Marine and Fishery Sciences 37 (1): 209-231 (2024)
https://doi.org/10.47193/mafis.3712024010107

REVIEW

Vanishing splendor: a comprehensive review of the decline in the original fish fauna of Lake Victoria

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ABSTRACT. The presence of the non-native Nile perch (*Lates niloticus*) in Lake Victoria and the resulting ecological transformations have garnered significant attention from the scientific community. However, details regarding the timing, origin, and purpose of the fish introduction have remained elusive. This paper reviews fish fauna changes in Lake Victoria, investigates causes, and advocates for biodiversity conservation through diversity and sanctuary sites. It examines different historical periods to understand changes and guide effective conservation strategies. The introduction of Nile perch has led to a substantial decline and even extinction of many native fish species, particularly cichlids, resulting in ecological imbalances and economic challenges for local fishing communities. To address these pressing issues, ongoing conservation efforts are being implemented. These initiatives focus on promoting sustainable fishing practices, safeguarding critical habitats, and reintroducing native fish species. Furthermore, cage fish farming is being explored as a potential solution to alleviate pressure on wild populations, as suggested by various authors. Recommendations stemming from this study include conducting virtual population analysis for stock assessments of indigenous species, intensify conservation efforts, diversify fishing practices, expand cage fish farming, increase public awareness and education, and enhance policy and governance frameworks. By implementing these recommendations, there is optimism for the recovery and resilience of indigenous fish species in Lake Victoria, leading to the conservation of biodiversity and the promotion of sustainable livelihoods for local communities.

Key words: Nile perch, extinction, invasive species, African cichlids, exotic species introductions.

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Received: 9 August 2023
Accepted: 15 September 2023

ISSN 2683-7595 (print)
ISSN 2683-7951 (online)

https://ojs.inidep.edu.ar

Journal of the Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP)

Esplendor en desaparición: una revisión exhaustiva de la disminución de la fauna de peces original del Lago Victoria

RESUMEN. La presencia de la perca del Nilo (*Lates niloticus*) exótica para el Lago Victoria y las transformaciones ecológicas resultantes, han generado una atención significativa por parte de la comunidad científica. Sin embargo, los detalles sobre el momento, el origen y el propósito de la introducción del pez siguen siendo difíciles de dilucidar. Este artículo analiza los cambios en la fauna de peces en el Lago Victoria, investiga las causas y aboga por la conservación de la biodiversidad a través de la diversidad y los santuarios. Examina diferentes períodos históricos para comprender los cambios y guiar estrategias de conservación efectivas. La introducción de la perca del Nilo ha provocado una disminución sustancial e incluso la extinción de muchas especies de peces nativos, en particular de cíclidos, lo que ha provocado desequilibrios ecológicos y desafíos económicos para las comunidades pesqueras locales. Para abordar estos problemas apremiantes, se están implementando esfuerzos de conservación continuos. Estas iniciativas se centran en pro-

mover prácticas de pesca sostenibles, salvaguardar hábitats críticos y reintroducir especies de peces nativas. Además, se está explorando la cría de peces en jaulas como una posible solución para aliviar la presión sobre las poblaciones silvestres, como sugieren varios autores. Las recomendaciones que surgen de este estudio incluyen realizar análisis de poblaciones virtuales para evaluar el *stock* de especies autóctonas, intensificar los esfuerzos de conservación, diversificar las prácticas de pesca, ampliar la piscicultura en jaulas, aumentar la conciencia y la educación públicas y mejorar los marcos de políticas y gobernanza. Al implementar estas recomendaciones, existe optimismo sobre la recuperación y la resiliencia de las especies de peces autóctonas en el Lago Victoria, lo que conducirá a la conservación de la biodiversidad y la promoción de medios de vida sostenibles para las comunidades locales.

Palabras clave: Perca del Nilo, extinción, especies invasoras, cíclidos africanos, introducción de especies exóticas.

INTRODUCTION

Lake Victoria, a freshwater lake shared by the eastern African countries of Kenya, Uganda, and Tanzania, is one of the largest tropical freshwater lake globally, covering a vast surface area of 68,900 km^2 (Okedi 1990). Unlike other notable lakes in eastern Africa, it stands out with its relatively shallow maximum depth ranging from 70 to 80 m (Njiru et al. 2018). The lake is renowned for its remarkable fish species diversity, with haplochromine cichlids and the introduced Nile perch (*Lates niloticus*) being dominant (Witte et al. 2007a). However, the past century has witnessed significant human-induced changes in the ecosystem of Lake Victoria (Hecky et al. 2010) with activities such as fishing, species introductions, and eutrophication having substantial impacts on the fish fauna.

Prior to the introduction of Nile perch, Lake Victoria boasted a diverse array of fish species, including *Haplochromine* spp., *Labeo victorianus*, *Propterus ethiopicus*, *Brycinus* spp., *Barbus* spp., *Momyrus kanume*, omena (*Rastaneobola angentinea*), and *Synodontis victorianus*, which served as an affordable source of protein for local communities along the lake's shorelines of Kenya, Tanzania, and Uganda (Katunzi 2003; Njiru et al. 2014). The unique nature of these fish populations attracted the global attention of biologists and taxonomists, contributing significantly to scientific research into Lake Victoria fisheries.

However, the rapid growth of the human population around Lake Victoria basin has brought various socioeconomic demands, such as the expansion of agricultural land, landing sites, cage farming, industrialization and urbanization (Onyango et al. 2021). Consequently, severe environmental degradation has occurred, primarily due to sediment pollution from unsustainable agricultural practices and the discharge of urban and industrial waste, particularly in Musoma, Jinja, and Kisumu. This has affected the mobility of fisherfolk in Lake Victoria region, significantly affecting their means of earning a living. Fisherfolk's movement patterns, such as migration and commuting, play a vital role in shaping their livelihood strategies (Nunan and Cepić 2020). The urgency of addressing these issues has led to the involvement of women in lake conservation efforts.

