to rehabilitate the lake fishery by introducing exotic tilapia species of *O. niloticus*, *O. leucostictus* and *T. zillii* (Welcomme, 1967), only *O. niloticus* thrived thereafter to support a substantial commercial fishery that continues to the present time. The piscivorous Nile perch also was introduced into the lake in the 1960s to convert the abundant haplochromines, considered "trash fish" by the European palate, to fish flesh of commercial importance on the global market. The Nile perch introduction was successful in that the annual catches of all fish species in Lake Victoria increased from 30,000 mt in the late-1970s (Njiru, Kazungu, Ngugi, Gichuki, & Muhoozi, 2008; Njiru et al., 2005) to peak catches of one million mt in 2006, declining thereafter to 900,000 mt in 2014 (LVFO 2011, LVFO unpublished). The rapid increase in total catches in the 1980s–1990s was attributed mainly to a dramatic increase in the Nile perch population, which constituted more than 90% to the catch (Njiru et al., 2008). The recent decline of the Nile perch catch in the lake is attributed to its intensive and overfishing. In the Kenya portion of Lake Victoria, for example, Nile perch catches increased from 146 mt in 1973, peaking at 115,000 mt in 1999, and being 43,000 mt in 2014 (Figure 1b). Acoustic surveys by Taabu-Munyaho et al. (2014) that covered the entire lake indicated the mean density of Nile perch had decreased from 21.6 ± 6.1 t/km^2 in 1999–2002 to 12.3 ± 3.4 in 2007–2011. Studies by Njiru et al. (2008) revealed a domination of juvenile Nile perch (~95%) in lake wide trawl surveys. The majority of adult Nile perch caught were below the recommended slot size of 50–85 cm total length (TL) (Njiru, Getabu, Othina, & Wakwabi, 2007; Njiru, Okeyo-Owuor, Muchiri, Cowx, & van der Knaap, 2007; Njiru et al., 2008, 2009), indicating fishers were catching undersized fish illegally, which could compromise future recruitment. Furthermore, the main population characteristics of the three main commercial fish species of Nile perch, Nile tilapia and *R. argentea* have changed towards highly exploited species (Njiru, Getabu et al., 2007). There was a decline, for example, in mean length, asymptotic length (L_∞) and length at first maturity (Lm_{50}), and an increase in the growth coefficient (K), total mortality (Z), fishing mortality (F) and exploitation rates (E). The capture of large numbers of juveniles and fish before maturity may further compromise recruitment, with an eventual depletion of the stocks (Njiru, Sitoki, Nyamweya et al., 2012).

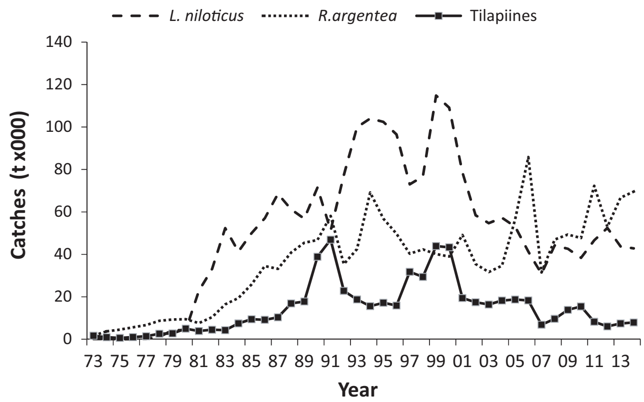

FIGURE 2 Trend of major commercial fish species in Lake Victoria, Kenya (KMFRI unpublished data)

The decline in fish catches and changes in the fish population parameters may be attributed to increased capacity, leading to increased numbers of fishers, boats (Figure 3a) and illegal gears (Figure 3b). In other words, there are simply too many fishers chasing too few fish in the lake. Because of its economic importance, the continued fish catch decline is of utmost importance to the riparian states, with the consequences being a serious threat to the local economies and livelihoods. Indirect effects of scarce resources could result in conflicts as witnessed in the ownership dispute of rich fishing grounds around a rocky island at the border of Kenya and Uganda (Howden, 2009), where both countries deployed security forces, with only diplomacy averting a possible bloody conflict.

