Journal of Great Lakes Research 49 (2023) 102211

Contents lists available at ScienceDirect

Journal of Great Lakes Research

journal homepage: www.elsevier.com/locate/ijglr

Lake Victoria: Overview of research needs and the way forward

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ARTICLE INFO

Article history:
Received 14 October 2021
Accepted 12 April 2023
Available online 6 July 2023
Communicated by Lauren Chapman

Keywords:
Sustainable management
Transboundary
Research needs
Climate change
Capacity building

ABSTRACT

Over 42 million people rely on Lake Victoria as their primary source of food, employment, and clean drinking water. The lake's fisheries have produced around one million tonnes in recent years, but the lake's growing population has resulted in a lower catch rate per capita. And the lake and its catchment have been negatively impacted by a wide variety of human activities, such as overfishing, oil spills, discharge of untreated waste, spread of invasive species, over-abstraction of water from the lake basin, and climate change, among other drivers of change. This paper presents existing research gaps, existing capacity, and presents a way forward for priority research on issues ranging from fish and fisheries, biodiversity, pollution, invasive species, aquaculture, human population growth and socio-economics, land use changes, habitat degradation, climate change and skills and knowledge. The purpose of this paper is to document: information that is currently available from previous research; the existing scientific capacity; and the resources required to guarantee that Lake Victoria becomes a heathy and biologically diverse resource for the millions of people who are dependent on it. It is clear from this synthesis that the biological, social, and economic benefits that can be derived from Lake Victoria can only be accomplished through the utilization of multi-disciplinary approaches in the research and monitoring of both basin-wide and lake-wide biophysical processes, as well as the modeling of all potential interactions between the ecology of the basin and the lake.

Introduction

Lake Victoria is the world's second largest lake by surface area, and Africa's largest. It is a water body shared by Kenya (6%), Tanzania (51%), and Uganda (43%) (Fig. 1). Like many other inland waters, Lake Victoria is a rich multi-use resource, particularly for

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https://doi.org/10.1016/j.jglr.2023.06.009
0380-1330/

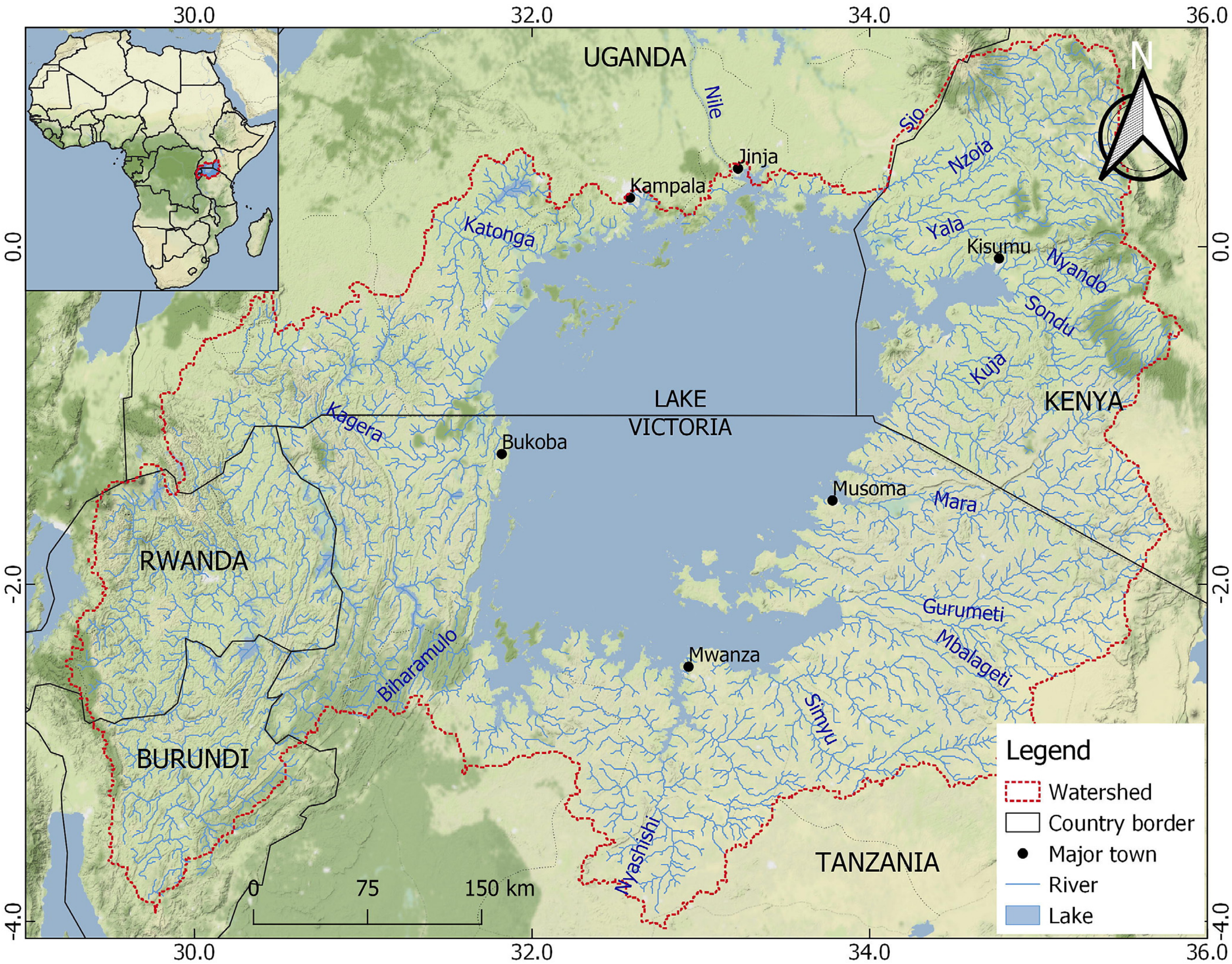

Fig. 1. Lake Victoria watershed covering five East African states.

its valuable, and vibrant fisheries. It employs over three million people in fisheries-related activities and provided around US$ 1.1 billion in 2021 to the East African Community (LVFO, 2022, 2017). Its capture fisheries produce more fish than all five Laurentian Great Lakes combined (Lauer, 2015), triple the harvest of Lake Tanganyika, and more than quadruple the harvest of Lake Malawi (Chimatiro et al., 2021).

Over the past 120 years, the fisheries and ecology of Lake Victoria have changed drastically due to problems associated with open-access fisheries, the introduction of new fishing gears, an increase in prohibited fishing gear and methods, overfishing, the introduction of exotic species, environmental degradation because of external stressors such as land use change and atmospheric deposition of nitrogen and phosphorus, eutrophication, climate change, and the proliferation of cage aquaculture (Dobbs, 1927; Graham, 1929; Kayanda et al., 2017; Njagi et al., 2022; Nyamweya et al., 2020; Olokotum et al., 2020; Pringle, 2005). These changes in the Lake Victoria Basin (LVB) water and land resources threaten many ecosystem services critical to LVB communities (Aura et al., 2022; Mpomwenda et al., 2022; Nyamweya et al., 2022; Nyboer et al., 2022). Nyamweya et al. (2020) highlight significant anthropogenic actions on Lake Victoria since the turn of the last century. However, correlation of events with ecosystem change has been problematic because to a lack of consistent and appropriate data, as well as the intrinsic challenge of tying pressure causality to impact, especially when many stressors are involved (Hecky et al., 2010; Nyamweya et al., 2016). This review aims to address this gap by examining the research needs, stakeholders, and resources required to understand the past, present, and future course of events, and ultimately to develop a decision support system that coordinates the management of Lake Victoria.

