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REVIEW ARTICLE

Threats to aquatic biodiversity and possible management strategies in Lake Victoria

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Abstract

Lake Victoria is the second-largest freshwater lake in the world, with a surface area of 68,800 km^2. The lake is rich in natural resources that are essential to the local economy and livelihoods. However, International Union for Conservation of Nature (IUCN) ranks 76% of freshwater species endemic to the Lake Victoria Basin as threatened with extinction. The biodiversity richness of the lake is still diminishing, and the risk of species extinction is increasing. Many species are yet to be identified, and thus the number of species threatened with extinction exceeds what is currently known. Furthermore, the lake is home to species that are found nowhere else on the planet, but its protection is never given the attention it needs. Genetic diversity loss is harmful to future populations and influences sustainability of the ecosystem. The decline in Lake Victoria's biodiversity is primarily attributed to various pressing issues, including water pollution, invasive species, climate change, overexploitation and the challenges stemming from high human population density. These problems are exacerbated by inadequate regulatory enforcement and a lack of comprehensive data and information to inform and guide conservation efforts. If these factors are not addressed, they may have a detrimental impact on Lake Biodiversity. This article aims to document the main threats to aquatic biodiversity as well as potential management strategies for preventing further losses of the aquatic biodiversity in Lake Victoria. The study recommends reviewing, bolstering and reinforcing the rules and regulations governing the extraction, accessibility and discharge of nutrients into the lake. The national governments should work with local governments, non-governmental organizations and local people to safeguard and conserve the lake's biodiversity. The national governments of the riparian nations should also reserve funds each fiscal year specifically for research that would inform effective management measures to prevent further losses of the lake's biodiversity.

KEYWORDS
biodiversity loss, extinction, IUCN, Lake Victoria, species

1 | INTRODUCTION

Freshwater environments occupy less than 1% of the Earth's land surface. Despite this relatively small geographic coverage in comparison to marine and terrestrial ecosystems, they are remarkable for hosting over 10% of all animal species and 35% of all vertebrate species (Campbell et al., 2022; Stendera et al., 2012). Lake Victoria is one of the largest freshwater environments in the world which is shared by three riparian countries – Kenya (6%), Uganda (43%) and Tanzania (51%). The lake covers 3500-km shoreline and has an average depth of 40 m (Njiru et al., 2010). It is well known for having a huge biodiversity and range of species all over the world. It was originally known as 'Darwin's dream-pond' because it is thought that many cichlid species have developed from a small number of species in just 15,000 years, which equates to a new species appearing after every three decades averagely (Seehausen, 2002). Biodiversity, representing the natural biological wealth of our planet (Lake Victoria Basin Commission [LVBC], 2011), plays a vital role in delivering essential goods and services. These services encompass the provision of goods like food and the regulation of natural processes, including erosion prevention, water purification, hazard mitigation and climate control. Additionally, biodiversity contributes to cultural values and supporting values, such as habitat provision, water cycling and knowledge systems. These contributions are of utmost importance, especially for residents along the shores of Lake Victoria, who may have limited access to market resources (Sayer et al., 2018). Furthermore, the Lake Victoria Basin serves as a habitat for a diverse range of plants, fish and birds, many of which hold significant commercial value and provide essential raw materials for construction (Agol et al., 2021).

Worryingly, Lake Victoria Basin has seen multiple negative changes that have left its species diversity in grave danger (Darwall et al., 2011). Macrophytes, algae, invertebrates, fish and non-fish vertebrates, including mammals, reptiles, birds and amphibians, are all important to one another and to human existence in the aquatic environment. The Lake Victoria Basin has a total of 44 mammalian species, 31 amphibian species and 28 reptile species (United Nations Human Settlements Programme [UN-HABITAT], 2008). Most of the present conservation efforts are concentrated on terrestrial rather than aquatic ecosystems, despite most of the aquatic species facing a threat of extinction. According to Red List Indices, Lake Victoria's biodiversity is declining and the risk of species extinction is rising. Recent statistics state that 19.7% of the freshwater biodiversity native to the lake is threatened, whereas 76% of freshwater species endemic to the lake basin are at risk of extinction (Sayer et al., 2018). Due to a reduction in the genetic pool of potential responses to stress, limited genetic variation causes inbreeding, poorer population fitness and diminished population resilience (Ishii et al., 2022). This implies that a species' ability to benefit an environment is reduced if the species or its genes are eliminated. Concerns for species conservation and environmental integrity are intricately linked to human welfare, just like they are everywhere else. Given the aforementioned, aquatic biodiversity becomes a very important issue as it directly or indirectly supports the livelihoods of more than 35 million people in the Lake Victoria Basin (Njiru et al., 2018).

Fish appear to be the most glaring indicator of the lake ecosystem's bad state of biodiversity loss, followed by mollusks, decapods, plants and odonates (Outa et al., 2020). For instance, the lake comprised approximately 500 fish species of commercial and scientific importance at the beginning of the 20th century, the majority of which were indigenous to the lake (LVBC, 2011). However, most Lake Victoria fish species are threatened in the basin due to poor fishing practices, overfishing and environmental degradation. *Labeobarbus microbarbis* is one of the native species of the lake that has been proven to have gone extinct (Sayer et al., 2018). Lungfish is a vital delicacy for the majority of local communities due to its relevance in enhancing the immune system, curing alcoholism and being sold for medical purposes and as a source of sustenance (Laku, 2021). Large wetlands are another component of the LVB, and they serve to filter pollutants and other wastes before they reach the lake. However, many people believe that most wetlands are empty land that should be exploited for agriculture (Sinthumule & Netshisaulu, 2022).