2.5 | Invasive species and biodiversity

A drastic decline of 500+ endemic haplochromine species and several native species is attributed mainly to Nile perch predation (Ogutu-Ohwayo, 1990). Experimental trawl studies in the late-1980s and early-1990s indicated Nile perch dominated catches, with native species rarely being caught (Figure 1a). The extinction of at least 200 haplochromine species, and the decline of several native species (*O. esculentus; O. variabilis; Bagrus docmak; Alestes* spp, *Barbus* spp; mormyrids), is associated with predation by Nile perch (Witte et al., 1992). The loss of fish species in Lake Victoria is the largest recorded for any aquatic ecosystem (Witte et al., 1999). Since the late-1990s, however, there has been a resurgence of the endemic fish species in the lake attributed to, among other factors, a decline in the Nile perch stocks (Figure 1a,b). The species appearing in catches are smaller and mature earlier than their predecessors, probably an adaptation for survival in the altered ecosystem (Witte et al., 2013).

The indigenous tilapias may have declined because of competition for food, breeding areas and hybridization with the exotic *O. niloticus* (Ogutu-Ohwayo, 1990; Welcomme, 1967). An increase in phytoplankton in the lake is attributed to reduced grazing by planktivorous haplochromines, subsequently leading to algal blooms and anoxia, the build-up of toxic gases, and enhanced eutrophication (Gophen, 2015). The haplochromines cichlids, which represented more than 40% of the fish biomass, were substituted by the pelagic *R. argentea* and the freshwater shrimp, *Caridina nilotica* (Marshall & Mkumbo, 2011). The reduced catch of cichlids was attributed mainly to predation by *L. niloticus* and overfishing (Witte et al., 1999), hybridization in haplochromine cichlids (Seehausen, van Alphen et al., 1997; Seehausen, Witte et al., 1997) and eutrophication (Kolding et al., 2008).

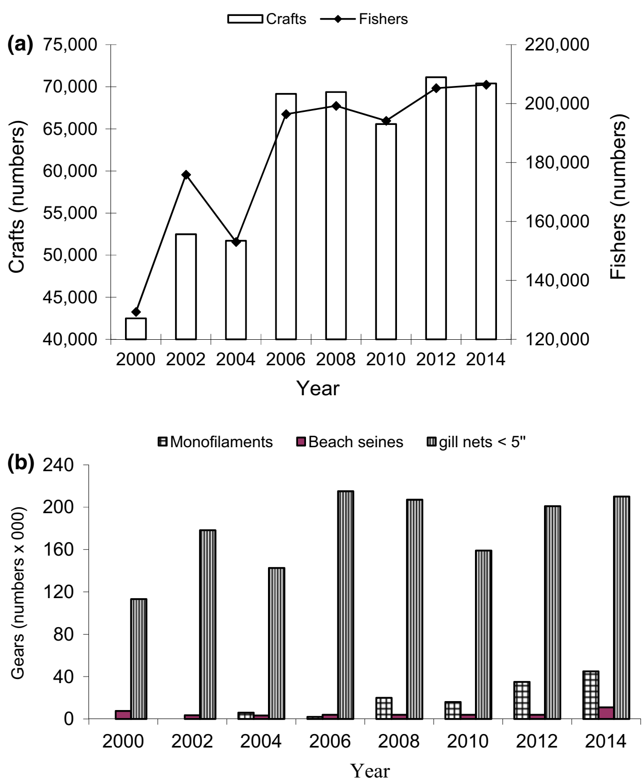

FIGURE 3 Capacity trend in Lake Victoria: (a) number of fishers and boats and (b) illegal gillnets (Source: Frame Survey 2014)