Study approach

This manuscript was written by an on-going collaboration of scientists from Kenya, Uganda, and Tanzania through a formal Lake Victoria Advisory Group (LVAG) formed during the African Great Lakes Stakeholders Network Workshop (https://www.agl-acare.org/2019-workshop-resources) held in Entebbe, Uganda in 2019. The group works under the auspices of the African Center for Aquatic Research and Education (ACARE). The members of LVAG meet virtually monthly, with the intended goals of providing research-based decision support to policy makers and resource managers for the sustainable management of the Lake Victoria Basin by: (i) initiating, improving and encouraging collaboration in research and timely dissemination of information to resource managers; (ii) driving investment opportunities to further research and collaborations; (iii) identifying sector weaknesses for capacity building; (iv) advocacy for resource sustainability; (v) problem identification and prioritization; (vi) developing tools for decision making; and (vii) promoting data collection and data sharing tools. Staff of both regional East African Community organizations, the Lake Victoria Fisheries Organization (LVFO) and the Lake Victoria Basin Commission (LVBC), are members of the LVAG. The LVFO is charged with developing conservation and management measures for sustainable fisheries and coordinating fishery management through fostering cooperation among and between partner states and community-run fishery management entities, the Beach Management Units (Lawrence et al., 2018; LVFO, 2011). The LVAG intends to shift short-term, parochial, and disparate approaches to research on Lake Victoria, and harmonize efforts to work towards comprehensive and long-term data and information flow. This information, in turn, will provide the basis on which Kenyan, Tanzanian, and Ugandan decision-makers can ensure the long-term health of the lake and the sustainable, and profitable, use of the lake's resources.

For a full description of methods (of which members of each advisory group used to write their papers for this special edition of the Journal of Great Lakes Research), see (Lawrence et al., 2023). For this manuscript, members of LVAG developed the priorities and ways forward using the following methods: i) Semi-formal and formal discussions that commenced in December 2019 and have continued virtually every month. At each meeting, discussions that highlighted important issues were noted and further discussed and considered for this manuscript and: i) if deemed relevant, certain issues were included as formal agenda items during meetings, and when this paper was outlined, these issues were taken into account; ii) when necessary, the LVAG members, with support from the secretariat of ACARE, engaged in both informal and formal surveys, to determine rankings of the most critical issues. In cases where issues were seen as of equal importance, formal discussions were created to ensure the way forward for presentation of those issues and their inclusion in the manuscript; iii) literature reviews were used to support the discussions and surveys taken by the LVAG, demonstrating that some issues regarding the lake had more or less peer-reviewed support, need more attention, or are crucial for decision-making process; and iv) response validation occurred through the above mechanisms, whereby discussions, surveys, and literature reviews supported the trends in discussion.

Dynamics on Lake Victoria

Fish and fisheries

Fishing is by far the most important economic activity for Lake Victoria lakeside residents. (Nyamweya et al., 2022; UNEP, 2006). Various strategies have been used to manage Lake Victoria's fisheries over the last century. The fishery was small scale in the pre-colonial era and was managed by traditional belief systems of the fishing communities. Following that, formal institutions (research and management) established in the riparian countries took over lake management (Jackson, 2000). In more recent times, it was recognized that the *trans*-boundary resource required a common management policy, which resulted in the formation of the Lake Victoria Fisheries Organization (LVFO) in 1994 to coordinate and manage the lake's fisheries resources (Nyamweya et al., 2017). The management institutions have variously implemented measures including gear size restrictions, enforcement of a ban on prohibited gear and slot size regulation (for Nile perch) ostensibly to ensure long-term viability of the fishery (Graham, 1929; Njiru et al., 2014). Most of these measures are aimed at regulating fishing gear and very few at regulating catch (Downing et al., 2014). In spite of this, catch rates have continued to drop (Nyamweya et al., 2020), casting doubt on the efficacy of the management methods implemented thus far in terms of both their design and their enforcement and compliance.

Currently there are programs collecting data on fish occurrence, distribution, abundance seasonal variation, life history, fishing effort dynamics and infrastructure, catch trends, post-harvest management and socio-economics. However, these programs are plagued by data scarcity in both spatial and temporal dimensions, as well as inconsistency in data collecting time. The datasets are rarely consolidated to provide ecological or fishery reference points. Furthermore, emergent data lacks age structure, which is required to generate information on recruitment, longevity, mortality, and fluctuations in the fishery induced by different year classes, all of which contribute to sustainable exploitation of fish stocks. The main causes for the absence of this element of fisheries data include a lack of equipment and requisite capabilities, necessitating the requirement for fish stock assessment scientists in the region to be reskilled and retooled. More significantly, constant financing is needed to allow for adequate and timely data collection, synthesis, and dissemination.

Biodiversity decline

The Lake Victoria Basin is one of the most biodiverse regions in the world, home to a wide array of endemic species of plants and animals. However, the region is facing significant challenges related to biodiversity loss, which has negative impacts on both the environment and the local communities (Sayer et al., 2018b, 2018a). The mass extinction of the endemic haplochromine cichlid fish community in Lake Victoria is one of the most well-known and alarming examples of biodiversity loss in the region. Haplochromine cichlids are a group of over 500 endemic species that were once highly diverse and abundant in the lake. However, in the 1980s and 1990s, the population of these fish experienced a dramatic decline, with some estimates suggesting that up to 200 species may have gone extinct (Witte et al., 1992). Efforts to protect and restore cichlid populations in the lake are crucial for the long-term sustainability of the ecosystem and the economy in the region.

Comprehensive assessments provide critical information for biodiversity conservation and sustainable exploitation. The identification of Key Biodiversity Areas (KBAs) for future delineation and conservation is a top priority. Because of the tremendous biodiversity in the Lake Victoria basin, species identification and characterization are difficult. This problem can be solved by genetic studies, however there is currently limited capacity in the region to do molecular research. As a result, there is a need for capacity enhancement through international partnerships, as well as the establishment of molecular laboratories and equipment in regional research organizations and universities (Table 1). Overall, the challenges related to biodiversity loss in the Lake Victoria Basin are complex and require a multifaceted approach to address. This includes conservation efforts to protect natural habitats and species, as well as efforts to promote sustainable development practices that balance economic growth with environmental protection.

Pollution

Nutrient loading from domestic, industrial and agricultural activities is one of the main water quality issues in Lake Victoria (Scheren et al., 2000). All states sharing the LVB agree that the main water quality problem parameters are nitrogen (N), phosphorus (P), biological oxygen demand (BOD, evidenced by decreasing dissolved oxygen) and suspended solids (including phytoplankton) (Odada et al., 2006). Algal blooms, which deplete dissolved oxygen (leading to fish mortalities), can alter species composition, and increase human health risks from cyanobacteria toxins, are enhanced by increased sediment runoff from catchments and asso-

Table 1
Matrix of needs assessment to address biodiversity decline in Lake Victoria.

What needs to be done and how	Resources required	Who does it	When	Category
Comprehensive fisheries stock assessment - Fisheries dependent (catch and effort) and independent (experimental fishing, hydroacoustic) surveys	Big data analytics and modeling expertise	Local experts	Annually	Long term
Identification of Key Biodiversity Areas (KBAs) - Baseline biological and ecological surveys	Human resources; field and laboratory equipment; research vessels; satellite research stations.	Local researchers in collaboration with international colleagues.	1–2 years	Short term
Genetic characterization of fish species in the lake and drainage basin, to ascertain genetic quality of the fish, as well as proper identification of fish species	Strengthening molecular capabilities; molecular research laboratory	Local researchers in collaboration with international colleagues.	1–5 years	Medium tern
Dedicated field survey surveys for key species, particularly in sublittoral and profundal habitats - Use of platforms; transects from vessels; basic research on species diversity using high throughput methods such as metabarcoding, especially for macroinvertebrates. Informed conservation status assessments (red listing etc.)	Capacity development in taxonomy; training for local communities in invasive species surveillance	A citizen science approach - members of the general public collaborating with professional scientists	1–3 years	Short term

ciated nutrient loads (e.g., in the form of adsorbed phosphorus) to the lake (Kayombo and Jorgensen, 2006; Ochumba, 1990, 1987). As a result, parts of Lake Victoria, especially the deeper areas experience anoxia (Bootsma and Hecky, 1993; Hecky, 1993; Njiru et al., 2012).