Additionally, the introduction of non-native fish species such as *Oreochromis* (*Linnaeus* 1857), *Oreochromis leucostictus* (Trewavas, 1933), *Tilapia zilli* (Gervais, 1848), and *Lates niloticus* Linnaeus, 1758, during the early 1960s resulted in interspecific competition and predation, leading to a decline in native fish species. According to Getabu et al. (2003), there was a continual decrease in Nile perch biomass along Lake Victoria shorelines, while populations of small pelagic species exhibited growth. Authors underscored the importance of establishing straightforward guidelines for species identification and implementing hydrographic monitoring to enhance the accuracy of echo-trace classification. Given the absence of any other comprehen-

sive source for estimating biomass, this study highlighted the significant utility of acoustic surveying as a valuable tool for assessing biomass in Lake Victoria. This has raised concerns among fisheries management experts regarding the conservation and management of the remaining endangered fish species. The combination of these introduced alien species with factors such as population growth, the use of illegal fishing methods and gears, the destruction of breeding and nursery grounds for native fish species, the illegal, unreported and unregulated (IUU) fishing, and changes in environmental conditions have significantly altered the composition of fish populations in Lake Victoria, resulting in a decline in species biodiversity (Witte et al. 2013). This study also explored how cichlid species diversity varies between naturally turbid and anthropogenically turbid habitats in Lake Victoria, shedding light on factors influencing the distribution and abundance of these unique fish species.

Currently, endemic fish species in Lake Victoria are rarely observed, with some facing the risk of complete disappearance and extinction (van der Meer et al. 1995; Njiru et al. 2008a). However, these vanished species from Lake Victoria can now be found in neighboring satellite lakes, dams, associated wetlands, and major islands within the lake basin (Kaufman 1992). This author reported on the catastrophic decline in biodiversity within Lake Victoria with the introduction of non-native species, particularly the Nile perch, which led to the extinction of many indigenous fish species. This decline in biodiversity had far-reaching ecological consequences. Furthermore, the study also highlighted how the introduction of the Nile perch disrupted the existing food web in the lake. Nile perch, being a top predator, led to a decline in smaller fish species such as *Happlochromis* spp. and caused significant changes in the trophic structure of the ecosystem of Lake Victoria.

Notably, some species have been reported to decline in prominent islands such as Kalangala (Uganda), Migingo (Uganda/Kenya), and Rusinga. According to Luomba et al. (2016), ecological and economic impacts of IUU fishing in Lake Victoria have contributed to overfishing, habitat destruction, and reduced fish stocks, hence the decline in most vital fish species. These islands, and alternative water bodies including rivers such as rivers Sio, Nzoia, and Nile, have distinct characteristics, e.g. the absence of Nile perch, and are often densely populated by emergent and sub-emergent aquatic macrophytes that act as breeding sites for most ingenious fish species. According to van den Broek et al. (2020), these plant masses act as significant barriers to fish reproduction and are unsuitable for species intolerant to low oxygen levels and high turbidity. Therefore, given the significant decline in fish biodiversity and the imminent threat of extinction for both native and introduced fish species in Lake Victoria, it has become crucial to identify and locate these endangered species in other water bodies within the lake basin and wetland areas of Lake Victoria.

Similarly, Odhone et al. (2020), in their study on gender roles in the dagaa (*Rastrineobola argentea*) fisheries value chain, observed a notable decline in crucial fish species, including dagaa, which used to be abundant and had a significant impact in the livelihood of local communities. Niyonkuru et al. (2023) reported a similar finding in their study on population dynamics and exploitation levels of two clupeid fish species, *Stolothrissa tanganicae* and *Limnothrissa miodon*, in the Burundian waters located in the northeastern region of Lake Tanganyika. Cinner et al. (2015) also reported on the changing adaptive capacity of fishing communities along Kenyan Lake Victoria, resulting in a decline of fish species and caused fishing communities to venture into cage farming along Lake Victoria shorelines. This is evidenced by the mass fish death reported among cage fish farmers in Kenya.

Despite extensive research conducted within the Lake Victoria ecosystem, ongoing ecological changes persist, primarily driven by climate

change, cultural eutrophication resulting from industrial activities, population pressure, and agricultural practices along the lake shorelines has also resulted in a decline in indigenous fish species of Lake Victoria (Mothersill et al. 1980). The introduction of predatory fish species, such as *L. niloticus*, has also had detrimental effects on native fish species (Njiru et al. 2018). The significant reduction in fish species has resulted in alterations of trophic levels and overall flora and fauna patterns within the lake ecosystems. According to Witte et al. (2013), these impacts have not only led to the loss of fish species biodiversity but have also affected the water quality of the lake, primarily due to high algae bloom leading to eutrophication. Overfishing and the proliferation of water hyacinths further disrupt the breeding sites of endangered species, especially in Kenya (Obiero et al. 2015). Authors further found that the impact of co-management strategies on the sustainability of fish stocks has led to improvements in fisheries resource conservation in Lake Victoria, or that overfishing remains a concern. Similarly, research on species distinction and the biodiversity crisis in Lake Victoria revealed that approximately 80% of native fish species in Lake Victoria are either endangered, extinct or at risk of extinction due to various human activities taking place along the east African shorelines of Lake Victoria (Witte et al. 2007a).

This paper aimed to provide a comprehensive review of observed alterations in the fish fauna of Lake Victoria and investigated the potential causes behind these changes. The primary objective was to advocate for the conservation of the lost biodiversity of Lake Victoria by identifying and establishing diversity and sanctuary sites where species are believed to thrive. To facilitate this analysis, the study divided the lake's history and fish species biodiversity over the last century into three distinct decade periods: before the introduction of Nile perch in the early 1980s, during the Nile perch introduction period, and the current scenarios. By examining these periods, a comprehensive understanding of changes in the fish fauna of Lake Victoria can be gained, enabling the implementation of effective conservation efforts.

The information in this review article was compiled from various secondary sources, including international journals, conference proceedings, internet searches, and relevant materials. The article covers the period from 1950 to 2023, incorporating 143 peer-reviewed articles focused on the evolution of fish species and the current state of biodiversity in Lake Victoria. Additionally, literature data related to fisheries management in Kenya, Uganda, and Tanzania was explored. Careful attention was given to organizing the secondary source materials in a logical sequence concerning Lake Victoria's fisheries and fish fauna biodiversity.