2.6 | Ownership Issues

With over 200,000 fishers and more than 1,400 landing areas in three countries and several levels of local government structure, the fisheries of Lake Victoria is one of the most complex fisheries in the world (Nunan, 2010). Before commercialization, the colonial government played little role in management of the fisheries, with the riparian communities using traditional norms and taboos in managing the fisheries (Nunan, 2010, 2014; SEDAWOG 1999). To prevent the capture of migratory breeding species, for example, fishing communities and norms prohibited fishers setting nets across river mouths. With commercialization of the fisheries local communities, however, the rights of ownership were weakened (Nunan, 2010, 2014; SEDAWOG 1999). The fish processing factories and prominent fishers controlled fishing activities in the lake. The factories operated below capacity (<20% of total capacity), and there was intense competition for fish to meet the demands (Abila, 2000; SEDAWOG 1999). The processors were business persons not from local communities, being able to manipulate and dictate terms in the fishing industry (SEDAWOG 1999). With this loss of control to "foreign investors," local fishers were dispossessed of the then-existing fishery traditional ownership (Geheb & Crean, 2000), thereby encouraging irresponsible fishing practices in competition for catches (Yongo et al., 2005). Indeed, the competition has almost vanquished the lake fisheries, especially that of Nile perch, with most factories currently closed down because of the lack of fish to process. Of 15 factories in Kenya, for example, only one factory is left, and it is operating below capacity.

2.7 | Ecological changes

2.7.1 | Water quality

Lake Victoria water quality has continued to deteriorate, mainly because of eutrophication caused by increased nutrient loads (Hecky, Mugidde, Lamlal, Talbot, & Kling, 2010; Kolding et al., 2008; Lung'ayia et al., 2000; Mugidde et al., 2005; Sitoki et al., 2010) and a change in the fish diversity, especially the algal-cropping haplochromines, leading to increased algal blooms (Gophen, 2015; Ogutu-Ohwayo, 1990). Eutrophication is more prominent in the shallow bays, especially those near large human settlements practicing agriculture activities and having urban areas (Sitoki et al., 2010). The population growth rate around the lake (>3% per annum) is more than twice the world average, with negative impacts on the lake ecosystem (PRB 2009). The major nutrients causing eutrophication in the lake mainly comprise phosphorus and nitrogen, which originate mostly from atmospheric deposition, poor farming and forestry practices, and partially treated municipal sewage and industrial effluents (COWI 2002). As a result of the long retention period of 23 years, and a flushing time of 138 years, pollutants entering the lake stay there for a long period (Bootsma & Hecky, 2003). Studies by Musa (2011) also revealed banned organochlorines such as DDT are still in use in the lake catchment, raising fears of accumulation of pesticide residues in the rivers and the lake, with future consequences for the food chain. Increased nutrients have led to unwarranted phytoplankton growth. There has been an increase in primary productivity, for example, in the Kenyan part of the lake, with the chlorophyll a concentration increasing from 3.0 to 4.6 μg/L in the 1960s (Talling, 1965) to 40–60 μg/L in the 1980s, with maximum concentrations of 650 μg/L (Sitoki et al., 2010). The lake phytoplankton community has shifted to a dominance of toxic cyanobacteria (Lung'ayia et al., 2000; Mugidde et al., 2005). Cyanobacteria blooms have suppressed the diversity and abundance of diatoms and green algae. Water at depths greater than 20 m in Lake Victoria exhibits long periods of anoxia (Figure 4a), limiting the habitat for certain species (Kaufman, 1992). The observed increased algal biomass and hypoxia may mirror a combination of increased nutrient levels and a loss of algal-cropping phytoplanktivorous haplochromine cichlids (Lung'ayia et al., 2000). Thus, algal blooms and subsequent anoxic conditions have been blamed for occasional fish kills in the lake (Ochumba, 1990). The decreased water transparency has been implicated in the reduced haplochromines diversity by disrupting their reproductive behaviour, which relies heavily on visual cues (Seehausen, Alphen et al., 1997). A narrow light spectrum has led to haplochromine hybridization wherein species have interbred with closely related individuals (heterospecific) rather than their own species (conspecific). This hybridization not only reduces biodiversity, but also the flexibility of the species to adapt to the dynamic Lake Victoria ecosystem conditions.