As a result of the high human population and its continued growth in the basin, waste disposal has been a major challenge for many municipalities. Many small towns along streams, rivers, and shores of Lake Victoria lack proper solid waste management and sewage systems (Calamari et al., 1995; Nyenje et al., 2010), while those with sewage services are operating above capacity (Juma et al., 2014; Ntiba et al., 2001). Scheren et al. (2000) showed that BOD load is highest on the Kenyan side, and that domestic BOD loads exceed industrial loads in all regions (although it is noted that industrial loads will contribute to a higher chemical oxygen demand). This highlights the need for management policies to be directed primarily towards the reduction of domestic pollution. Nutrient input originates mainly from atmospheric deposition and runoff from agricultural areas, and these non-point sources, together, for approximately 90% of phosphorus and 94% of nitrogen load into the lake (Scheren et al., 2000).

Agricultural intensification, and the associated increase in the use of pesticides and other agrochemicals, also pose a threat to fish and other organisms (Osoro et al., 2016). Notable levels of these chemicals have been found in water and sediments (Getenga et al., 2004; Madadi et al., 2006; Musa et al., 2011; Osano et al., 2003). In addition, industrial activities in the LVB, such as textiles, sugarcane processing, alcohol distilleries, food processing, pulp and paper industry, and other informal sectors (e.g., brewing of the traditional beer), are potential sources of pollution via untreated wastewater released into rivers and the lake (Musungu et al., 2014; Nyenje et al., 2010; Oguttu et al., 2018).

Concerns have also been raised on the potential of small-scale gold mining, leather, and metallurgy industries as sources of heavy metals discharged into Lake Victoria, its satellite lakes, and influent rivers (Campbell et al., 2003a; Kishe and Machiwa, 2003; Oguttu et al., 2018; Ongeri et al., 2009). Traces of heavy metals and agrochemical residues (especially pesticides) have been reported in fish samples from the LVB (Campbell et al., 2003b; Ssebugere et al., 2014). Although the levels are low, the threat to food webs and human health through bioaccumulation and biomagnification should not be underestimated (Outa et al., 2020; Poste et al., 2015).

Prioritizing research to identify main pollution agents should be a top priority in the near future in order to solve the issue of pollution in Lake Victoria. Training enough people at universities and research centers to carry this out is essential. Additionally, the appropriate institutions should be supplied with cutting-edge equipment for both the field and the laboratory analyses. Research teams conducting pollution monitoring in Lake Victoria and its basin will need to gain skills in hydrodynamic modelling to better understand the fate of pollutants and nutrients from various sources. Few institutions in the region have the earth observation and geographic information system (GIS) capacity needed to track the spatial–temporal patterns of macrophytes and algal blooms, thus efforts should be undertaken to establish equivalent capability in all countries sharing the Lake Victoria Basin. The abundance and distribution of macrophytes and algae in a body of water can be a useful indicator of its ecological health and the level of pollution it is experiencing. By monitoring changes in macrophyte and algae populations, scientists and environmental managers can gain insight into the health of aquatic ecosystems and identify potential sources of pollution that need to be addressed (Dubey et al., 2022). To understand patterns of historical pollution there is a need to conduct more lake-wide paleolimnological studies. Lake sediments contain the historical record of the lake, making it possible to understand changes in the lake and catchment over time. This is very important when lake monitoring data are limited or fragmented. Paleolimnology data can be used to determine changes in climate, ecology and sediment accumulation rates (Hecky et al., 2010; Perga et al., 2015; Verschuren, 2002). Paleolimnology data can be compared to the historical changes in other indicators (e.g. population growth, land use and land cover changes, economic development, extreme weather events) to ascertain the likely causes of the ecological changes in the lake (Ribbe et al., 2021; Verschuren, 2002). Establishing long-term, well-maintained databases and information management systems should also be addressed to increase access and exchange of available data in order to facilitate prompt decision making (Table 2).

Aquatic alien plants

Water hyacinth is the primary aquatic alien plant in Lake Victoria. The first record of water hyacinth infestation in the lake was in the late 1980s when the plant entered the lake from Rwanda through River Kagera (Albright et al., 2004; Wilson et al., 2007). It is believed to have been introduced through the ornamental plant trade. Since then, the plant has spread rapidly throughout the lake, reaching peak coverage in the late 1990s and early 2000s. The spread of water hyacinth in Lake Victoria has been characterized by periodic fluctuations. After the initial rapid expansion, the plant's coverage has been reduced by various factors, such as biological control agents (e.g., weevils), mechanical removal, and the use of herbicides (Albright et al., 2004; Williams et al., 2005). However, the plant has shown a tendency to rebound, especially during periods of high rainfall and nutrient inflows that favor its growth (Gichuki et al., 2012). The distribution of water hyacinth

Table 2
Matrix of needs assessment to address pollution in Lake Victoria.

What needs to be done and how	Resources required	Who does it	When	Category
Lake Victoria water quality and pollution monitoring. Prioritizing pollution-causing catchments based on pollutant analysis (including organic, inorganic and microbiological parameters)	Trained personnel; field and laboratory equipment; remote sensing/earth observation capacity	Research institutions and universities (both local and international)	1–2 years.	Short term
Modeling. This includes modelling of nutrient loadings from watercourses and sub-basins, as well as temperature dynamics.	Nutrient concentration and river flow rates, expertise in hydrographic model	Research institutions and universities (both local and international).	1–5 years.	Medium term
Monitoring, mapping and assessment of the spatial and temporal distribution of alien plant species and algal blooms	ICT Hardware and software, access to satellite images, training on remote sensing and GIS	Research institutions, universities, NGOs and CBOs	1–5 Year	Medium term
Paleolimnological studies – Sediment coring and analyses to reconstruct pollution history	Expertise in geosciences; coring sampling equipment; processing and analytical equipment; reference collections	Research institutions and universities (both local and international).	1–5 Year	Medium term
Improved access to and sharing of available water quality data.	Data sharing policies and protocols; long-term, well-maintained databases where information can be stored in a usable form.	Research institutions and universities, as well as the African Great Lakes Information Platform	1–10 years.	Short – long term

in Lake Victoria is not uniform. The plant tends to be more prevalent in shallow, sheltered bays, wetlands, and near river mouths, where nutrient input is higher. In particular, the Winam Gulf in Kenya, the Murchison Bay in Uganda, and the Mara River estuary in Tanzania have experienced significant infestations (Albright et al., 2004).

The proliferation of this plant resulted in clogged waterways impeding water flow, which increased the rate of siltation, inhibiting oxygen diffusion into the water resulting in depleted dissolved oxygen levels (Ongore et al., 2018). In addition, the plant has resulted in disrupted fishing activities, transport, irrigation, water treatment, and has enhanced breeding grounds for vectors of human diseases (including malaria and bilharzia), and impacted on biodiversity (Opande et al., 2004; Ouma et al., 2005). Eradication of water hyacinth infestation is impractical. Instead, it is a situation that must be continually managed. Management techniques that have been employed to manage water hyacinth in Lake Victoria include biological control using weevils that feed on the plant, and manual removal and beach cleanup efforts (World Bank, 1996).

Aquaculture

In recent years, demand for fish and fish products has increased despite a plateau or reduction in landings of the main commercial species in Lake Victoria (Nyamweya et al., 2022). This, together with increased demand for the African catfish (*Clarias gariepinus*) fingerlings for live bait fishing in the Nile perch fishery, stimulated aquaculture investments in the in the lake region, resulting in increased demand for aquaculture inputs like seed, feed, and equipment. As a response, many private catfish hatcheries have been established to meet the tremendous demand for catfish bait (approximately 3 million pcs/day) and food fish in the Lake Victoria region (Isyagi, 2007). The Lake Victoria basin is generally suitable for aquaculture development on both land and water (Ssegane et al., 2012). The majority of rural fish farmers use ponds to raise fish on a subsistence scale for household food security (Maithya et al., 2007; Mwanja et al., 2007). Commercial aquaculture producers use both land-based (ponds/tanks) and water-based (cages) production systems to raise Nile tilapia (*Oreochromis niloticus*), African catfish, and ornamental fish (Jacobi, 2013; Munguti et al., 2006; Rutaisire et al., 2010).