Because the majority of the declining species are fish, which are particularly important as a source of food, the loss of biodiversity has had a substantial impact on the livelihoods of the rural poor residents surrounding the lake (Outa et al., 2020). Freshwater plants are also utilized for several purposes, including food, medicine, building and handicrafts (van Dam & Kipkemboi, 2018). Given the local communities and national economies' heavy reliance on the ecosystem as well as the distinct nature of the diverse species within the freshwater ecosystem, conservation activities are required to reverse the rising loss of biodiversity in Lake Victoria. We hope that by documenting the major threats to the freshwater ecosystem, this article will inspire action and inform conservation programmes and policymakers about workable management solutions to lessen the long-term effects of biodiversity loss on local livelihoods and the national economy.

2 | METHODOLOGY

A scoping literature search of scientific databases, including but not limited to PubMed, Web of Science and Google Scholar, was conducted. The search focused on articles, reports and studies related to aquatic biodiversity in Lake Victoria, threats to biodiversity and management strategies. The search terms incorporated in the search strategy encompassed words, such as 'Lake Victoria', 'aquatic biodiversity', 'threats', 'management strategies', 'extinction' and 'conservation'. The inclusion criteria for the reviewed literature included relevance to the topic, full-text publication in peer-reviewed journals and publication between the years 2005 and 2023. Articles that were not available in English were excluded.

Data from the selected articles were extracted, including information on the various threats to aquatic biodiversity in Lake Victoria, potential management strategies and their impacts. The extracted data were analysed to identify the main threats to aquatic biodiversity and the corresponding management strategies. Key findings and trends from the selected literature were synthesized to provide a comprehensive overview of the threats and potential management strategies.

3 | RESULTS AND DISCUSSION

3.1 | THREATS TO BIODIVERSITY

3.1.1 | Water pollution

Over the last 50 years, both point and non-point source water pollution have become important issues as a result of the negative impact of de-oxygenation, which has fundamentally shifted the environmental state of Lake Victoria from mesotrophic to eutrophic conditions (LVBC, 2011; Xu, Tan, et al., 2022). Agricultural runoff (including pesticides and herbicides), untreated industrial waste, pharmaceuticals from nearby metropolitan areas like Kisumu, Kampala and Mwanza and household sewage from lakeshore settlements are the major sources of wastes in Lake Victoria (Nassali et al., 2020). Agricultural operations surrounding Lake Victoria have significantly grown over the last three decades, resulting in high quantities of phosphorus and nitrogenous contaminants being thrown into the lake (Njagi et al., 2022).

Agricultural runoff, which contributes to around 75% of the nitrogen flow into the lake, is the main reason for the lake's high nitrogen burden (Mnaya et al., 2007). This is because large-scale tea, coffee, cotton, maize, rice, tobacco and sugar plantations consistently employ agrochemicals, which causes soils to become acidic (Shayo & Limbu, 2018). Soil erosion is a significant problem for agricultural areas situated on elevations with gradients higher than 1.5 to 2.0 degrees. Thus, during times of intense rain, all agrochemicals used in agricultural regions are washed into the lake. Urban garbage accounts for a sizable portion of the trash poured into the lake. For example, in Mwanza, untreated sewage water at a volume of about 2 million litres every 24 h is released into Lake Victoria through Igogo Creek and the Mirongo River (Kondoro & Mikidadi, 1998; Nassali et al., 2020). Approximately 16 million gallons of semi-treated garbage are also discharged into the lake each day by the Nakivubo sewage system in Jinja, Uganda (Mugisha et al., 2007).

The ecology and productivity of aquatic ecosystems are impacted by nutrient enrichment, which causes weeds, macrophytes and algal blooms (Kyomuhendo, 2003). The amount of algae blooming in Lake Victoria has multiplied by 8–10 times, blocking sunlight and deteriorating the anoxic conditions that impair plant life and increase fish mortality (Kazmi et al., 2022). Since the 1960s, 30%–50% of the oxygenated waters have disappeared, restricting the variety of creatures vulnerable to low oxygen levels (Mugidde et al., 2005). This is clear from Simiyu and Kurmayer's (2022) research that the majority of invertebrates have relocated from deep to intermediate and surface waters as a result of anoxia, leaving them exposed to selective fish predation. Several zooplankton species have also come under threat from pollution and changes in the phytoplankton's composition.

Additionally, algal blooms emit toxins and are dominated by poisonous and unpleasant cyanobacteria, which not only induce anoxia but also cause other negative effects (Valeria et al., 2006). Algal toxins known as microcystins are created intracellularly in cyanobacteria cells before being released into the environment. The ecosystem is negatively impacted by this, especially fish species that are susceptible to low water quality. The situation is worsened by the equatorial climate in the lake region, where the warm heat lengthens the duration of harmful algal blooms, exacerbating the release of toxins by cyanobacteria (Paerl & Huisman, 2009). Previous research from several studies has established the existence of microcystin in Lake Victoria (Githukia et al., 2022; Mchau et al., 2019; Miles et al., 2013; Simiyu et al., 2018).

The lake's phosphorus levels have more than doubled (Deirmendjian et al., 2021). Total suspended solids concentrations are higher where rivers enter the lake than they are in the middle of the lake, for instance, at the northwest of the lake, Winam Gulf, and Speke Gulf (LVBC, 2011). Green algae, including *Ankistrodemus* spp., *Pediastrum* spp. and *Cosmarium* spp., as well as diatoms such as *Aulocoseria* spp. (*Aulacoseira agassizii* and *Aulacoseira nyassensis*), are reportedly highly vulnerable to excessive phosphorus (Simiyu & Kurmayer, 2022). Fish and invertebrates prefer these species because they have a high nutritional value. Their disappearance has changed the quality and quantity of algae on which fish and invertebrates feed.