The lake has experienced a massive investment of cage culture in the recent past. In the Kenyan part of the lake, for example, there are more than 2,000 cages stocking over three million tilapia fingerlings (per. com). Most farmers utilize sinking fish pellets, which have a high crude protein content (up 35%). The quantity of nitrogenous waste in the water is bound to make the situation worse, with algal bloom scums and fish kills already having been observed in areas containing massive cage installations.

2.7.2 | Water Hyacinth

Water hyacinth (*Eichhornia crassipes*) invaded Lake Victoria in 1988, rapidly expanding in the late-1990s because of increased nutrients

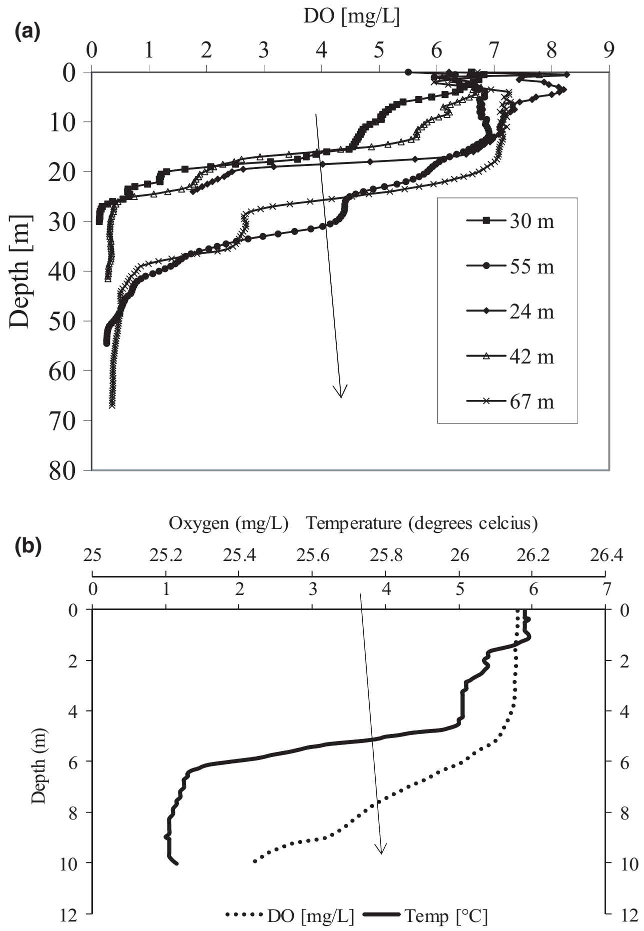

FIGURE 4 Typical oxygen profiles in Lake Victoria during stratification (a) deep sampling sites; Source: Njiru, Sitoki, Nyamweya et al. (2012); (b) oxygen and temperature at a shallow sampling site; vertical line represents oxygen concentration (DO <3 mg/L) considered critical for fish in the lake. Source: Unpublished data, Kenya Marine and Fisheries Research Institute

levels (Mugidde et al., 2005; Njiru, Othina, Getabu, Tweddle, & Cowx, 2002; Ogari & van der Knaap, 2002). Water hyacinth have serious environmental and socioeconomic impacts on the lake, interfering with in-lake transport, water quality and fisheries. Regarding the fisheries, water hyacinth have reduced the levels of production, reduced the species diversity in fish catches, reduced the quality of the fish and increased the operation costs associated with obstruction by the weed, resulting in lower incomes to fishers and higher prices to fish consumers. The dissolved oxygen (DO) concentrations in the water below the mats were as low as 0.01 mg/L, creating unsuitable habitats for fish survival (Njiru et al., 2002). Water hyacinth, however, have also contributed to the recovery of some native species (e.g., *C. gariepinus; P. aethiopicus*; haplochromines) by creating anoxic water refugia for native fishes less sensitive to low DO concentrations than are Nile perch (Njiru et al., 2002, 2008). The hyacinth mats also provide feeding, breeding and nursery grounds for such species. Water hyacinth was brought under control by the late-1990s through mechanical and biological control (Williams, Duthie, & Hecky, 2005). Solarization, for example, used black polythene sheets to cover water hyacinth mats and appeared successful at a small scale in controlling the hyacinth (Ogari & van der Knaap, 2002). As a result of continued increased nutrients loads entering the lake, however, there is constant resurgence of local hyacinth in the lake (Wilson et al., 2007).