Subsistence aquaculture production from land-based systems is still low, but this can be improved through integration of aquaculture-agriculture systems and provision of supplemental low-cost feed (Charo-Karisa et al., 2006; Mwanja and Nyandat, 2013; Shoko et al., 2011). On the other hand, substantial yields (40–120 kg/m^3) are currently being realized using tilapia cage farming, with the potential to meet the region's need for fish (Musinguzi et al., 2019). The number of fish cages has risen considerably in a short period of time. In 2012, the Kenyan portion of Lake Victoria had very few floating aquaculture fish cages. This figure has risen dramatically, with Njiru et al. (2019) stating that over 3,000 cages had been installed on the Kenyan portion of L. Victoria. Hamilton et al. (2019), on the other hand, counted 4357 fish cages covering 62,132 m^2 on the same portion of the lake in 2018 utilizing unmanned aircraft systems (UAS), satellite, and GIS technology. By April 2022, the number of cages in the same section of the lake had risen to 5,252 (KMFRI unpublished data).

There are emerging concerns about the impact of aquaculture investments in Lake Victoria if best practices are not followed. These include loss of biodiversity, the introduction of fish pathogens, safety of products and pollution (AU-IBAR (African Union - Interafrican Bureau for Animal Resources), 2016; Egesa et al., 2018; Musinguzi et al., 2019; Namulawa et al., 2020; Opiyo et al., 2018; Tibihika et al., 2020; Walakira et al., 2018). Biosecurity and biosafety policies for aquaculture should be implemented to ensure sustainable growth of the sub-sector. Farmers have organized themselves into associations/groups to access services, markets and inputs which has accelerated aquaculture development in this region (Aanyu et al., 2020; Stutzman et al., 2017). Other efficient innovations include the use of recirculating aquaculture systems that are suitable for seed production on a small area (Gukelberger et al., 2020; Opiyo et al., 2018). Aquaculture can be used to conserve threatened aquatic species, through promotion of "finger ponds' established in wetlands which have a potential to restore biodiversity (Kipkemboi et al., 2007). Species (Tilapia: *Oreochromis niloticus*, *O. variabilis*, *O. leucostictus*), *Clarias* sp., *Protopterus aethiopicus* and *Haplochromis* spp. are reported to have migrated to finger ponds and breed to increase fish production. Currently, efforts are being made to monitor the impact of cage farming in Lake Victoria, and propose mitigation strategies through Integrated Multi-trophic Aquaculture to guide planners in the region (Granada et al., 2016; Hamilton et al., 2019).

Other uses

Lake Victoria supports a wide range of socioeconomic activities, including transportation, industrial use, waste treatment tourism, and recreational activities. Economic exploitation of the lake is expected to expand in the future, with a rise in population in the lake basin, development goals guided by the Blue Economy strategy, and an increase in aquaculture in the lake. These emerging lake uses risk increasing environmental load risk and resource user conflicts in the face of expanding lake utility. Support in building an integrated planning framework for aquaculture in the lake is required to handle the lake's many uses while guaranteeing economic and ecological sustainability. To make this a reality, it is necessary to facilitate suitability mapping, carrying capacity assessment, and lake zoning (Table 3).

Dynamics in the Lake Victoria catchment

Increasing human population and socio-economic dynamics

The Lake Victoria basin is home to about 42 million people with an average population density of 250 people per km^2 which is about four times the average (67 people per km^2) for East Africa. The national population growth rates in Burundi, Kenya, Rwanda, Tanzania and Uganda are 3.0, 2.2, 2.7, 2.9, and 3.3%, respectively (PRB, 2021). With several large cities located along the shores of the large bays and gulfs, the Lake Victoria basin has one of the highest population densities in Africa (Olokotum et al., 2020). This is mainly influenced by rapid urbanization along the lakeshore, with the expansion of cities such as Entebbe, Kisumu and Mwanza. For instance, the population in Mwanza increased by 26% in the 10-year inter-census period of 2002–2012, that is, from 2.06 million to 2.77 million. However, about 90 % of the population in the basin is still rural (NELSAP/GiZ, 2020). The basin communities are among the poorest in the world, with most of the population living on less than $1.25 per day. The poverty rates in Burundi, Kenya, Rwanda, Tanzania, and Uganda are at 72.8 percent % (2013), 37.1 percent % (2015), 56.5 percent % (2016), 49.4 percent % (2017), and 41.5 percent % (2016), respectively (Cowx and Ogutu-Owhayo, 2019).

Over 70% of the people in the Lake Victoria basin engage in subsistence farming (Defersha and Melesse, 2012). Pressure on land has resulted in unsustainable agricultural practices, deforestation and encroachment into wetlands, river banks, and on the lake shore. Many of the people have no access to clean water or improved sanitation facilities, resulting in high incidences of water-related diseases. The majority of the rural and urban population in the basin is involved in small-scale economic activity using labor-intensive technologies, which are greatly vulnerable to socio-economic and physical conditions. This is exacerbated by a huge unproductive young population (under 15 years old), which accounts for 41% (78.1 million) of the population in East African countries (Table 4). Uganda has the largest proportion of youth under 15 years old (46%, 21.7 million), while Rwanda has the lowest (37%, 4.9 million) in the region (PRB, 2021). The high number of youth under 15 years old is a looming concern for East African countries that will have to provide employment, housing, and medical care for a huge number of people in the coming years.

Despite a plethora of resources, including the large fishery, Lake Victoria region residents are among the poorest in the world, with the majority living on less than USD 1.25 per day (Nyamweya et al., 2022; The World Bank, 2016). An in-depth evaluation of population structure, dynamics, and trends, including gender considerations, is required to better understand the underlying causes of the Lake Victoria basin's poor socioeconomic situation. Such research will shed light on the influence of culture in the socioeconomics of the region's communities. The distribution of gender roles should be a basic consideration when developing a community support project, since an intervention without it can disproportionately empower one part of society, resulting in gender imbalance. Valuation of ecological services, mapping socio-economic benefits, and reorganization of fisheries data to include a complete valuation of the fisheries and aquaculture value chains are among the other research required to harness the Lake Victoria basin's socio-economic potential (Table 5).

Land use and land cover changes

Over the past 100 years, Lake Victoria has witnessed fundamental environmental and ecological changes, the most pervasive being land use and land cover changes at the basin scale (Odada et al., 2009; Verschuren, 2002). The demand for land and its associated resources and ecosystem services, such as agriculture, grazing land, urbanization, rural and urban settlements is still increasing in much of East Africa. This has driven human-related change over short and long-term scales (Mugo et al., 2020). Many studies have offered valuable information on the trends and drivers of land use and land cover changes in the Lake Victoria basin, while also proposing specific mitigation strategies for dealing with the changes and their implications on ecosystem structure and function. The relationship between climate change and variability in land use change has also over the years received attention (Maitima et al., 2010; Olokotum et al., 2020; Wasige et al., 2012). The Lake Victoria basin is a prominent hotspot where people are exposed to extraordinarily high levels of climate change consequences, owing to the confluence of population growth on lands with weather fluctuations (Awange et al., 2007). Droughts and floods have had an impact on agricultural production, water availability, and hydroelectric power generation with parts of the basin in Rwanda and Burundi experiencing periodic landslides during periods of heavy rains. The land-related challenges associated with the basin's drought and floods cycles have exerted pressure on land cover hence accelerating land conversions from indigenous forests, woodlands, grasslands, and wetlands to small-scale farming and settlement. Such changes in land use and land cover have implications for Lake Victoria's water quality as well as a reduction in the quality of ecosystem services within the watershed (Maitima et al., 2010). Consequently, monitoring of chemical, physical, and biolog-

Table 3
Matrix of needs assessment to address aquaculture in Lake Victoria.