Study area

The Lake Victoria basin refers to the region surrounding Lake Victoria, the largest freshwater lake in Africa and the second-largest in the world (Figure 1). It spans Kenya, Tanzania, and Uganda and covers an area of approximately 250,000 km^2 (Verschuren et al. 2002). The basin is known for its rich fish biodiversity and ecological importance. While some fish species are underreported due to overfishing and predation, notable species in Tanzania include tilapia and Nile perch, vital for both commercial and subsistence fishing (Onyango 2011). The basin also supports diverse bird species and mammals like hippos and crocodiles (Ikingura et al. 2006).

In Kenya, the Lake Victoria basin comprises eight significant rivers, namely Sio, Nzoia, Yala, Nyando, Sondu, Miriu, Migori, and Mara. These rivers, located west of the Rift Valley, contribute nearly half of Kenya's runoff, flowing into Lake Victoria acting as a breeding ground for most of indigenous fish species such as lungfish (*P. aethiopicus*) (Njiru et al. 2008a). The basin is the

largest and most critical of the five catchments that feed Lake Victoria, playing a vital role in supporting downstream countries such as Sudan and Egypt through the River Nile (Ntiba et al. 2001; Aura et al. 2020). In Kenya, the basin encompasses Nyanza and western Provinces, extending from Cherangani Hills to Mau Forest and including the former Rift Valley Province and Masai Mara Game Reserve (Kundu et al. 2017). However, with the extensive basin, conservation of indigenous fish species is still an issue due to overfishing and predation associated with *L. niloticus*.

The Lake Victoria basin holds immense importance for east Africa due to its abundant resources, including fisheries, biodiversity, water, land, forests, wildlife, minerals, transportation routes, communication networks, and tourism potential (Hecky 1993). It offers opportunities for environmental conservation, preservation of indigenous fish species, scientific research, socio-political collaboration, and economic investments (Muyodi et al. 2010). Recognizing its significance, the East African Community (EAC) designated the basin as an 'economic growth zone' (Ogutu-Ohwayo 2004).

Rivers within the Kenyan catchment area of the Lake Victoria basin contribute to the world's largest freshwater fish species. This fishery has an average value of 980,000 t and generates an estimated annual revenue of over USD 560 million (Allison and Ellis 2001). Various conservation projects, such as the Lake Victoria Environmental Management Project (LAVEMP), have

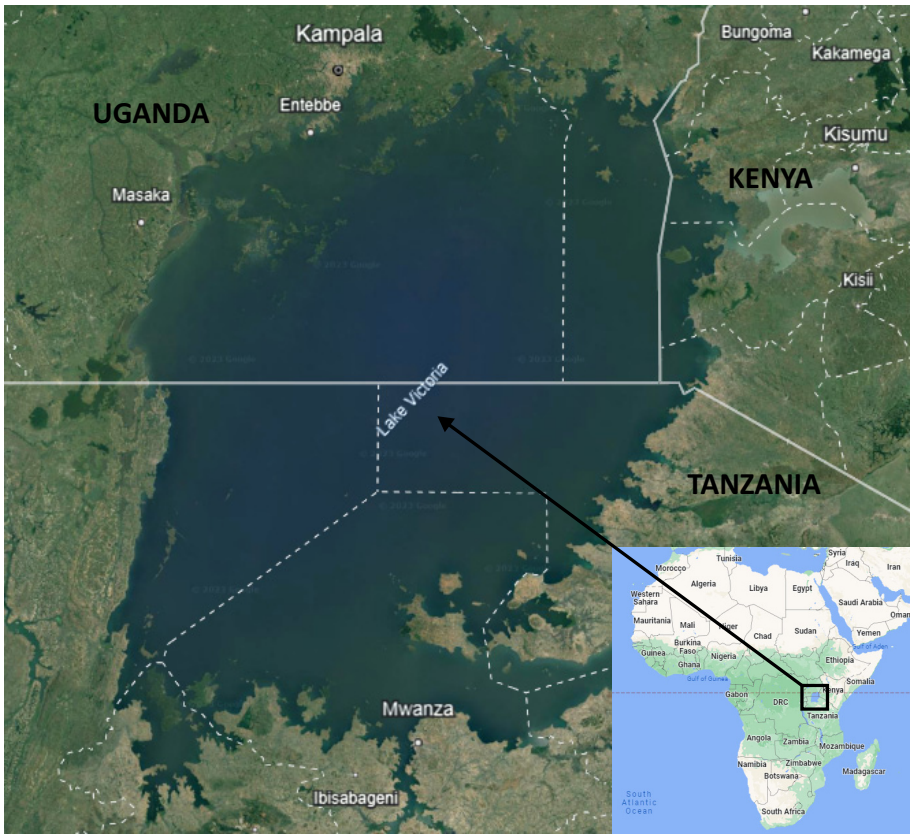

Figure 1. Lake Victoria basin with potential fisheries resources sites and the three riparian countries.

been initiated through the Lake Victoria Fisheries Organization to protect and sustain the economic benefits of Lake Victoria and environmental conservation (Witte et al. 2000; Langan et al. 2018).

Despite the implementation of various fisheries management and Lake Victoria management initiatives by the three riparian countries, i.e. Kenya, Uganda and Tanzania, the native fish population in the lake has been steadily declining. According to Cadwalladr (1965) and Goudswaard et al. (2002a), many of the original fish species, such as lungfish (*P. aethiopicus*), that once inhabited the lake basin, have disappeared. Therefore, the conservation of remaining species has become a pressing concern for fisheries researchers at both local and international level. However, finding a solution is complicated by numerous governance and fisheries management challenges in the fisheries sector across the three riparian countries sharing fishery resources in Lake Victoria.