2.8 | Climate change

Global climatic changes may be contributing to water temperature and water inputs (e.g., rain, rivers) of Lake Victoria. Compared to the 1920s, the temperature of Lake Victoria (surface average of 24.69°C in 1927 is about 1°C warmer (surface average of 25.88°C in 2009) (Sitoki et al., 2010; Talling, 1966). The thermal stratification is more stable and lasts longer, limiting nutrient exchange from the bottom into the surface waters (Figure 4). The process of thermal stratification has an effect on dissolved oxygen and nutrient exchange from deeper to surface waters, contributing to development of low oxygen conditions, distribution of plankton, fish and accumulation of toxic organic. It is postulated that seasonal anoxia and accumulation of toxic compounds force less-tolerant native species into the oxygenated surface waters where they are exposed to heavy predation by Nile perch, and probably a higher fishing mortality (Chapman, Kaufman, Chapman, & McKenzie, 1995; Getabu, Tumwebaze, & MacLennan, 2002; Witte et al., 1992). Hypoxia was more common in waters more than 60 m deep (Talling, 1966) in the 1960s, although this has spread to shallow inshore areas (Sitoki et al., 2010). Other studies have reported hypoxic conditions are now frequent in waters up to 5 m deep (Figure 4b). Chapman et al. (1995) reported 3 mg/L as the critical DO level below, which most species in Lake Victoria cannot survive. Furthermore, there are indications that up to 40% of the fish habitat areas in the lake may have been lost because of deoxygenation (Mugidde et al., 2005).

Climatic changes and deforestation have also likely led to reduced rainfall in the lake basin (Sutcliffe & Petersen, 2007). The inflow to the lake is dominated by rainfall, accounting for 84% of the total, while the other 16% is from rivers draining the lake basin (Sutcliffe & Petersen, 2007). The lake has experienced a reduced water level of up to 1 m, which may be attributed to reduced rainfall and damming of rivers in the basin for electricity generation (Sutcliffe & Petersen, 2007). These changes have ecological impacts on the lake fisheries, including reduced fish habitats because of receding lake water levels. Climate predictions models indicate the East Africa region will received more season rainfall, leading to increased run-off (Doherty, Sitch, Smith, Lewis, & Thornton, 2010). Increased rainfall, coupled with ongoing deforestation and land clearance for agriculture, may lead to severe erosion and increased siltation and nutrient run-off into the lake.

2.9 | Inadequate Information

How environmental interactions influence the ecosystem and fisheries processes of Lake Victoria is not clear (Kolding et al., 2008). Kolding et al. (2008) argued the main threat to the Lake Victoria fishery is hypereutrophication, rather than overexploitation, as was previously claimed (Cowx, 2005; Njiru, Getabu et al., 2007; Van der Knaap et al., 2002). Kolding et al. (2008) further argued that the fish stock-assessment models used might not be suitable for Lake Victoria as the lake is not in a biological steady state. Taabu-Munyaho et al. (2014) argue the recent increase in *R. argentea* and haplochromines in the lake could further discount the notion that deoxygenation is the factor driving the stocks in the lake. These findings imply the role of limnology in influencing the Lake Victoria ecosystem merits further consideration. Most current regulations governing utilization of Lake Victoria resources were formulated on the basis of limited scientific findings, and before the transformation of the lake's fisheries (Mkumbo, 2002). In November 2001, for example, Kenya created a regulation to close its fishery from April to August (high rainfall months) each year in an effort to protect *R. argentea*, whose breeding typically peaks during this period (Njiru et al., 2002; Ojwang et al., 2014). In contrast, fishing for the species continued in the Ugandan and Tanzanian portions of the lake during this period. There were insufficient data to prove whether or not the closure of the fishery had any profound effects on the stocks of *R. argentea* in the entire lake (Ojwang et al., 2014).