Pollution has also led to the disappearance of endemic haplochromine species as a result of genetic differentiation loss, a process known as reverse speciation (Seehausen, 2006). Reduced water transparency as a result of increased primary production mediates the process (Seehausen, 2006; Seehausen et al., 1997). The Secchi disk depth of Lake Victoria has declined significantly, from 5 m in the 1930s to less than 1 m in the 190 s (Lubovich, 2009). According to an earlier laboratory study, when conspecific males are not present, female haplochromines mate with heterospecific males (Egger et al., 2011; Magalhaes et al., 2013). Male haplochromines are unable to recognize conspecifics during breeding because of how differently they perceive female colours due to the lake's increased turbidity (Maan & Sefc, 2013). Low visibility causes originally different species to meld into hybrid individuals. Because of the process, the adaptive environmental diversity that differentiates the cichlid radiation is rapidly degrading, causing species extinction to happen much more quickly than population decrease (Seehausen, 2015; Seehausen et al., 1997). High turbidity has also slowed the growth of *Anabaena* species.

Gold mining seems to be escalating in some parts of the Lake Victoria Basin, though it is carried out on a small scale (Appleton et al., 2005). Due to gold mining, heavy metals, mainly mercury, are dumped into lakes (Shen et al., 2022). Mining seepage poses a threat to six per cent of the freshwater fish species in Lake Victoria. Two species that are in significant danger are the delicate *Labeo victorianus* and the endemic *Labeobarbus acuticeps*. These dangerous metals damage aquatic environments, putting organisms at risk (Birungi et al., 2007). Motor oil from cars and boats is another factor contaminating the lake. There have previously been reported oil spillages associated with transportation as the majority of filling station drainage systems permit oil to flow into sewage systems that feed the lake (Awange & Obera, 2007).

3.1.2 | Introduced/Invasive species

Nearly 200 of the 500 distinct fish species in Lake Victoria became extinct as a result of the introduction of the Nile perch (*Lates niloticus*) and three tilapiine species in the early 1950s (Outa et al., 2020). Nile perch were introduced into the lake in the 1950s and 1960s in order to convert many low-value haplochromines into high-value Nile perch (Goudswaard et al., 2002). Haplochromines made up more than 80% of the lake's demersal fish populations in the 1970s, making them the most common fish species (Marshall, 2018). Nile perch proved to be a fierce predator while having little economic value, which led to a significant decline in local fish species. By the late 1980s, the lake's native fish biomass had dropped from more than 80% in the 1970s to less than 1% (Marshall, 2018).

To make up for the lake's declining fish biomass, especially for native tilapiines (*O. variabilis and Oreochromis esculentus*) exotic tilapiines (*O. niloticus*, *O. leucostictus, Tilapia zillii and Tilapia rendalii*) were introduced (Outa et al., 2020). Between 1961 and 1964, unusually high lake levels brought on by a lot of rain made it easier for tilapias to establish themselves (Nassali et al., 2020). The introduction of *O. niloticus* endangered the native tilapiine species through interspecific competition, hybridization and genetic swamping (Kwikiriza et al., 2023). Currently, *O. niloticus* predominates the majority of fish landings, whereas other tilapiine species are rarely fished (Wasonga et al., 2017). As a result, the lake's fishery is now made up of two invasive species, *L. niloticus* and *O. niloticus*, and one native species, *Rastrineobola argentea*, as opposed to the lake's previous multi-species fishery.

Invasive species are coded as a threat to 31% of native freshwater species and 73% of threatened native freshwater species (Sayer et al., 2018). Inadvertently introducing water hyacinth (*Eichhornia crassipes*) from South America into the lake in the 1980s has significant social and environmental effects (Twongo & Wanda, 2004). At its peak, thick floating mats covered over 10% of the lake's surface (Güerea et al., 2015; Mugidde et al., 2005). Higher nutrient levels have been linked to its success in establishing itself in Lake Victoria (Mugidde et al., 2005). The mats negatively affect the amount of oxygen and nutrients in the water. When the weed degrades, the lake becomes anoxic, with oxygen levels as low as 0.01 mg L^{-1} being observed (Nassali et al., 2020). The inability of native biodiversity to compete or survive in contaminated regions has caused them to dwindle and eventually perish.

3.1.3 | Climate change

Today, everyone agrees that climate change poses a present and future threat to biodiversity (Intergovernmental Panel on Climate Change [IPCC], 2014). Since the Holocene period, the climatic system surrounding Lake Victoria has evolved, and it is anticipated that it will continue to change and have an impact on the ecosystem (Chritz et al., 2015). Several observable consequences of climate change are being felt in Lake Victoria, including a decline in biodiversity. According to Nassali et al. (2020), local processes that disrupt the hydrological cycle and the temperature–rainfall balance include deforestation and forest fires, reduced infiltration, topsoil degradation and soil erosion. These local processes are the primary causes of climate change's effects on the basin's water systems. According to Deirmendjian et al. (2021), the lake is now warmer than it was in the 1990s and the early 2000s. Additionally, recent climatic trends have shown a 10%–40% fall in precipitation since 1960, with the potential for further declines (Nassali et al., 2020). Climate projections generated for the entire African continent indicate that, following the Representative Concentration Pathway 8.5 scenario, certain locations within the basin are expected to experience an increase of over 3°C in mean monthly temperatures by 2055 (Platts et al., 2015). Lake water levels are dropping, with rivers contributing 20% and rains 80% (Awange et al., 2007). This is due to excessive evaporation losses caused by high temperatures (Awange et al., 2007).