What needs to be done and how	Resources required	Who does it	When	Category
Mapping of existing aquaculture extent	Trained personnel; drones	Research institutions and universities (local)	1–2 years	Short term
Suitability mapping, carrying capacity assessment, and zoning	Biophysical and geochemical data; ecosystem models	Research institutions and universities (both local and international)	1–2 years	Short term
Water quality monitoring	Field and laboratory equipment	Research institutions	1–10 years	Short-long term
Fish pathology research	Expertise if fish pathology, laboratories and diagnostic equipment	Research institutions and universities (both local and international)	1–5 years	Medium tern
Developing data and information management systems for aquaculture	Data collection and management system; capacity building of farmers	Research institutions and universities (both local and international); LVFO	1–2 years	Short term
Aquaculture policy establishment and improvement	Data and stakeholder involvement	LVFO; fisheries management institutions	1–2 years	Short term

Table 4
Human population trends and characteristics in East Africa. (). Source: PRB, 2021

Country/ Region	Population (millions) in mid-2021	Population growth rate (%)	Population mid-2050 (millions)	% of Population < 15 years	Youth Ages 15–24 with HIV/AIDS (%)	Urban Population (%)
Burundi	12.2	3	25.6	43	0.55	13
Kenya	54.7	2.2	89.6	38	1.65	32
Rwanda	13.3	2.7	23	37	0.9	22
Tanzania	62.1	2.9	124.2	42	1.65	35
Uganda	47.1	3.3	97.8	46	1.85	24
East Africa average	38	3	72	41	1.32	25
Africa average	1,373	2.5	2,529	40	1.1	43

Table 5
Matrix of needs assessment to address population growth and socio-economic dynamics in Lake Victoria.

What needs to be done and how	Resources required	Who does it	When	Category
Assessment of demographic structure, dynamics and trends – Analysis of available socio-demographic data	Funds for research collation and analysis of data; capacity building of local scientists	A multi-sectoral group/team drawn from Government, NGOs, research institutions, universities	1–3 years.	Short term
Valuation of ecosystem services	Funds for research collation and analysis of data; capacity building of local scientists	Research institutions and universities (both local and international)	1–2 years	Short term
Mapping of socioeconomic interaction and benefits	Socio-economic modeling expertise	Research institutions and universities (both local and international)	1–5 years	Medium term
Reconstructing fisheries statistics – complete valuation of the fisheries and aquaculture value chains	Financial and human resources; capacity building of local scientists	Research institutions and universities (both local and international)	1–5 years	Medium term

ical conditions in the lake is pivotal for understanding changes occurring in the catchment and the lake and identifying hotspots. Monitoring land use and land cover changes using remote sensing with ground truthing should be done in addition to measurements of some key indicator parameters in the rivers (e.g., sediment and nutrient fluxes, and discharge). Data on the use of soils, fertilizer and pesticide application are also needed.

Despite the availability of both in-situ and remote sensing data, connections between land cover types have yet to be demonstrated. Furthermore, there are few studies that have looked at potential connections between environmental processes and natural resource utilization in transboundary basins. To provide accurate land cover change, a basin-scale, operational, Earth-observation-based monitoring system for land cover and land use change is required. To standardize methodology and interpretations, countries sharing transboundary resources need to collaborate. Land use policies and the economic environment that influence land cover changes differ by country. Methodological differences in the computation of harmonized estimates of land cover change can have an impact on the quantification of ecosystem services provided by natural land cover, resulting in an underestimation of the value of these services (Mugo et al., 2020). To address and alleviate such issues, a basin-wide, standardized land cover map employing an internationally recognized categorization (e.g., Mugo et al., 2020) and adequate monitoring resources are required (Table 6).

Riparian deforestation

Conversion of forest lands and human settlements on riparian areas, including the growth of towns, is changing water quality and quantity, organic matter and nutrient inputs, and the diversity and composition of aquatic communities (Odada et al., 2006). Clearing of indigenous vegetation and planting of eucalyptus (Myrtaceae) species on riparian zones in the upper reaches of most streams and rivers have wrought changes in the landscape and plant composition. Loss of indigenous trees species on the riparian zones of streams and rivers and their replacement with exotic species can influence organic matter input, its processing and contribution to riverine food webs (Masese et al., 2014). Considering the predominance of intro-

Table 6
Lake Victoria's land use and land cover (LULC); habitat degradation and climate change: a needs assessment matrix.

What needs to be done and how	Resources required	Who does it	When	Category
Spatial-temporal analysis of LULC changes at the river and lake basin scales - Remote sensing GIS mapping; ground-truthing surveys; environmental sampling	Tools for GIS and remote sensing; high-resolution satellite imagery; funding for ground-truth surveys; e-DNA analysis costs	Government authorities; research institutions; universities.	1–3 years	Short term
Harmonization of LULC analysis methods and interpretations in the LVB - create a standardized land cover map using an internationally recognized classification	Funding; regional working groups	Resource managers and policy makers	1–5 years	Medium term
Studies on effects of climate change	Trained personnel	Research institutions & universities (both local and international)	1–2 years	Short term
Mapping of climate impact and vulnerability, adaptation pathways and identification of mitigations options	Climate modeling expertise	Research institutions & universities (both local and international	1 – 5 years	Medium term
Coordinated/synchronized Catchment and Lake Monitoring	Regional working groups; protocols/standard operating procedures.	Government authorities; research institutions; universities.	1 – 10 years	Long term

duced plant species such as sugar cane, maize and *Eucalyptus spp*. on riparian areas, restoration and maintenance of indigenous riparian forests should be prioritized. Maintenance of buffer strips along riverbanks will prevent sediment erosion from agricultural hillslopes and can stabilize river flows especially during the dry periods (Cole et al., 2020; World Agroforestry Centre, 2006). At the catchment level, deforestation should be checked and the current rehabilitation programs expanded and strengthened.

Habitat degradation

While the effects of nutrient input and eutrophication on Lake Victoria have been widely discussed in the literature (e.g., Hecky, 1993; Hecky et al., 2010; Sitoki et al., 2010), studies on the effects of habitat degradation, sedimentation, and nutrient inputs in rivers and lakes are limited. With more than 70% of the over 42 million people in the lake basin estimated to be engaged in agriculture (ADB, 2016), mostly as small-scale farmers, deforestation and unsustainable agricultural practices that do not embrace soil and water conservation have increased soil erosion (Defersha and Melesse, 2012; Kayombo and Jorgensen, 2006; Scheren et al., 2000). Coupled with increasing human and livestock populations, soils have been degraded, resulting in severe soil erosion and sedimentation of streams and rivers (Defersha and Melesse, 2012; Dutton et al., 2018; Okungu and Opango, 2005). Large areas of the southern Lake Victoria basin lay in semi-arid areas that are mainly used for grazing large numbers of livestock (cattle, goats and sheep) that are replacing native wildlife populations (Hongo and Masikini, 2003; Ogutu et al., 2016; Veldhuis et al., 2019). This livestock grazing can contribute to high sediment yields (Dunne, 1979; Dutton et al., 2018; Glover and Wateridge, 1968).

Climate change

The Lake Victoria basin has undergone ecological changes linked to climatic changes (Onyango and Opiyo, 2022). These changes have raised concerns to people in the region because of the effects they have on their livelihoods (Petty et al., 2022). Devastating floods and landslides were produced by heavy rainfall in East Africa between late 2019 and mid-2020. As a result of these downpours, in May 2020, Lake Victoria reached its highest level since records began being kept (Pietroiusti et al., 2022). Nicholson (1998) pointed out that the lake level has exhibited fluctuations since the 1960s. Since the 1980s, there have been periods of prolonged drought and unpredictable rainfall patterns that have negatively affected food production in the region (Awange et al., 2007). However, in May 1998 the water level of Lake Victoria was 1.06 m above its 10-year average from 1992 to 2001. The rise was due to the high amount of rainfall in 1997 and early 1998 which was likely generated by the El Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD). In the year 2020 Lake Victoria recorded a maximum change of more than + 2 m above datum, last witnessed in the 1960s, thereby claiming terrestrial habitats. This affected ecosystems and livelihoods, especially fishers who depend on fisheries as their only source of livelihood (Aura et al., 2020). Currently, there is limited capacity in the LVB

Table 7
Some East African institutions that offer courses in Fisheries, Aquatic, Marine, and Aquaculture sciences. Certificate (C), diploma (D), bachelor (B), master's (M), Ph.D. (P).