2.10 | Unharmonized policies

Mobile natural resources like fish in Lake Victoria do not recognize borders. Without riparian cooperation, therefore, the integrity of shared resource can be jeopardized by unsustainable use by one of the states (UNU-INWEH 2011). When the Lake Victoria was mainly for subsistence use, there were not many challenges in its exploitation and management. This situation changed, however, following the increased demand for Nile perch after its commercialization in 1990s. The reduced stocks and increased demand lead to conflicts in exploitation and access to fishing grounds. Even with the emerging challenges, the three riparian states lacked an overall management policy for the Lake Victoria fishery. There was poor assessment of transboundary needs and engagement on appropriate interventions in fisheries management. National policies that affected fisheries (e.g., those dealing with water resources, agriculture and forestry) give little attention to lake or transboundary water resource and fisheries management issues (Kayambo & Jorgensen, 2006). The policies and regulations were disjointed, lacking proper coordination. An example is pollutants entering the lake and subsequently affecting the fisheries, which originate in the catchment, while management activities are largely nationally focused in some instances, with no harmonization between ministries even within the same country (Kayambo & Jorgensen, 2006). Furthermore, where the regulations of all three countries are similar, the penalties for not adhering to them differ. Lack of harmonized policies makes it difficult to institute remedial measures taken by one government. In addition, the lake fishery regulations were designed mainly to protect the commercially important species, ignoring the native species upon which most poor people depend (Njiru, Okeyo-Owuor et al., 2007; Ntiba et al., 2001; Van der Knaap et al., 2002). Lack of inclusion of native species in policies and regulations is also a major challenge in managing Lake Victoria fisheries, as the much smaller native species can only be caught using banned gears (gillnets <4 in., beach seine), capturing juveniles of commercial species of Nile perch and Nile tilapia in the process.

3 | FISHERY MANAGEMENT STRATEGIES

Lake Victoria fishery management has exhibited several scenarios in fisheries management regimes, based mainly on catch changes and available scientific information. The Lake Victoria fishery management strategies have mainly focused on managing fishing efforts and catch of major species. It has historically been a top-down, command-and-control-type management approach, whereby fishery management was overseen by relevant government agencies (Geheb & Crean, 2000). This structure caused resources users to associate the fishery with the government, thereby causing the users to make little effect to conserve it. Social studies regarding the lake indicated that over 70% of fishers felt the lake and the fishery belonged to the government (Abila, 2002). The regime mainly involved the "top-down" management approach with the government developing regulations for fishers to implement, an approach that has not improved either the fish stocks or the health of the lake. The strategy is viewed as being too narrow and lacking an holistic approach that would involve ecological considerations that may affect fish populations (Kolding et al., 2008; . A new paradigm shift is now based on ecosystem-based management.

3.1 | Community-based management

It has been argued that community involvement in fisheries management may be able to assist in reversing the downward trajectory trend (SEDAWOG 1999; Imende, Hoza, & Bakunda, 2005). Fisheries comanagement is an approach involving shared responsibilities among governments, fishers, public and private stakeholders (Imende et al., 2005). To realize community-based management, the riparian governments and development partners formed over 1,400 community-based Beach Management Units (BMUs) spread throughout the entire lakeshore (Nunan, 2010). The BMUs were to tackle illegal fishing in their area of jurisdiction, be involved in joint planning, sharing of ideas and pooling resources to fund particular activities. The BMUs did not succeed, however, based on the increased illegal fishing gears, overcapture of fish and overall fish catch decline (Njiru et al., 2014). It has been argued that the BMU concept was too much fishery-based, too focused on a single species and ignored the ecology of the lake (Njiru et al., 2014).