The enormous climatic changes (Figure 1) brought on by the high evaporation, including floods and droughts, cause the flood plains to silt up and dry out. Large volumes of silt are washed into the lake by rain due to soil erosion, deforestation and poor farming techniques. Due to their high sensitivity, ostensibly limited potential for adaptation and surprisingly high exposure to change, especially in severely turbid environments, freshwater fish are highly vulnerable to climate change (Sayer et al., 2018).

3.1.4 | Overexploitation and habitat destruction

The primary cause of the lake's declining native and economically significant fish species is attributed to heavy exploitation (Kishe-Machumu et al., 2015). Overfishing decreases population numbers to levels that encourage inbreeding and genetic drift, thus posing a threat to the genetic diversity of wild fish populations (Xu, Dou, et al., 2022). Up until the 1970s, the Lake Victoria fisheries were dominated by more than 200 species of haplochromine cichlids and two species of tilapiine cichlids, *O. esculentus* and *O. variabilis* (Yongo et al., 2021). The number of fishermen, boats, nets and hooks employed on the lake, however, increased between 2000 and 2006, according to a survey by the Lake Victoria Fisheries Organization (LVFO) (LVFO, 2008; Nyamweya et al., 2020), which caused commercial fishing to drastically plummet. For example, the Nile perch fisheries stock decreased to 0.82 million mt between 2005 and 2006 from about 1.29 million mt between 1999 and 2001. The Nile perch stock decreased from 59% to 39% of the overall Lake Victoria fish diversity between 2001 and 2006 (Lubovich, 2009). The African Lungfish (*Protopterus aethiopicus*) population in the lake has also decreased due to overfishing and poor fishing techniques, whereas riverine species like ningu (*L. victorianus*), which move into rivers to spawn, have been threatened by overfishing near river mouths (Outa et al., 2020).

Furthermore, seven fish fillet processing plants run inside Kenyan shoreline cities, according to LVFO (2012), creating a high demand for fish landing. This has led to an increase in fishing capacity and the employment of illegal fishing gear such as beach seines and small-mesh-size nets, which trap juvenile fish, disturb spawners and destroy breeding grounds (Njiru et al., 2010), offering little hope for the

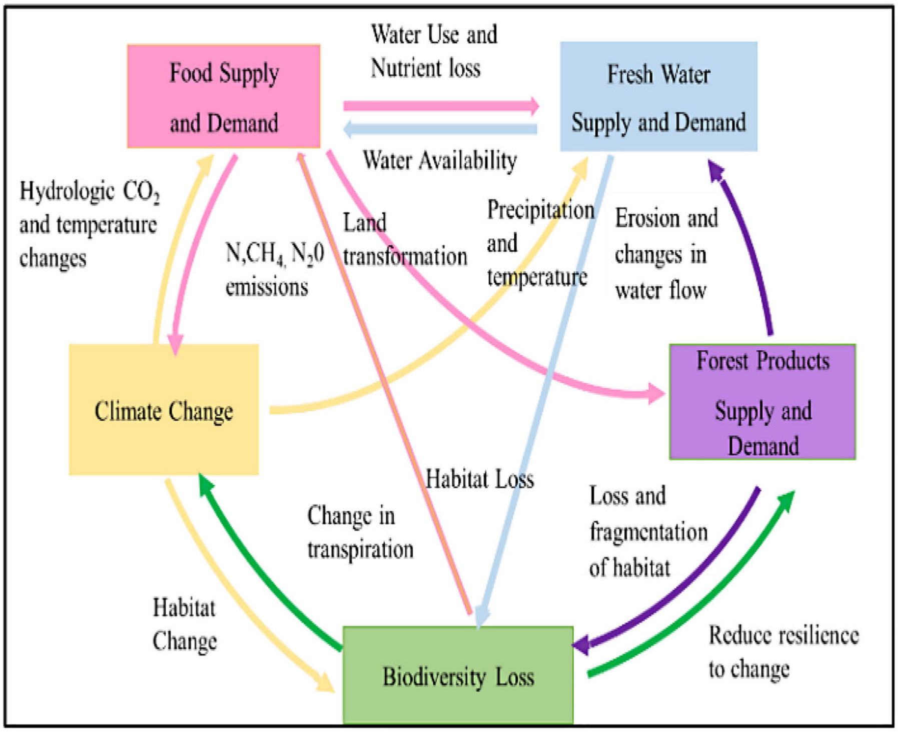

FIGURE 1 Drivers and effects of climate (Nassali et al., 2020).

recovery of fish populations. The abrupt decline in commercial fish harvests has led to job losses and financial losses for regional and national economies (Aloo et al., 2017). As seen by the first collapse of native tilapiines (*O. esculentus* and *O. variabilis*) in Lake Victoria, overfishing has also affected typical amounts of gene flow between local populations and, as a result, genetic population structure has negatively been impacted (Wasonga et al., 2017).