Exploring the pre-Nile perch era: a historical overview of Lake Victoria and its early fish species biodiversity

Lake Victoria is renowned for its diverse fish fauna, particularly the cichlid fish species. During the pre-Nile perch era, the lake homed a rich variety of unique and endemic fish species (Kaufman et al. 1997). Among these, *Haplochromis* sp. (cichlids) was the most abundant and diverse group (Ogutu-Ohwayo 1990a) (Figure 2), displaying a wide range of colours, shapes, and behaviours (Kaufman et al. 1997). The lake was characterized by the remarkable adaptive radiation of several endemic haplochromine cichlid species (Eggert and Lokina 2010), that played a significant role in the ecological dynamics of Lake Victoria (Vranken et al. 2019). Throughout history, their presence and abundance in Lake Victoria have been influenced by various factors (Meer 1993). In the past, Lake Victoria harboured

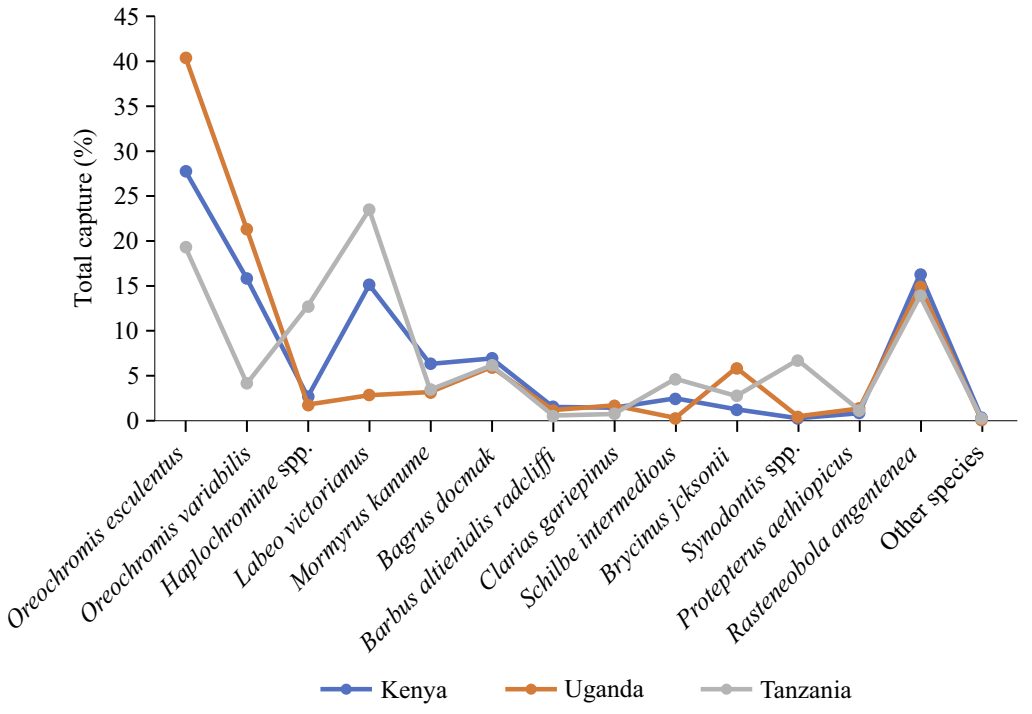

Figure 2. Percentage of indeginous fish species landed in Lake Victoria in 1957. Data redrawn from (Ogutu-Ohwayo 1990b).

a large number of endemic haplochromine cichlid species, with estimates ranging from 500 to 800 species (Njiru et al. 2005; Vranken et al. 2019). These cichlids constituted a dominant group in the fish community and played crucial roles in its ecosystem, including trophic interactions, nutrient cycling, and habitat structuring. However, the introduction of non-native species, overfishing, habitat degradation, and pollution have severely affected the cichlid populations in Lake Victoria, as reported by Kaufman et al. (1997) and Njiru et al. (2014).

The most significant ecological disturbance occurred in the 1980s when the predatory Nile perch (*L. niloticus*) was introduced into the lake to revive declining fisheries (Kaufman et al. 1997; Zeeuw 2010). The Nile perch decimated numerous haplochromine cichlid populations, especially those in the nearshore areas of Kenya and Uganda, where the Nile perch was most abundant (Njiru et al. 2008b). It was estimated that over 200 haplochromine cichlid species went extinct because of this introduction (Witte et al. 1992; van der Meer et al. 1995; Ogutu-Ohwayo 2004). The decline of haplochromine cichlids caused a cascade of ecological changes in Lake Victoria. With the disappearance of cichlids, the balance of the fish community was disrupted, leading to an increase in algal blooms and a decline in water quality (Konijnendijk et al. 2011). Additionally, the loss of cichlids significantly impacted the livelihoods of local fishing communities, who relied on them for their sustenance and income. This primary threat was likely to be overfishing, leading to declines in fish populations, especially for commercially valuable species along the Yala River basin in Lake Victoria (Aloo 2003).

In recent years, efforts have been made to restore cichlid populations in Lake Victoria. Conservation programs have focused on protecting and restoring critical habitats, implementing fishing regulations and controlling the spread of invasive species (Achieng 1990). As a result, there have been some positive signs of recovery for haplochromine cichlids in certain areas of the lake in Kenya, Uganda, and Tanzania. However, according to Naigaga et al. (2011), the recovery process is complex and ongoing, as the resilience of haplochromine cichlids is still threatened by multiple factors, including continued fishing pressure, habitat degradation, pollution, and climate change. Additionally, Witte et al. (2007a) observed that the introduction and spread of new invasive species pose ongoing challenges for the restoration of cichlid populations in Lake Victoria. The history of haplochromis cichlids in Lake Victoria has been characterized by their ecological dominance, followed by a severe decline due to human activities. While efforts have been made to restore their populations through the adoption of fisheries regulations, especially in Kenya (Aura et al. 2020), the overall trend remains precarious, requiring sustained conservation efforts to ensure the long-term survival of these iconic fish in Lake Victoria.

Regarding *O. esculentus* (ngege/tilapia), it is important to note that this species is no longer commonly found in Lake Victoria. It has been reported as extinct in the lake. Currently, there are several known tilapia species in Lake Victoria, including *O. niloticus* and *O. leucostictus*. The trend in capture for tilapia in Kenya, Uganda, and Tanzania has been on the decline (Njiru et al. 2005). These authors further suggested effective management options that included regulations, restoration efforts, balanced harvesting, community involvement, research, and international cooperation to ensure the sustainability of the fishery while mitigating the ecological impacts of exotic species.