3.2 | Information sharing

A strategy for collaboration, networking and sharing of information is vital for successful transboundary fishery management (Njiru et al., 2005; Nunan, 2014). For fishers to be well informed, for example, requires simplified laws, policies, regulations and guidelines related to fisheries management, and available in their major local languages (Dholuo, Kiswahili and Luganda). Strengthening cross-border exchange visits would allow BMUs to meet, learn from each other, raise awareness and develop remedial measures to address resource exploitation, and transboundary conflict issues. The riparian states currently involve their respective scientists in joint hydroacoustic surveys covering the entire lake. Frame surveys, although undertaken by individual countries, are carried out during the same period. These survey data are analysed and shared among the states to better understand the fishery and improve fishery management efforts. Information sharing also can be extended beyond the three Lake Victoria riparian countries. Efforts to strengthen scientific information exchanges between large freshwater systems globally have occurred for almost two decades between experts from Lake Victoria and the North American Great Lakes. The two organizations have formally committed to (a) develop and harmonize research themes for the lakes and their fisheries designed to facilitate answering pertinent questions for the two ecosystems; (b) improving climate change predictions and the possible consequences, including gaining a better understanding of the capability of General Circulation Models (GCMs) to predict precipitation, wind and temperature changes and their effects on the lakes and their fisheries; and (c) exchanging social and natural science information. The twinning efforts are meant to enable a better exchange of scientific understanding of the myriad challenges affecting Lake Victoria fisheries.

Other information-sharing processes have also taken place over the past two decades, including the Great Lakes of the World conferences, whereby freshwater experts, mostly from Africa, convene every two years to share information on their specific large lake (including many in the African Great Lakes region). Recent efforts have increased to get large freshwater body experts together to address the myriad problems facing these resources, with the most recent large-scale effort being the Africa Great Lakes Conference (AGLC) held in Entebbe, Uganda, in May 2017 (https://www.greatlakesofafrica.org). The AGLC, facilitated by The Nature Conservancy, linked science and best practices to solutions for conservation and sustainable development of the African Great Lakes, including Lake Victoria. The major conference outcomes included the use of an ecosystem approach in management; sustainable utilization of resources harmonization of policies and regulations; implementing strategies to reduce population pressures; use of science to develop relevant information; strengthening and better coordination of institutions; and increased funding to facilitate problem solutions.

3.3 | Ecosystem approach

An ecosystem approach to fisheries management endeavours to balance different community needs, taking into account the dynamics of the ecosystem (Dimech, Barros, & Bianch, 2014; FAO 2003; Garcia, Zerbi, Aliaume, Do Chi, & Lasserre, 2003). Reestablishment of the East Africa Community (EAC) in 1994, which had collapsed in 1977, was a major paradigm shift towards implementing an ecosystem approach to managing Lake Victoria and its basin. This approach was further enhanced by such procedures as the 2004 *Protocol for the Sustainable Development of Lake Victoria Basin* (LVB), which was a legal instrument negotiated and agreed by partner governments for regulating Lake Victoria water quality and quality. The EAC designated Lake Victoria and its basin as an "area of common economic interest" and a "regional economic growth zone" (EAC 2000, 2004). The EAC recognized economic growth, and increased employment opportunities would only be achieved through sustainable utilization of natural resources and conservation of the environment (UNEP 2006). This sustainable growth will require collaboration between EAC governments, development partners, nongovernment organizations (NGOs) and the private sector. To achieve this growth, EAC developed a protocol addressing environmental concerns throughout the lake basin. It also formed several institutions focusing on a broad range of issues affecting their partner states, of which Lake Victoria forms a part, including the East African Parliament, the Supreme Court, East African Development Bank (EADB), the Inter-University Council for East Africa (IUCEA), East African Business Council (EABC), East Africa Law Society (EALS), Lake Victoria Basin Commission (LVBC) and LVFO (Kayambo & Jorgensen, 2006).