Also overexploited are the aquatic microphytes that border the beaches, which has led to a decline in microphyte diversity, abundance and distribution. Healthy papyrus, which was common in the lake basin and helped reduce the effects of nitrogen loading and sedimentation, has been threatened by excessive harvesting and clearing for agriculture, infrastructure and urban populations. As a result, the lake now has a high nutrient load from non-point sources. This is because microphytes' capacity to continue performing these essential ecological activities has been reduced (Kansiime et al., 2007). The vegetative cover around the lake is used by the majority of aquatic animals for hiding, mating, roosting and breeding. But these settings are continually deteriorating due to human activity. For instance, whereas many water birds use vegetation as a haven for eating and nesting, *O. esculentus* is primarily reliant on water lilies as nursery grounds. But the lilies have all but disappeared from the lake, leading to the extinction of this species (Yongo et al., 2021). The recruitment and survival of several species that depend on the vegetation during their infancy have been adversely affected by the clearance of bordering marshes surrounding the lake (Wanyonyi, 2016).

3.1.5 | High population density

With most settlements having more than 100 inhabitants and some parts having population densities as high as 1200 persons/km^{-2}, the Lake Victoria catchment area has one of the highest rural population densities in the world (Lubovich, 2009). High population density is a result of the lake's abundant natural resources, increased urbanization and job prospects, especially in the area close to the shore (Lehman, 2009). The catchment area is the primary source of income for close to 30 million people. The main industries in the area include manufacturing, agriculture and fishing. In the agricultural environment, hydroclimatic conditions and sustainable land use management are crucial. The lake catchment region is becoming environmentally unstable due to inefficient farming practices, high levels of poverty and increased agricultural land demand (Nassali et al., 2020).

Swamps surrounding the lake have been invaded because of the dense population to make more space for farming and habitation. The lake basin has been reported to have severe water erosion due to deforestation, with an estimated 45% of the land being at risk (Odero & Odenyo, 2021). Deforestation has led to the extinction of water lilies and other water weeds, especially in marshy places. *O. niloticus* nursery grounds and the feeding niche for higher-level plants utilized as food by invasive *T. zillii* have both decreased as a result of wetland removal (Balirwa, 2017). Together with the high population density, the agricultural and industrial sectors' extraordinary expansion has led to rising pollution and, eventually, severe lake degradation. Unchecked high population density would have detrimental consequences on lake biodiversity given current population trends and forecasts of more than 40 million people by 2050 (van Soesbergen et al., 2019).

3.1.6 | Poor enforcement of policies and regulations

Given the distinctive and varied biodiversity found in Lake Victoria, lake management calls for the stringent application of laws and regulations to stop the loss of these species (Maithya, 2021). The rules and regulations controlling lake pollution and fishing activities are implemented with a considerable deal of laxity and weakness. For instance, the LVFO organizes the three riparian governments of Kenya, Uganda and Tanzania in terms of managing Lake Victoria, whereas their respective fisheries ministries are in charge of putting agreed-upon measures into action (Lawrence et al., 2018). The laws and regulations on how to fish in the lake to reduce overfishing and other destructive fishing practices are quite explicit, yet due to lax enforcement of the law (Obiero et al., 2015).

Additionally, international agreements made during the 1920s and 1950s, when colonial authority was at its peak, control the lake. The agreements were created to guarantee Sudan and Egypt have access to enough water year-round as irrigation schemes sustain their economies (Luilo, 2010). The existence of numerous species is threatened by the lack of uniformity in water and wastewater standards as well as differences in agricultural practices throughout the three riparian nations. The economies of the three riparian nations are fragile and their waste management systems are subpar. As a result, their end-of-pipe waste management techniques continue to seriously affect the Lake Victoria ecology (Luilo & Kabudi, 2003). Both Uganda's Uganda Environment Management Statute, 1995, and Kenya's National Environmental Management and Coordination Act, 1999, are cross-sectoral environmental legal frameworks created by parliamentary acts (Oulu & Boon, 2011). The Environmental Management Act of Tanzania was only passed in 2004 (Somi, 2022). Despite having the power to protect the environment, the organizations made possible by these legal provisions struggle to fulfil their obligations because of a lack of human, technical and financial resources. They are limited to providing advice to their respective governments as a result of their inability to monitor and enforce laws (Nassali et al., 2020).

Man has also occupied areas that were formerly home to wildlife near aquatic habitats (Njagi et al., 2022). Hippopotamus and sitatungas, which are threatened with extinction in some areas of the LVB due to wildlife hunting, have been affected. There have been allegations of corruption, including officials who were bought off to permit illegal activity in the lake (Nunan et al., 2018). The lackluster coordination and legislative procedures at national and regional entities are to blame for everything. National policies are not well-aligned concerning the enforcement and conservation of biodiversity. The direct release of untreated effluents into the lake is prohibited by laws and regulations; however, they are not often followed.

3.1.7 | Lack of adequate data and information to guide conservation

Extensive research efforts in Lake Victoria's ecology face challenges in acquiring data and knowledge for aquatic biodiversity management (Aura, Roegner, et al., 2022). The disorganized data management leads to duplicated efforts (Obiero et al., 2020) and gaps in identifying many species, hindering comprehensive descriptions. There is also a lack of statistics on the value and interdependencies of aquatic life forms. Moreover, data on human-induced factors, like climate change, impacting Lake Victoria is scarce (Wasige et al., 2013). Understanding the species in rivers, which connect the land and the lake, is limited. Information on wetlands' capacity, underwater plant inventory, water quality, nutrient levels and the roles of various species in environmental health and fishing support is lacking (Simonit & Perrings, 2011).