Country	Institution(s)	C	D	B	M	P
Kenya	University of Eldoret		X	X	X	X
	Jomo Kenyatta University of Agriculture and Technology			X		
	Maasai Mara University			X		
	University of Nairobi			X	X	X
	Moi University			X		
	Egerton university			X		
	Kisii university	X	X	X		
	South Eastern Kenya University			X	X	
	Karatina university	X	X	X	X	
	Maseno university			X	X	
	Chuka university			X		
	Masinde Muliro University of Science and Technology			X		
	Technical university of Mombasa			X		
	Pwani University			X		
	Kenya Wildlife Service Training Institute	X	X			
	Ramogi Institute of Advanced Technology (RIAT)	X	X			
Uganda	Makerere University.			X	X	X
	Kampala University.			X		
	Mbarara University of Science and Technology.			X		
	Uganda Christian University.			X		
	Cavendish University Uganda.			X		
	Kyambogo University.			X		
	Clarke International University.			X		
	Gulu University			X		
	Busitema University				X	
	Nkumba university		X			
	Fisheries Training Institute		X			
Tanzania	St. Augustine University of Tanzania.			X		
	University of Dar es Salaam.		X	X	X	X
	University of Dodoma			X	X	X
	St John's University of Tanzania.			X		
	The State University of Zanzibar Vuga Campus.			X		
	St. Joseph University in Tanzania.			X		
	University of Arusha.			X		
	Sokoine University of Agriculture.			X	X	X
	Fisheries Education and Training Agency		X			

region to determine and assess the effects and trajectory of climate change. There is need for research that addresses the impacts caused by climate and weather extremes.

Skills and knowledge

Existing capacity

Fisheries, Aquatic, Marine, and aquaculture sciences

Fisheries Science is taught in all three Lake Victoria riparian nations, and the number of universities that offer it has increased in recent years. Most universities provide bachelor's level training in Fisheries, Aquatic, Marine, and Aquaculture sciences, with only a handful providing postgraduate training in the same subjects. Certificate and diploma level training is available in the region's vocational fisheries training institutes (Table 7). Oceanography training is provided in East African countries through a variety of programs in Biology, Ecology, Chemistry & Biochemistry, Environmental Studies, and Aquatic Sciences. At the undergraduate or postgraduate level, there is no single curriculum that specializes in limnology. Egerton University offers a joint M.Sc program in Limnology and Wetlands Management (LWM) that includes modules in fisheries, aquaculture, and wetlands, river and lake /riverine ecology in collaboration with the University of Natural Resources and Life Sciences, Vienna BOKU (Vienna, Austria) and the IHE-Delft Institute for Water Education, the Netherlands. Undergraduate and postgraduate programs at Makerere University's College of Natural Sciences (CoNAS) in Uganda include limnology components.

Environmental education

The only environmental education program identified during this study is provided at the Masters level at Kenyatta University. This means that there are likely to be significant gaps in environmental education training and capacity building. However, several middle-level colleges, such as Kenya Wildlife Training Institute (KWTI), provide environmental education training programs. Furthermore, the National Environment Management Authority (NEMA) in Kenya and Uganda, the National Environmental Management Council (NEMC) in Tanzania, and the Rwanda Environmental Management Authority (REMA) in Rwanda are in charge of pollution control and environmental issues. Academic institutions under LVB have also issued guidance on appropriate curriculum requirements for training on Environmental Impact Assessment (EIA) and Environmental Audit (EA).

Environmental monitoring and remote Sensing/GIS

Almost all public universities that provide science-based programs have environmental programs at both the undergraduate and postgraduate levels. In Kenya and Tanzania, many generic programs in biology, aquatic ecology, and fisheries sciences address challenges connected to coastal zone management. There are graduate-level programs in Geographical Information Systems. In addition, many universities and colleges provide short courses in GIS and remote sensing to train students and those currently working in the area on modern mapping techniques in demand in the labor market. Such short courses are available at the Regional Centre for Mapping of Resources for Development, the Institute for Recourse Assessment at the University of Dar es Salaam, The Open University of Tanzania, Ardhi University, and Makerere University. The National University of Rwanda offers a Bachelor of Science degree in Soil and Environmental Management, a Master of Science degree in Water Resources and Environmental Management (WREM), and a Postgraduate Certificate in Applied Geo-Information and GIS.

Gaps

Trans-Disciplinary training for managers including ecosystem approach and modeling skills

The Lake Victoria region lacks enough trained human resources in the modeling profession. Few people are trained with cutting-edge approaches in modeling and the ecosystem approach to aquatic ecosystem conservation and management. A review of higher learning institutions in 10 African Great Lakes countries (Ethiopia, Kenya, Uganda, Tanzania, Rwanda, Burundi, Democratic Republic of the Congo, Malawi, Mozambique, and Zambia) and the quality of publications in the last decade (from 2010 to 2020) revealed that no individual from these institutions published ecosystem models. More people should be trained in this discipline in order to understand the complex ecosystem processes, structure, and function and link them with the increasing state of perturbation from the catchments to the lake.

Fishing Technology, implementing of quality control in industry

University of Eldoret, Maseno University, Jaramogi Oginga Odinga University of Science and Technology, and Masinde Muliro University of Science and Technology all provide undergraduate and graduate programs that include the concept of fishing technology. The University of Nairobi and Egerton University both offer undergraduate and postgraduate food processing degrees, but none expressly targets fish processing. In Uganda, Nkumba University provides diploma and undergraduate training in Fisheries Management and Technology, with some components on public health and hygiene, fisheries policies, laws, and institutions, fishing methods and gear technology, and fish handling, processing, and preservation, whereas Makerere University CoNAS offers fish processing technology and quality assurance at both the undergraduate and graduate levels, but no fishing gear technology at either level.

Biodiversity, taxonomy and curation

Academic institutions in the Lake Victoria region that provide training and capacity building can teach biodiversity and taxonomy at both the undergraduate and graduate levels, but their ability for curation is limited. The bulk of these institutions, however, cooperate closely with the National Museums of Kenya (NMK), Tanzania (NMT), and Uganda (UNM), which have the infrastructure, space, and expertise to collect specimens for taxonomic analysis and curation. However, the Lake Victoria Basin's aquatic invertebrates and fishes are still little documented. The majority of the techniques and indices utilized in the biological evaluation of lotic and lentic systems are adapted from subtropical and temperate climates. Most institutions of higher learning and research do not have equipment and techniques for genetic identification and classification of aquatic animals, including well-trained specialists in DNA barcoding, genomics, and aquatic organism sequencing.

Conclusion

Lake Victoria's importance to the socioeconomic and nutritional well-being of lake-edge communities and riparian countries through the provision of numerous ecosystem goods and services cannot be over emphasized. The lake is under tremendous strain as a result of human activity and climate change. And, the complexity of the ecosystem, along with negative human actions on the lake and its catchment (sometimes without prior studies of potential impacts), has hampered our understanding of the system dynamics, major processes, drivers, and responses. Efforts to collect data about the lake and its catchment often focus on one or a few components (such as water quality parameters, aquatic species, land use, pollution, climate factors etc.) of the ecosystem and are generally limited in time and space. This is because much of the basic research is donor-funded and led by expatriates, while national governments do not adequately fund long-term research programs that allow local skills to develop, despite the existence of many higher learning institutions that offer advanced training on various fields relevant to the management of Lake Victoria and its catchment. This review identified key research needs in Lake Victoria and its basin that can result in a coordinated and efficient approach to research to understand the past, present, and future.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

ACARE provided support for this study. The anonymous reviewers' huge work and guidance are likewise greatly appreciated.

References

Aanyu, M., Denis, O., Cassius, A., Gertrude, A., 2020. Potential for enhancing and sustaining commercial aquaculture in Uganda: Producer organizations, contract farming schemes and public-private partnerships. Int. J. Fish. Aquat. Stud. 8, 258–264.

ADB, 2016. Feed Africa: Strategy for agricultural transformation in Africa 2016–2025.