The African lungfish (*P. aethiopicus*) is a primitive fish species that can tolerate drought conditions and inhabits swamps and stagnant areas of Lake Victoria (Goudswaard et al. 2002a). This species has a long evolutionary history and is considered a living fossil. Before the introduction of the Nile perch in Lake Victoria, the African catfish was the dominant species, and the pres-

ence of African lungfish in the lake can be traced back to prehistoric times when it was part of a larger water system known as Lake Victoria-Nile (Fryer 1960). The current status of the African lungfish is uncertain, and its conservation is a concern due to various factors affecting the lake ecosystem. Environmental changes caused by human activities such as deforestation, pollution, and the introduction of invasive species can impact *P. aethiopicus* population (Sitoki et al. 2010). Additionally, the African lungfish has been subjected to intensive fishing pressure, both for subsistence and commercial purposes (Verschuren et al. 2002; Onyango and Jentoft 2010).

The silver cyprinid (*R. argentea*), also known as omena or dagaa, is a small pelagic fish that plays a significant role in the Lake Victoria food web. It is an essential source of protein for local communities and is crucial to the lake ecosystem. Dagaa is one of the early fish species found in Lake Victoria prior to the introduction of the Nile perch (Odhone et al. 2020). However, it is important to note that the lake ecosystem and fish population have undergone significant changes over time due to various factors, including human activities and the introduction of non-native species (Fryer 1960; Witte et al. 2007b).

Indigenous cyprinids

Lake Victoria was historically known for hosting a diverse array of cyprinid fish species (Cadwalladr 1965). However, in recent years, some of these species, including *L. victorianus*, known locally as 'ningu' in Kenya and Tanzania, have become endangered and have disappeared from fishermen's nets (Figure 3). *Labeo victorianus* was once abundant in local markets along the shoreline of Lake Victoria and its surrounding areas, with a high number of individuals being caught in Kenya and Tanzania (Cadwalladr 1965). The decline in the capture of *L. victorianus* can be attributed to several factors, including the introduction of the Nile perch in the lake (Mothersill et al. 1980). Since then, the population of *L. victorianus* has suffered significantly, as the Nile perch is believed to prey on *L. victorianus* (Cadwalladr 1965; Hauser et al. 1998; Njiru et al. 2005). Additionally, overfishing and the use of illegal fishing gear, such as beach seines and fish poisoning (Eggert and Lokina 2010), have contributed to the decline of *L. victorianus* in Kenyan waters. Unfortunately, the current status of this species is largely unknown to both fisheries experts and local fishermen. Conducting stock assessments will therefore play a vital role in informing conservation efforts and ensuring the long-term survival of *L. victorianus* in Lake Victoria (Witte et al. 2007a, 2007b). The decline of *L. victorianus* and other cyprinid fish species in Lake Victoria is a concerning issue. It is essential to address factors contributing to their decline, such as the introduction of invasive species (Fryer 1960), overfishing (Nunan 2014), and the use of illegal fishing methods (Njiru et al. 2014). Therefore, according to Mkumbo and Marshall (2015), signs of overfishing in the Nile perch population of Lake Victoria are a cause for concern due to their ecological, economic, and social implications. Effective management measures, including fishing regulations, gear restrictions, and community involvement are essential to address these challenges and ensure the long-term sustainability of the Nile perch fishery and the health of the lake's ecosystem.

Barbus altinialis is another cyprinid species once thrived in Lake Victoria until the introduction of *L. niloticus*. It was predominantly captured along the Migori and Mara rivers. Before the 1980s, *B. altinialis* made a substantial contribution to fish landings, estimated to be over 8,700 t (Olowo and Chapman 1996). However, over time, the population of *B. altinialis* has declined significantly and current numbers are not accurately reported (Kundu et al. 2017). The whereabouts of these fish species raises questions. Witte et al. (2000) have revealed traces of *B. altinialis* upstream in Kenyan rivers such as Nzoia, Mara, Migori, and Sio, which drain into

Figure 3. *Labeo victorianus* (ningu) of Lake Victoria (retrieved from Okeyo and Ojwang 2015).

Lake Victoria. This suggests that these rivers could serve as an escape route for the species, enabling them to evade the invasive *L. niloticus* within Lake Victoria. Unfortunately, many cyprinid species have experienced a significant decline without adequate conservation measures in place (Geheb et al. 2008).

The alarming rate at which indigenous fish species are vanishing from Lake Victoria has become a regional concern among the three riparian countries (Witte et al. 2013). The loss of these species not only affects the ecological balance of the lake but also has significant socio-economic implications for local communities that depend on fishing. Therefore, it is crucial for stakeholders to recognize the importance of conserving remaining populations of indigenous fish species. The introduction of cage farming in Lake Victoria can be a promising trial approach for the conservation of such species. According to Njiru et al. (2019), cage fish farming is currently considered both a boom and a potential disaster. However, when such endangered species are adopted and fed formulated feeds with improved additives, their growth and spawning rates can be enhanced (Syanya et al. 2023a). Efforts should be made to implement effective conservation measures, including habitat protection, sustainable fishing practices, and the control of invasive species (Dudgeon et al. 2006; Okafor-Yarwood et al. 2020). Based on the findings of these authors, cooperation between countries bordering Lake Victoria, in addition to engaging local communities, researchers, and fisheries specialists, is imperative to tackle this regional issue. By giving precedence to the preservation of native fish species, we can work towards rejuvenating the ecological well-being of Lake Victoria and securing the enduring viability of its fish populations.

Family Mormyridae, commonly known as elephant fish or mormyrids (Barilwa 1995), includes a diverse group of freshwater species found in various water bodies in Africa, including Lake Victoria (Barilwa 1995; Gichuki et al. 2001) (Figure 4). These fish are known for their unique physiological adaptations and specialized electric sensing organs used for navigation, communication, and locating prey (Greenwood 1966). These species have evolved to occupy different ecological niches within the lake, adapting to various

Figure 4. *Mormyrus kannume* of Lake Victoria (retrieved with permission from https://www.hippocampus-bildarchiv.de/tier_3718_Mormyruskannume.htm).

habitats and feeding strategies (Ogutu-Ohwayo 1990a). One well-known species of mormyrid found in Lake Victoria is the Nile elephant fish (*Gnathonemus petersii*) (Witte and Van Densen 1995). It is a large, torpedo-shaped fish with a long snout and a unique electric organ (Greenwood 1966; Chapman et al. 1996). This organ generates weak electric fields that the fish use to navigate and communicate in murky waters of the lake. The Nile elephant fish primarily feeds on small invertebrates and plant matter (Ligtvoet et al. 1995). Similar fish species have been reported during fish stock assessments in Lake Kyoga, Uganda (Kudhongania et al. 1992).