A significant issue is the absence of fundamental knowledge regarding freshwater species' distribution and status in the basin. Data mainly focus on larger organisms, particularly commercially important fish, with minimal information on smaller organisms. Taxonomic challenges persist due to incomplete and varied data formats. Addressing these challenges requires identifying and protecting endangered fish species in Lake Victoria and their habitats, potentially through freshwater protected areas. Higher taxa, including reptiles, mammals, amphibians, birds and other species, also lack sufficient data throughout the lake basin (Ochieng et al., 2019). Comprehensive surveys are needed to collect data on these taxa and understand their roles in the ecosystem. Safeguarding riverine fish during their breeding seasons at river mouths necessitates the identification and management of catchment practices that degrade riverine ecosystems.

3.2 | POSSIBLE MANAGEMENT STRATEGIES

3.2.1 | Alternative source of income

Every year, the human population around the lake increases by roughly 3% (United Nations Environment Programme [UNEP], 2006). The lake is the main source of income because agriculture is underdeveloped and rainfall is erratic. Due to the rising human population and high demand for exports within the lake basin, there will never be enough fish available, even with the best management practices (Njiru et al., 2014; Yongo et al., 2005). According to Mushi et al. (2005), approximately 1 million tons of fish are needed annually for local human consumption, regional markets and the fish processing sector. The riparian nations that border the lake have to think about putting funds into alternative income sources. The nations, for instance, have enough natural resources to engage in aquaculture. Therefore, they should finance and implement cutting-edge, environmentally friendly aquaculture technologies to invest in the growth of aquaculture (Heijden et al., 2018). The pressure on fishing resources would also be reduced by other economic activities like horticulture and ecotourism (Omambia, 2008).

3.2.2 | Improved agricultural practices

Fertilizers from agricultural fields, together with other pollutants from untreated sewage and uncontrolled effluents from urban areas, wash into the lake and contribute to its high eutrophication rate (Olokotum et al., 2020). Improved agricultural techniques can aid in reducing nutrient emissions into the lake, such as reducing vegetation removal to minimize soil erosion and reducing slash-and-burn vegetation, which raises phosphorus levels in the atmosphere (Mugidde et al., 2005). Tertiary waste treatment should be undertaken in addition to industrial waste treatment to reduce the amount of nutrients entering the lake using created wetlands. Laws against the release of trash into the environment should be reviewed, strengthened and enforced (Obongo et al., 2021).

3.2.3 | Capacity enforcement

Despite being threatened, most of the biodiversity may be restored if the lake is properly managed (Njiru et al., 2002). Before it becomes necessary to limit open access to the lake, licencing programmes, enforcement, monitoring and extension initiatives should be put in place to stop further biodiversity loss. The management of the lake should come up with a plan to guide actions to prevent illegal fishing, limit fishing effort and enhance data collection (Plummer et al., 2021). To preserve the lake's shallow nursery and breeding zones, a no-fishing zone should be established around 200 meters from the coast (Njiru et al., 2010). Additionally, the use of closed zones is necessary to protect fisheries at their most delicate stages of growth. The restricted areas should also include riverine settings, river mouths and adjoining floodplains where anadromous fish species, including *Brycinus*, *Labeo*, and *Barbus*, breed (Mkumbo et al., 2007). To manage water quality and quantity, a water policy governing the release of water into and out of the lake should be developed and updated. Bush burning is one example of a human action that increases P and N loads in the lake and should be controlled.

New legal frameworks should be formulated and existing ones including local community involvement should be enhanced (Obiero et al., 2015; Ogello et al., 2013). To assist the management of biodiversity resources, baseline surveys and long-term monitoring programmes are essential. To make sure that freshwater ecosystems offer water, food, medicine, money and other ecosystem services in the long run while also sustaining biodiversity, integrated river basin management and environmental flow approaches should be used (Juffe-Bignoli & Darwall, 2012). This will have an economic and social impact on local livelihoods.

3.2.4 | Enhanced research

To preserve aquatic biodiversity, there are several research gaps in Lake Victoria that need to be filled. Consistent research is necessary for the periodic updating of species red list assessments and surveillance of critical biodiversity regions to track patterns in the anticipated total extinction risk of freshwater species and inform managers about the efficacy of any management actions (Sayer et al., 2018). Furthermore, nothing is known about how climate change affects the ecosystem around the lake. Therefore, an in-depth study of how climate change affects the social and political environment is necessary. Additionally, it is important to conserve areas involved in the conservation of fish species diversity, such as marine parks, protect the wetlands around the lake, collect data to help with management and locate, map, and maintain biodiversity areas within the lake basin (Guerreiro et al., 2010).

The wetlands in the basin must be inventoried and defined, and their biomass must be calculated. The value of wetlands in carrying out diverse activities must also be evaluated to develop wetland management plans, sustainable wetland resource utilization techniques and wetland biodiversity conservation strategies (Maithya, 2021). More research is also required into the status, trends and composition of the diversity of algal species, particularly for those that generate toxins to reduce their impact on other organisms and people who depend on the environment for a living (Miruka et al., 2021). Freshwater species conservation may be aided by site-scale conservation, with a focus on key biodiversity areas. Thirty-nine major river, lake and wetland habitats were identified by Sayer et al. (2018) as key biodiversity areas for freshwater biodiversity. Therefore, it is important to adopt conservation measures and increase awareness of their role as validated key biodiversity areas. A network of areas crucial for freshwater biodiversity in the Lake Victoria ecosystem was identified through a detailed review of ecosystem management. It is suggested that this be utilized as scientific evidence for potential protected area creation and expansion in the Lake Victoria ecosystem to better represent endangered, endemic and freshwater species vulnerable to climate change (Sayer et al., 2019).