Albright, T.P., Moorhouse, T.G., Mcnabb, T.J., 2004. The rise and fall of water hyacinth in Lake Victoria and the Kagera River Basin, 1989–2001. J. Aquat. Plant Manag. 42, 73–84.

AU-IBAR (African Union - Interafrican Bureau for Animal Resources), 2016. Mapping study of aquatic animal diseases in Africa – Eastern Africa. Nairobi.

Aura, C.M., Nyamweya, C.S., Odoli, C.O., Owiti, H., Njiru, J.M., Otuo, P.W., Waithaka, E., Malala, J., 2020. Consequences of calamities and their management: The case of COVID-19 pandemic and flooding on inland capture fisheries in Kenya. J. Great Lakes Res. 46, 1767–1775. https://doi.org/10.1016/j.jglr.2020.09.007.

Aura, C.M., Roegner, A., Owiti, H., Birungi, D., Fiorella, K.J., Corman, J., Kayanda, R., Mbullo, P., Nyamweya, C.S., Mchau, G., Daniels, M., Abila, R.O., 2022. Mind the gaps for the best practices: Enhancing the management of Lake Victoria fisheries resources. Lakes Reserv.: Sci. Policy Manage. Sustain. Use 27, 1–10. https://doi.org/10.1111/lre.12411.

Awange, J., Aluoch, J., Ogallo, L., Omulo, M., Omondi, P., 2007. Frequency and severity of drought in the Lake Victoria region (Kenya) and its effects on food security. Clim. Res. 33, 135–142. https://doi.org/10.3354/cr033135.

Bootsma, H.A., Hecky, R.E., 1993. Conservation of the African great lakes: A limnological perspective. Conserv. Biol. 7, 644–656. https://doi.org/10.1046/j.1523-1739.1993.07030644.x.

Calamari, D., Akech, M.O., Ochumba, P.B.O., 1995. Pollution of Winam Gulf, Lake Victoria, Kenya: A case study for preliminary risk assessment. Lakes Reservoirs: Sci. Policy Manage. Sustain. Use 1, 89–106. https://doi.org/10.1111/j.1440-1770.1995.tb00010.x.

Campbell, L., Dixon, D.G., Hecky, R.E., 2003a. A review of mercury in Lake Victoria, East Africa: Implications for human and ecosystem health. J. Toxicol. Environ. Health Part B-Crit. Rev. 6 (4), 325–356.

Campbell, L.M., Hecky, R.E., Muggide, R., 2003b. Variation and distribution of total mercury in water, sediment and soil from northern Lake Victoria, East Africa. Biogeochemistry 65, 195–211.

Charo-Karisa, H., Komen, H., Rezk, M.A., Ponzoni, R.W., van Arendonk, J.A.M., Bovenhuis, H., 2006. Heritability estimates and response to selection for growth of Nile tilapia (*Oreochromis niloticus*) in low-input earthen ponds. Aquaculture 261, 479–486. https://doi.org/10.1016/j.aquaculture.2006.07.007.

Chimatiro, S., Simmance, F.A., Wesana, J., Cohen, P.J., Westlund, L., Linton J., 2021. The African Great Lakes Regional Food System The contribution of fisheries and the case of small pelagic fishes. Penang, Malaysia. https://hdl.handle.net/20.500.12348/4957.

Cole, L.J., Stockan, J., Helliwell, R., 2020. Managing riparian buffer strips to optimise ecosystem services: A review. Agr. Ecosyst. Environ. 296, 106891. https://doi.org/10.1016/j.agee.2020.106891.

Cowx, I.G., Ogutu-Owhayo, R., 2019. Towards sustainable fisheries and aquaculture management in the African Great Lakes. Fish. Manag. Ecol. 26, 397–405. https://doi.org/10.1111/fme.12391.

Defersha, M.B., Melesse, A.M., 2012. Field-scale investigation of the effect of land use on sediment yield and runoff using runoff plot data and models in the Mara River basin, Kenya. Catena (Amst) 89, 54–64. https://doi.org/10.1016/j.catena.2011.07.010.

Dobbs, C.M., 1927. Fishing in the Kavirondo Gulf, Lake Victoria. J. East African Nat. History Soc. 3.

Downing, A.S., van Nes, E.H., Balirwa, J.S., Beuving, J., Bwathondi, P.O.J., Chapman, L.J., Cornelissen, I.J.M., Cowx, I.G., Goudswaard, K.P.C., Hecky, R.E., Janse, J.H., Janssen, A.B.G., Kaufman, L., Kishe-Machumu, M.A., Kolding, J., Ligtvoet, W., Mbabazi, D., Medard, M., Mkumbo, O.C., Mlaponi, E., Munyaho, A.T., Nagelkerke, L.A.J., Ogutu-Ohwayo, R., Ojwang, W.O., Peter, H.K., Schindler, D.E., Seehausen, O., Sharpe, D., Silsbe, G.M., Sitoki, L., Tumwebaze, R., Tweddle, D., van de Wolfshaar, K.E., van Dijk, H., van Donk, E., van Rijssel, J.C., van Zwieten, P.A.M., Wanink, J., Witte, F., Mooij, W.M., 2014. Coupled human and natural system dynamics as key to the sustainability of Lake Victoria's ecosystem services. Ecol. Soc. 19, 31. https://doi.org/10.5751/ES-06965-190431.

Dubey, D., Kumar, S., Dutta, V., 2022. In-situ anatomical and elemental response of aquatic macrophytes against nutrient enrichment in freshwater tropical lakes. Appl Water Sci 12, 163. https://doi.org/10.1007/s13201-022-01681-9.

Dunne, T., 1979. Sediment yield and land use in tropical catchments. J. Hydrol. (Amst) 42, 281–300. https://doi.org/10.1016/0022-1694(79)90052-0.

Dutton, C.L., Subalusky, A.L., Anisfeld, S.C., Njoroge, L., Rosi, E.J., Post, D.M., Bouchez, J., 2018. The influence of a semi-arid sub-catchment on suspended sediments in the Mara River, Kenya. PLoS One 13 (2), e0192828.

Egesa, M., Lubyayi, L., Tukahebwa, E.M., Bagaya, B.S., Chalmers, I.W., Wilson, S., Hokke, C.H., Hoffmann, K.F., Dunne, D.W., Yazdanbakhsh, M., Labuda, L.A., Cose, S., 2018. Schistosoma mansoni schistosomula antigens induce Th1/Pro-inflammatory cytokine responses. Parasite Immunol. 40, 1–11. https://doi.org/10.1111/pim.12592.

Getenga, Z.M., Keng'ara, F.O., Wandiga, S.O., 2004. Determination of organochlorine pesticide residues in soil and water from River Nyando drainage system within Lake Victoria Basin, Kenya. Bull. Environ. Contam. Toxicol. 72 (2), 335–343.

Gichuki, J., Omondi, R., Boera, P., Okorut, T., Matano, A.S., Jembe, T., Ofulla, A., 2012. Water Hyacinth *Eichhornia crassipes* (Mart.) Solms-Laubach dynamics and succession in the Nyanza Gulf of Lake Victoria (East Africa): implications for water quality and biodiversity conservation. Sci. World J. 2012, 1–10. https://doi.org/10.1100/2012/106429.

Glover, P.E., Wateridge, L.E.D., 1968. Erosion terraces in the Loita-Aitong areas of Kenya Masailand. Afr. J. Ecol. 6, 125–129. https://doi.org/10.1111/j.1365-2028.1968.tb00909.x.

Graham, M., 1929. The Victoria Nyanza and its fisheries. Crown Agents, London.

Granada, L., Sousa, N., Lopes, S., Lemos, M.F.L., 2016. Is integrated multitrophic aquaculture the solution to the sectors' major challenges? – a review. Rev. Aquac. 8 (3), 283–300.

Gukelberger, E., Atiye, T., Mamo, J.A., Hoevenaars, K., Galiano, F., Figoli, A., Gabriele, B., Mancuso, R., Nakyewa, P., Akello, F., Otim, R., Mbilingi, B., Adhiambo, S.C., Lanta, D., Musambyah, M., Hoinkis, J., 2020. Membrane bioreactor–treated domestic wastewater for sustainable reuse in the Lake Victoria region. Integr. Environ. Assess. Manag. 16, 942–953. https://doi.org/10.1002/ieam.4281.