Before the introduction of Nile perch and the impact of climate change within the East African region, a total of five species from Family Mormyridae were observed (Seehausen 1996; Witte et al. 2000). Among them, four small mormyrid species, specifically *Pollimyrus nigricans*, *Hippopotamyrus grahami*, *Marcusenius victoriae*, and *Gnathonemus longibarbis* (Outa et al. 2020), were found exclusively near mouths of rivers Awach (Kendu Bay) and Sio. The fifth species, *Mormyrus kannume*, a larger species highly sought after commercially, was observed in rocky areas around Asembo Bay, Mbita, and at the mouth of Nzoia River, Kenya (Cadwalladr, 1965; Seehausen 1996; Katunzi 2000). All of these river mouths have soft bottoms and shallow waters, with adjacent papyrus swamps, similar to those reported in Lake Naivasha, Kenya (Muthuri 1989). However, since the introduction of Nile perch fishing communities along Lake Victoria have reported the disappearance of all of these species. For instance, Ogutu-Ohwayo (1995) observed that small species were captured in nets that were set overnight, while no mormyrids were caught in nets set during daytime. These findings support the observations made by Welcomme (1964) that certain fish species exhibit habitat and habit preferences, with migrations typically occurring at night, particularly during dusk and dawn. This explains why the majority of fishermen in Lake Victoria prefer to fish at night.

According to Pitcher and Hart (1995), another notable species in east African Lake Victoria is the longfin mormyrid (*Pollimyrus isidori*). This species possesses elongated fins and a slender body, enabling it to navigate efficiently through

the dense vegetation and shallow waters of the lake. It utilizes its electric organ to detect prey and communicate with conspecifics (Pitcher and Hart 1995; Rabuor and Polovina 1995). The east African longfin mormyrid primarily feeds on small aquatic insects and crustaceans (Bugenyi 1998).

In addition to overfishing and the impact of invasive Nile perch on indigenous fish species, it is important to note that the ecosystem of Lake Victoria has undergone significant changes in recent decades (Kudhongania et al. 1996; Njiru et al. 2000). These changes include but are not limited to, the invasion of water hyacinth (Harley 1990; Njiru et al. 2000; Van der Knaap et al. 2002), the introduction of non-native fish species (Taabu-Munyaho et al. 2016; Ogari 2000), and environmental degradation (Hecky and Bungenyi 1992; Harper and Mavuti 1996). These factors have impacted mormyrid populations and their habitats, emphasizing the importance of conservation efforts for their long-term survival. They have significantly contributed to the decline in mormyrid fish species within Lake Victoria.

Synodontis victorianus

Synodontis is a genus of catfish that is widely distributed throughout major lakes of Africa, including Lake Victoria. Within Lake Victoria, several species of *Synodontis* can be found, each with its own specific distribution patterns and ecological preferences (Mothersill et al. 1980; Aloo 2003). According to Witte et al. (2007a), *S. victorianus* is endemic to Lake Victoria and is one of the most common and abundant catfish-like fish species found in the lake. It is distributed throughout the lake and can be found in various habitats, including rocky shores, sandy bottoms, and vegetated areas. Seehausen (1997) also reported the existence of *S. nigrita*, a species native to Lake Victoria with a wide distribution across the lake. It is often found in rocky habitats, especially along shorelines and near islands such as Rusinga, Migingo, Kalangala and among numerous other small islands in Lake Victoria (Cadwalladr 1965; Ogutu-Ohwayo 1995).

Other species of *Synodontis* native to Lake Victoria that have been reported include *S. woosnami*, *S. afrofischeri*, and *S. koensis* (Witte et al. 2000; Njiru et al. 2005). Most of these species prefer habitats with dense aquatic vegetation, such as marshes, swamps, and areas with abundant plant cover (Kashindye et al. 2015). Therefore, before the introduction of Nile perch, the distribution of *Synodontis* spp. within Lake Victoria was influenced by various factors, including habitat preferences, water quality, food availability, and interactions with other fish species (Hecky 1993). Different species may occupy specific niches within the lake (Witte et al. 2013), utilizing different feeding strategies and occupying different microhabitats. It is worth noting that the introduction of non-native fish species, such as the Nile perch, has had significant impacts on the native fish populations in Lake Victoria, including *Synodontis* species, affecting the distribution and abundance of many native fish species (Greenwood 1974; Pitcher and Bundy 1995). According to several authors, such as Witte et al. (2007b), Hecky et al. (2010) and Taabu-Munyaho et al. (2016) *Synodontis* has become one of the endangered fish species in Lake Victoria, with a decline in catches among the three riparian countries.

The dominance Nile perch era and the decline in fish species diversity in Lake Victoria

Lake Victoria has undergone significant changes in the biodiversity of its fish species and ecosystem dynamics since the introduction of the Nile perch in the 1980s. According to Achieng (1990), who assessed the impact of the Nile perch introduction in Lake Victoria, this species is a predatory fish that was introduced with the intention of boosting fisheries and controlling the population of smaller fish species, particularly introduced predatory cichlids. However, Taabu-Munyaho et al. (2016) reported that the unintended

consequences of the Nile perch introduction have been profound.

Prior to the introduction of the Nile perch, Lake Victoria was known for its diverse and unique fish fauna, comprising numerous endemic fish species (Fryer 1960). The lake was home to hundreds of different cichlid species (Kudhongania et al. 1992), along with other fish families such as catfish (*Synodontis* spp.), lungfish (*P. aethiopicus*), and tilapia (*Oreochromis* spp.) (Ogutu-Ohwayo 1990a; Goudswaard et al. 2002b).

Immediately after the introduction of Nile perch, it became the dominant predator in Lake Victoria, leading to a decline in the diversity and abundance of endemic cichlid species. Many endemic cichlid populations were decimated or entirely wiped out, causing a loss of biodiversity and ecological disruption (Mkumbo and Ligtvoet 1992; Matsuishi et al. 2006). Ogutu-Ohwayo (1990b) estimated that more than 200 cichlid species have become extinct or severely endangered due to the presence of Nile perch.