3.2.5 | Government funding

Riparian governments do not devote a sizable amount of money to lake research despite receiving US$600 million annually from lake resources (Lawrence, 2015). Donors fund most of the lake research projects. However, donor funds are infrequent and often designated for certain goals (Kleih et al., 2013). The riparian government should thus think about allocating some money for research that is motivated by urgent concerns regarding the management of ecological diversity. Research and lake management can be funded in part by taxes, particularly those imposed on the fishing business. This research-based data collection will help in quantifying and evaluating the values of diverse aquatic biodiversity components in Lake Victoria, as well as their effects on livelihoods (Funge-Smith & Bennett, 2019). It will also help communities become more aware of the value of managing lake resources sustainably. Lake infrastructure might also be improved by riparian administrations to reduce post-harvest losses (Aura, Owiti, et al., 2022). For instance, offering electricity and refrigerated facilities would enable fishermen to store their catches for longer periods and benefit more from them.

3.2.6 | Improved governance, policy, legal and institutional frameworks

Successful institutional structures for executing policies and legal instruments are required for effective and efficient resource management (Börner et al., 2007). Ineffective and disjointed institutions that carry out policies and enforce laws, lack of commitment and occasionally corruption among law enforcers, and lack of participation and commitments from beneficiary communities to sustainable resource management are some of the obstacles to the conservation and sustainable use of aquatic biodiversity in Lake Victoria (Obwanga et al., 2020). In order to prevent the primary threats to biodiversity, such as pollution, eutrophication, climate change, loss of habitats and extinction of species, aquatic biodiversity management should call for the conversion of data and information into recommendations for enabling policies, laws and regulations (Balasubramanian et al., 2021).

Biodiversity concerns are covered by several international laws and treaties, including the Rio Declaration on Environment and Development. The World Heritage Convention and other international agreements and protocols address fair and sustainable use as well as the preservation of biodiversity. LVFO Council of Ministers have formulated two commitments to sustainable fisheries management, including the Regional Plan of Action from Management of Fishing Capacity and the LVFO Regional Plan of Action to Prevent, Discourage, and Eliminate Illegal, Unreported, and Unregulated (IUU) fishing (Nunan, 2014). The use of regional, national and international legal procedures, however, has fallen short, which has led to the continuous deterioration of ecosystems and species. As a result, it is necessary to strengthen the enforcement of legal provisions, for example by involving user communities (Luomba et al., 2016). The International Plan of Action on IUU Fishing, which seeks to outlaw IUU fishing, is one of several international legal papers connected to the Code of Conduct for Responsible Fisheries. Additionally, a regional strategy has been created to address IUU fishing in Lake Victoria, but its implementation has been poor, and the illegalities in the fishery have continued to affect commercially important fish (Luomba et al., 2016).

3.2.7 | Community-based management

Government enforcement has not lessened human impact on the lake which necessitates alternative options. Community-based management systems may be established to co-manage the ecosystem with governmental organizations through monitoring, control and surveillance, (Mahatane et al., 2017). A previous study found that community-organized beach patrol squads were very effective at keeping an eye on fishing areas to deter thieves and illegal fishing nets (Obiero et al., 2015). Involving communities that are also engaged in resource use increases a sense of ownership, reduces costs and enables quick reaction to signs of environmental degradation and overuse (Geheb et al., 2007). Recently, the LVFO has promoted the formation of neighbourhood beach management organizations to manage lake resources in collaboration with local authorities and fisheries professionals. The portion of the lake nearest to the beach management units' homes is under their jurisdiction. This has made a significant contribution to the lake's natural resource preservation (Kateka, 2010). Numerous regional species that are close to extinction can be saved by increasing the number of community-based management organizations aimed at protecting the environment from other major threats like pollution (Nunan & Cepić, 2020).

3.2.8 | Improved institution and expert networking

Lack of a single database to guide management decisions and clear guidelines for data and information exchange between organizations and experts that collect and maintain data is a major barrier to the conservation of aquatic biodiversity (Ganzevoort et al., 2017). This is caused in part by how institutions and experts manage the limited available information. These organizations include academic institutions, regional and international organizations, parastatals, non-governmental organizations, research and management institutes in the fields of fisheries, wildlife, water and wetlands (NGOs). Excel spreadsheets, field notes, grey literature and password-protected databases are just a few of the formats that institutions and experts use to store data (LVBC, 2011). However, information ownership and sharing should be encouraged, and institutional infrastructure and human resource management should be improved. In order to build national biodiversity databanks and connect them to regional databases, institutions should be able to work together at the national level. Researcher working groups made up of subject-matter experts may also be formed for those concentrating on certain biodiversity issues. Additionally, data gathering should develop into a continuous process that encompasses both maintaining and obtaining fresh data (Drescher et al., 2013).

Kenya Marine Fisheries Research Institute (KMFRI), National Fisheries Research Institute (NaFIRRI) and Tanzania Fisheries Research Institute (TAFIRI) are three important research organizations that are engaged in Lake Victoria data collection (Bernardes, 2010). Among the academic institutions are Maseno, Nairobi, Moi, Kenyatta, Masinde Muliro, Makerere, Dar es Salaam and Sokoine Universities. Government parastatals include National Environment Management Authority (NEMA), Wildlife Authorities, and National Museums, as well as NGOs like Osienala, Lake Basin Development Authority (LBDA), Uganda Fisheries and Fish Conservation Association (UFFCA),