Although management is mostly sectoral among the Lake Victoria riparian States, fisheries management through the LVBC and LVFO is the most coordinated sector, probably because of its economic importance, and inputs from external development partners with stakes in the Nile perch fishery. The two institutions perform the vital role of bringing together all the riparian partner states through policy harmonization for Lake Victoria Basin resources management and utilization. The LVFO is specific in the creation and implementation of a viable regional management of the lake fisheries, having developed a Strategic Vision based on an "ecosystem approach" encompassing five specific areas, namely a healthy lake ecosystem, integrated fisheries management, coordinated research programmes, information generation/flow/exchange and institutional/stakeholder partnership (LVFO 2008).

The LVBC is concerned with general development and management matters of the Lake Victoria Basin (LVB; EAC 2000), serving as the caretaker of the lake and its resources on behalf of the people of its basin. To facilitate holistic research and data collection, LVBC coordinates several projects focusing on the health of the Lake Victoria ecosystem. The Lake Victoria Environmental Management Project (LVEMP), for example, is one of the major projects utilizing an holistic approach to managing the lake and its basin with stakeholders involvement through National Task Forces (NTFs) appointed by the EAC in consultation with the national governments. This gives the project East African ownership at regional-, national- and local-level (grassroots) involvement, which can facilitate its success.

4 | CONCLUSION

The Lake Victoria fisheries are affected by numerous variables attributed mainly to human stressors, including intense fishing, loss of biodiversity, fishery ownership issues, pollution, invasive of exotic species, climate change, inadequate information and unharmonized policies. There have been numerous approaches undertaken by various and disparate agencies, NGOs and government ministries around the basin to address various problems that either directly or inadvertently affect Lake Victoria waters and fisheries. The interventions have not yet exhibited much success in reducing degradation of the lake water quality and the decline in fish catches.

It is suggested, therefore, that a mechanism be created to harmonize all efforts in such a manner that protects Lake Victoria and its fisheries. With the interlinked functions of the Lake Victoria ecosystem and its basin, the optimal approach for managing the resources would be an ecosystem approach that encompasses science and the lake environment. There is need to embrace a paradigm shift incorporating increased scientific exploration of the effects of the various inputs and stresses on the lake, climatic changes to water levels and fisheries and increased communications among riparian countries and national government ministries to address adverse pollution effects on the lake resources, especially those affecting the fisheries. The recently concluded African Great Lakes conference proposed the formation of a "Network of African Great Lakes Basin Stakeholders" to meet within the next 5 years to report on the status, trends and values of major ecosystem services, and to review promising interventions, new science and priority issues of relevance to the lake basin (https://www.greatlakesofafrica.org). Furthermore, the formation of the African Center for Aquatic Research and Education (ACARE) is focusing on increasing efforts to utilize Lake Victoria and its resources in a sustainable manner (www.agl-acare.org). This collaborative centre of excellence will be dedicated to increasing the local capacity of scientists, managers and politicians through courses, training and practical education on African Great Lakes. Furthermore, the recent FAO-sponsored conference in 2016 emphasized the role of inland fisheries in the growth of the blue economy, providing a roadmap on the assessment of inland fisheries and how to utilize them in a sustainable manner. It developed the Rome Declaration, containing components geared towards responsible utilization of inland fisheries (Taylor, Bartley, Goddard, Leonard, & Welcomme, 2016). On a local level, harmonized research activities among the riparian states, sharing of information and promotion of multisectoral integrated community-based development tools that contribute to sustainable conservation and management of natural resources should be encouraged.

Major constraints to the ecosystem approach to management of the ecosystem include inadequate funds, inadequate knowledge and resistance to needed changes. Nevertheless, concerted efforts on the part of stakeholders and sensitization at all levels can actualize a more holistic approach to managing Lake Victoria basin and its fisheries and reduce some of the associated challenges.

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