Despite the ecological impacts of the introduction of Nile perch, the Nile perch fishery expanded rapidly due to its economic value as an export commodity (Matsuishi et al. 2006). The fishing industry targeting Nile perch became a significant sector in the eastern Africa region, with large-scale commercial fishing and processing operations (Natseba et al. 2005; Matsuishi et al. 2006). However, overfishing and unsustainable practices have posed additional challenges to the long-term viability of the fishery (Reynolds et al. 1995). Fish processing factories have been set up to handle the increased Nile perch capture, ensuring the quality of fish through freezing and frozen storage (Karungi et al. 2004; Syanya et al. 2023b). This has increased due to the exploitation of not only *L. niloticus* but also other indigenous tilapia species.

Njiru et al. (2005) reported that the expansion of the Nile perch fishery in Lake Victoria has followed a notable trend over the years. Indigenous fish species are on the brink of decline due to the highly predatory nature of the Nile perch colony in the lake. According to Nunan (2010), the fishery initially experienced a rapid increase in fishing efforts and commercial operations following the introduction of the Nile perch in the 1980s. The high demand for Nile perch in international markets, particularly in Europe and the United States of America, fueled the expansion of the fishery (Kudhongania et al. 1992; Hauser et al. 1998). Therefore, very little concern was given to indigenous fish species of Lake Victoria, which are believed to fetch a lower price in the global fish market. Who cares? Fisheries conservation measures set in place within fisheries management policies and acts of the three riparian countries are silent on the conservation of biodiversity of fish species of Lake Victoria (Witte et al. 2013).

During the 1970s and 1980s, the fishery of Lake Victoria reached its peak with a surge in fishing fleets and processing facilities around the lake (Ntiba et al. 2001). The introduction of more efficient fishing techniques and larger vessels contributed to increased catch rates and higher production levels. This period witnessed a substantial rise in export volumes of Nile perch (Witte and Van Densen 1995; Ntiba et al. 2001; Eggert and Lokina 2010), making it a significant economic activity for countries surrounding Lake Victoria. However, as the fishery expanded, concerns about sustainability and impacts on the lake ecosystem began to emerge. Overfishing became a prominent issue, with some areas experiencing a decline in Nile perch populations and the depletion of smaller fish species, including the endemic cichlids (Seehausen 1996; Cowx et al. 2003). In response to these concerns, efforts were made to regulate the fishery and implement sustainable practices. Fishing quotas and size and species restrictions were introduced to protect juvenile fish and allow for stock recovery (Eggert and Lokina 2010). Collaborative initiatives involving government authorities, fishing communities, and conservation organizations were also established to promote responsible fishing practices and ensure the long-

term viability of the Nile perch fishery (Ntiba et al. 2001; Obiero et al. 2015). However, very little has been done to control the direct impact of predatory effects of Nile perch on declining native fish species, as evident from landing data reports. This has resulted in the mobility of fishermen seeking better livelihoods (Nunan 2010).

In recent years, the expansion of the Nile perch fishery has become more focused on sustainable practices and responsible management. This included promoting value-added processing, quality control, and traceability systems to meet international market standards and improve the economic returns for fishers and processors (Mkumbo and Marshall 2015). Additionally, there has been a growing emphasis on addressing social and environmental issues, such as labor rights, bycatch reduction, and the reduction of post-harvest losses (Njiru et al. 2005).

The introduction of Nile perch has brought about a change in the composition of fish species in Lake Victoria. For example, Greenwood (1965), Fitzsimmons and Watanabe (2010), and van der Meer et al. (2012) have documented a decrease in native cichlids and the rise of Nile perch as the dominant species, resulting in a significant alteration of the fish species composition of the lake. Currently, the most abundant and economically significant fish in the lake is the Nile perch and several introduced tilapia species, with Nile tilapia (*O. niloticus*) being the primary one (Kishe-Machumu et al. 2008; Seehausen 2008).

Many of endemic cichlids that once characterized the lake diversity have become rare or extinct (Witte et al. 1992). Similarly, changes in the fish species composition of Lake Victoria have had far-reaching ecological consequences. According to Seehausen (1998), the loss of diverse cichlid species has affected the trophic structure of the lake, nutrient cycling, and overall ecosystem functioning. Furthermore, Witte et al. (2000) documented that as a primary predator, the Nile perch has disrupted the dynamics of other cichlid fish populations in Lake Victoria and disturbed the ecological equilibrium of the lake. Therefore, recognizing ecological challenges and the importance of preserving the biodiversity of Lake Victoria, conservation efforts have been initiated. Efforts included measures to protect remaining endemic cichlid species and the establishment of closed seasons during critical fish breeding periods to protect spawning aggregations and ensure the recruitment of young fish into the population (Greenwood 1974), restore degraded habitats such as swamps and lakes along noticeable rivers such as Sio and Yala (Aloo 2003), promote sustainable fishing practices, and regulate the fishing industry to ensure the long-term sustainability of the lake's resources (Okeyo 2014). The decline of endemic cichlids and the dominance of the Nile perch have reshaped the ecosystem dynamics and posed challenges for conservation and sustainable fisheries management. However, according to Muyodi et al. (2010), efforts were initiated in order to mitigate impacts and restore the ecological balance of fish communities of Lake Victoria.

Conservation measures to protect indigenous fish species from Nile perch predation in Lake Victoria

Conservation measures aimed at protecting indigenous fish species from Nile perch predation in Lake Victoria involve a combination of strategies to preserve and restore the ecological balance of the lake. Gichuki (1994) and Kokwaro and Johns (1998) proposed habitat restoration along the shorelines of Lake Victoria to preserve and conserve indigenous wetland vegetation and protect breeding grounds for most fish species. Ogutu-Ohwayo (1990b) made a similar observation, emphasizing the importance of enhancing and restoring critical habitats for indigenous fish species. This author recommended promoting the growth of aquatic vegetation, creating spawning grounds, and protecting areas with high biodiversity. These efforts provide shelter and food

sources for smaller fish species such as cyprinids, reducing their vulnerability to Nile perch predation. Garrod (1961) reported that establishing protected areas and fish sanctuaries can contribute to the rational exploitation of *Tilapia* spp. in Buruma islands of Lake Victoria. Protected zones limit fishing pressure and provide a safe refuge for vulnerable species such as *Barbus* spp., *Mamyrus karnume*, and *Cynodontis* spp. This allows them to reproduce and maintain sustainable populations (Willoughby et al. 1993; Reynolds et al. 1995).