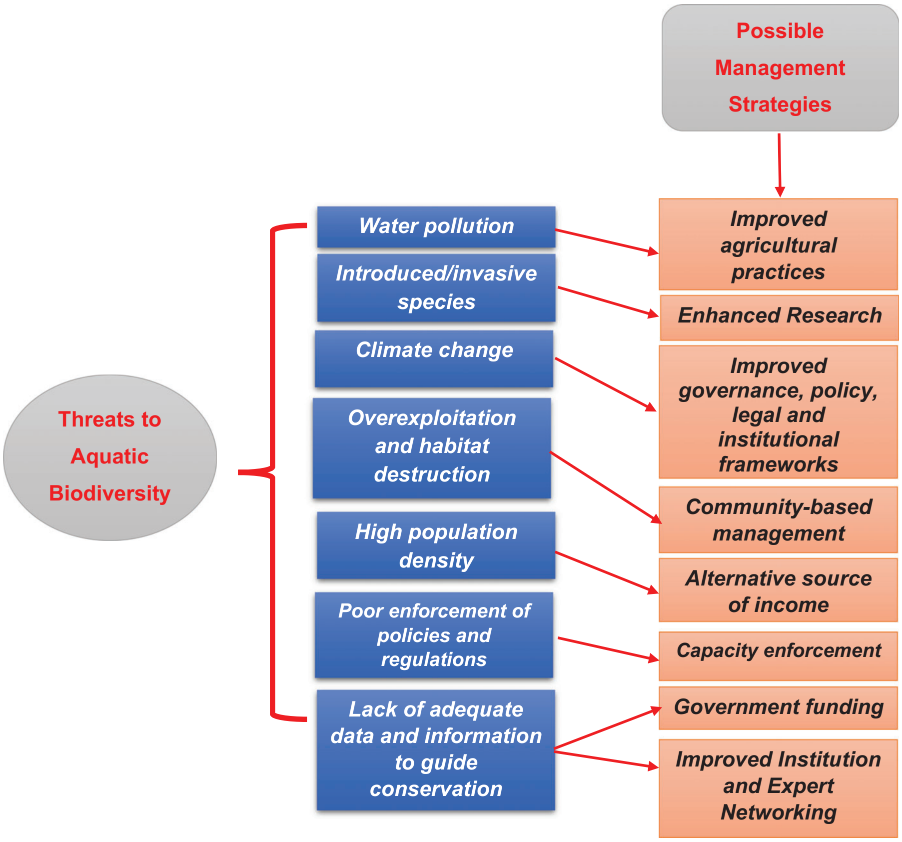

FIGURE 2 A diagram summarizing threats to aquatic biodiversity in Lake Victoria and corresponding management strategies.

LANESA, fish processors and exporters groups, regional organizations like LVFO and global organizations like the IUCN and (World Wide Fund) WWF for nature (Onyango & Opiyo, 2021; Ouko, 2012). These experts and academic institutions keep the bulk of the data they collect, and the majority of these institutions do not have databanks. It is also crucial to identify the leading experts in the many branches of biodiversity and, if feasible, group them into expert working groups. Additionally, it is crucial to identify and link organizations that gather related data to streamline data harmonization, format sharing and reduce work duplication.

3.3 | An overview of the key threats and possible management strategies

Figure 2 provides a visual summary of the key findings from the review article. The figure illustrates the various threats to aquatic biodiversity in Lake Victoria and their corresponding management strategies. It depicts the seven major threats, including water pollution, introduced/invasive species, climate change, overexploitation and habitat destruction, high population density, poor enforcement of policies and regulations and a lack of adequate data and information. Each of these threats is connected to one or more management strategies, which are designed to address the respective threat.

For instance, to address the challenge of water pollution, implementing improved agricultural practices becomes pivotal, effectively reducing pollution stemming from agricultural runoff. The management of introduced and invasive species hinges on intensified research efforts aimed at understanding and controlling these species in the lake. Furthermore, climate change's multifaceted impacts necessitate the establishment of improved governance structures as well as comprehensive policy, legal and institutional frameworks. In response to overexploitation and habitat destruction, the implementation of community-based management strategies emerges as a practical solution, allowing local communities to play an active role in conservation.

The impact of high population density can be ameliorated by encouraging the development of alternative sources of income, lessening the pressure on the lake's resources. To bolster the enforcement of existing policies and regulations, capacity enforcement is indispensable, ensuring that conservation measures are effectively upheld. Addressing the issue of insufficient data and information calls for government funding to support research endeavors. Moreover, the enhancement of institutions and expert networking can facilitate the collection of vital data and information.

4 | CONCLUSION

The lake's biodiversity has declined as a result of human-induced factors, including water pollution, invasive/introduced species, climate change, overexploitation, high population density, inadequate regulatory enforcement and a lack of appropriate data and information to guide conservation efforts. If these issues are not resolved, they can have a harmful effect on the biodiversity of the lake. It is necessary to examine, enhance and enforce the laws and regulations controlling exploitation, accessibility and nutrient discharge into the lake. To safeguard and sustain the lake's biodiversity, local, federal, state and municipal governments, as well as non-governmental groups, should work together. The national governments of riparian countries should also allocate funds each fiscal year for research that will help determine the best management practices to stop future biodiversity losses in Lake Victoria.

AUTHOR CONTRIBUTIONS

Mavindu Muthoka: Conceptualization; writing—original draft. **Nicholas Outa**: Conceptualization; writing—original draft. **Erick Ogello**: Conceptualization; writing—review and editing. **Kevin Ouko**: Visualization; writing—original draft. **Jimmy Mboya**: Visualization; writing—original draft. **Bramwel Mukaburu**: Visualization; writing—original draft. **Kevin Obiero**: Formal analysis; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable for this article as no new data was generated.

ETHICS STATEMENT

As it was a review article, no animal subjects were employed in the current investigation. The concepts presented have been taken from authors whose work has been cited.

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