Kaufman (1997) and Njiru et al. (2010) both emphasized the importance of regulating fishing practices as a measure to conserve the ever-declining original fish species of Lake Victoria. Implementing fishing regulations, such as mesh size restrictions, closed seasons, and fishing quotas, can contribute to the protection of indigenous fish species (Njiru et al. 2008b; Outa et al. 2020). By managing fishing efforts and preventing overfishing, these measures allow fish populations to recover and reduce the pressure of Nile perch predation. Species-specific conservation programs have also been initiated in different sections of Lake Victoria to protect species such as the African lungfish (*P. aethiopicus*) (Goudswaard et al. 2002a). Developing targeted conservation programs focusing on endangered or threatened indigenous fish species is crucial. These programs may involve captive breeding and restocking efforts, genetic studies, and monitoring population dynamics to ensure the survival and recovery of these species within Lake Victoria basin (Bailey and Jentoft 1990; Béné 2003; Mugisha et al. 2007).

Invasive species management is another recommended approach (Achieng 1990; Ogutu-Ohwayo 2004; Agembe et al. 2019). Based on the findings of these authors, managing invasive species, such as the Nile perch itself, is essential to reduce its impact on indigenous fish populations. This can include measures like controlling the introduction and spread of non-native species, monitoring and mitigating the ecological effects of invasive, and researching methods to manage their populations.

Community engagement and education through the formation of beach management units within all landing sites along the shores of Lake Victoria have also been reported (Ntiba et al. 2001; Njiru et al. 2008a). Involving local communities in conservation efforts is key to long-term success. Similar findings were documented by Chapman et al. (2002), emphasizing the need to regulate the pollution of wetlands and swamps that may result in the hypoxia of fish in Lake Victoria. Engaging with fishing communities, raising awareness about the importance of protecting indigenous fish species, and promoting sustainable fishing practices can help foster a sense of stewardship and ensure community support for conservation initiatives (Mathia and Fotedar 2012; Syanya and Mathia 2023). By observing these measures, local communities along shorelines of Lake Victoria can enhance fish health and biosecurity management systems, thus conserving endangered fish species.

Collaborative governance among the three riparian countries in boosting conservation and researching on indigenous fish species of Lake Victoria has been reported by Obiero et al. (2015) and Nunan and Cepić (2020). Collaborating with governmental authorities, researchers, conservation organizations, and local communities is crucial for the effective conservation of declining fish species in Lake Victoria (Nunan et al. 2012; Etiegni et al. 2017). Engaging in collaborative governance models can help ensure that decisions regarding fishing regulations, habitat management and conservation strategies are based on scientific knowledge and include perspectives and expertise of relevant stakeholders, most of whom are women in Lake Victoria fisheries (Nunan et al. 2012; Nunan and Cepić 2020). Therefore, by implementing these conservation measures and maintaining a holistic approach to the management of Lake Victoria, it is possible to mitigate

the impact of Nile perch predation on indigenous fish species and restore the ecological balance of the lake ecosystem.

FINAL REMARKS

The introduction of Nile perch (*L. niloticus*) to Lake Victoria in the 1980s has had profound and complex effects on the indigenous fish species in the lake. This invasive predator has led to the decline and extinction of many native fish species, particularly cichlids (Achieng 1990; Taabu-Munyaho et al. 2016). This has resulted in ecological imbalances within the lake, impacting the overall functioning of the ecosystem and causing economic challenges for local communities. To address these challenges and ensure the future prospects of indigenous fish species in Lake Victoria, various conservation efforts and initiatives are being undertaken. These include promoting sustainable fishing practices, protecting critical habitats, reintroducing native fish species, and exploring cage fish farming as an alternative source of income and a means to reduce pressure on wild populations. Research and monitoring programs are also crucial for understanding ecosystem dynamics and informing management strategies.

Based on findings from explored articles, the following recommendations are made:

- Strengthen conservation efforts: riparian countries should continue and enhance conservation initiatives aimed at protecting indigenous fish species in Lake Victoria. This includes promoting sustainable fishing practices, establishing protected areas, and implementing effective management strategies.
- Diversify fishing practices: encourage the diversification of fishing practices to reduce reliance on indigenous fish species along the shoreline of Lake Victoria as the primary target species by local fishermen. This can help alleviate pressure on indigenous fish populations and promote their recovery.
- Expand cage fish farming: develop and regulate cage fish farming as a means to reduce pressure on wild populations and provide alternative income sources for local communities. However, it is crucial to prioritize the implementation of appropriate monitoring and management measures to prevent incidents such as fish poisoning.
- Collaborative research and monitoring: the three riparian countries should Foster collaboration among research institutions, organizations, and local communities to conduct comprehensive research and monitoring programs. This will improve understanding of the ecosystem dynamics, evaluate the impacts of Nile perch predation, and inform evidence-based management decisions.
- Promote public awareness and education: increase public awareness and education about the importance of conserving indigenous fish species and the ecological significance of Lake Victoria. Promote sustainable fishing practices and engage local communities in conservation efforts through capacity building and outreach programs.
- Strengthen policy and governance: enhance policy frameworks governance structures and fisheries legal instruments to ensure the effective implementation of conservation measures and sustainable management practices. This can include the establishment of regulations, enforcement mechanisms, and collaboration with regional and international organizations.
- Long-term monitoring and evaluation: establish long-term monitoring and evaluation programs to assess the effectiveness of conservation interventions and adapt strategies as needed. Regular monitoring of fish populations, habitat conditions, and socioeconomic factors will provide valuable insights for adaptive management.

By implementing these recommendations, there is a higher likelihood of restoring and maintaining the biodiversity and ecological balance of Lake Victoria, while also supporting the sustainable livelihoods of local communities dependent on fisheries resources. These efforts are essential for securing the future of indigenous fish species in the lake and preserving its ecological integrity.

Author contributions

Fredrick Juma Syanya: conceptualization, literature review, writing-original draft. Zachary O. Winam: further review of the literature and editing. Wilson M. Mathia: drawing figures, visualization, formal editing and grammar checking.

Competing interests

All authors collectively and unanimously declare that they have no competing interests in this work and that no funding was obtained to fund this research work.

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