Hamilton, S.E., Gallo, S.M., Krach, N., Nyamweya, C.S., Okechi, J.K., Aura, C., Oragi, Z., Roberts, P., Kaufman, L., 2019. The use of unmanned aircraft systems and high-resolution satellite imagery to monitor tilapia fish-cage aquaculture expansion in Lake Victoria. Kenya. Bull. Mar. Sci. 96, 71–93. https://doi.org/10.5343/bms.2019.0063.

Hecky, R.E., 1993. The eutrophication of Lake Victoria. Verhandlungen Internationalis Vereingung for Theorestiche and Angewandte Limnologie 25, 39–48. https://doi.org/10.1080/03680770.1992.11900057.

Hecky, R.E., Mugidde, R., Ramlal, P.S., Talbot, M.R., Kling, G.W., 2010. Multiple stressors cause rapid ecosystem change in Lake Victoria. Freshw. Biol. 55, 19–42. https://doi.org/10.1111/j.1365-2427.2009.02374.x.

Hongo, H., Masikini, M., 2003. Impact of immigrant pastoral herds to fringing wetlands of lake Victoria in Magu district Mwanza region, Tanzania. Phys. Chem. Earth Parts A/B/C 28, 1001–1007. https://doi.org/10.1016/j.pce.2003.08.041.

Isyagi, A.N., 2007. The aquaculture potential of indigenous catfish (*Clarias gariepinus*) in the Lake Victoria Basin. University of Stirling, Uganda.

Jackson, P.B.N., 2000. Freshwater fishery research organisations in central and eastern Africa - A personal recollection. Transactions of the Royal Society of South Africa 55, I–81.

Jacobi, N., 2013. Examining the Potential of Fish Farming to Improve the Livelihoods of Farmers in the Lake Victoria Region, Kenya – Assessing the Impacts of Governmental Support. University Centre of the Westfjords, Iceland.

Juma, D.W., Wang, H., Li, F., 2014. Impacts of population growth and economic development on water quality of a lake: case study of Lake Victoria Kenya water. Environ. Sci. Pollut. Res. 21, 5737–5746. https://doi.org/10.1007/s11356-014-2524-5.

Kayanda, R.J., Chande, A.I., Mgaya, Y.D., Mlaponi, E., Mkumbo, O.C., 2017. Stock assessment of commercial fish species of Lake Victoria, in: Mgaya, Y., Mahongo, S. (Eds.), Lake Victoria Fisheries Resources. Monographiae Biologicae, Springer, Cham, pp. 107–135. doi: 10.1007/978-3-319-69656-0_6.

Kayombo, S., Jorgensen, S.E., 2006. Lake Victoria. In: Jorgensen, S.E. (Ed.), Experiences and Lessons Learned Brief. Royal Danish University of Pharmaceutical Sciences, Copenhagen, pp. 431–446.

Kipkemboi, J., van Dam, A.A., Ikiara, M.M., Denny, P., 2007. Integration of smallholder wetland aquaculture-agriculture systems (fingerponds) into riparian farming systems on the shores of Lake Victoria, Kenya: Socio-

economics and livelihoods. Geogr. J. 173, 257–272. https://doi.org/10.1111/j.1475-4959.2007.00246.x.
Kishe, M.A., Machiwa, J.F., 2003. Distribution of heavy metals in sediments of Mwanza Gulf of Lake Victoria, Tanzania. Environ. Int. 28, 619–625.
Lauer, T.E., 2015. Fishery of the Laurentian Great Lakes, in: Freshwater Fisheries Ecology. John Wiley & Sons, Ltd, Chichester, UK, pp. 134–150. doi: 10.1002/9781118394380.ch10.
Lawrence, T.J., Achieng, A.O., Chavula, G., Haambiya, L.H., Iteba, J., Kayanda, R., Kaunda, E., Ajode, M.Z., Muvundja, F.A., Nakiyende, H., Nyamweya, C., Obiero, K., Plisnier, P.-D., Phiri, H., Sibomana, C., Smith, S., 2023. Future success and ways forward for scientific approaches on the African Great Lakes. J. Great Lakes Res. 49, 102242. https://doi.org/10.1016/j.jglr.2023.102242.
LVFO, 2017. Regional status report on Lake Victoria Bi-ennial Frame Surveys between 2000 and 2016. Jinja, Uganda.
LVFO, 2022. Regional Catch Assessment Survey report for Lake Victoria. Jinja, Uganda.
Madadi, V.O., Wandiga, S.O., Jumba, I.O., 2006. The status of persistent organic pollutants in Lake Victoria catchments, in: Proceedings of the 11th World Lakes Conference: Vol. 2. Nairobi, Kenya, pp. 107–112.
Maithya, J.M., Kimenye, L.N., Mugivane, F.I., Ramisch, J.J., 2007. Profitability of agro-forestry based soil fertility management technologies: the case of small holder food production in Western Kenya. Nutr. Cycl. Agroecosyst. 76, 355–367. https://doi.org/10.1007/s10705-006-9062-6.
Maitima, J.M., Olson, J.M., Mugatha, S.M., Mugisha, S., Mutie, I.T., 2010. Land use changes, impacts and options for sustaining productivity and livelihoods in the basin of Lake Victoria. J. Sustain. Dev. Africa 12, 189–206.
Masese, F.O., Kitaka, N., Kipkemboi, J., Gettel, G.M., Irvine, K., McClain, M.E., 2014. Macroinvertebrate functional feeding groups in Kenyan highland streams: evidence for a diverse shredder guild. Freshwater Sci. 33, 435–450. https://doi.org/10.1086/675681.
Mpomwenda, V., Tómasson, T., Pétursson, J.G., Taabu-Munyaho, A., Nakiyende, H., Kristófersson, D.M., 2022. Adaptation strategies to a changing resource base: case of the gillnet Nile perch fishery on Lake Victoria in Uganda. Sustainability 14, 2376. https://doi.org/10.3390/su14042376.
Mugo, R., Waswa, R., Nyaga, J.W., Ndubi, A., Adams, E.C., Flores-Anderson, A.I., 2020. Quantifying land use land cover changes in the Lake Victoria Basin using satellite remote sensing: the trends and drivers between 1985 and 2014. Remote Sens. (Basel) 12, 2829. https://doi.org/10.3390/rs12172829.
Munguti, J.M., Liti, D.M., Waidbacher, H., Straif, M., Zollitsch, W., 2006. Proximate composition of selected potential feedstuffs for Nile tilapia (*Oreochromis niloticus* Linnaeus) production in Kenya. Bodenkultur 57, 131–141.
Musa, S., Gichuki, J.W., Raburu, P.O., Aura, C.M., 2011. Risk assessment for organochlorines and organophosphates pesticide residues in water and sediments from lower Nyando / Sondu-Miriu river within Lake Victoria Basin, Kenya. Lakes Reserv.: Sci. 16, 273–280. https://doi.org/10.1111/j.1440-1770.2011.00486.x.
Musinguzi, L., Lugya, J., Rwezawula, P., Kamya, A., Nuwahereza, C., Halafo, J., Kamondo, S., Njaya, F., Aura, C., Shoko, A.P., Osinde, R., Natugonza, V., Ogutu-Ohwayo, R., 2019. The extent of cage aquaculture, adherence to best practices and reflections for sustainable aquaculture on African inland waters. J. Great Lakes Res. 45, 1340–1347. https://doi.org/10.1016/j.jglr.2019.09.011.
Musungu, P.C., Lalah, J.O., Jondiko, I.O., Ongeri, D.M.K., 2014. The impact of nitrogenous and phosphorous nutrients from selected point sources in Kisumu City on River Kisat and Nyalenda Wigwa Stream before their discharge into Winam Gulf. Lake Victoria. Environ. Earth Sci. 71, 5121–5127. https://doi.org/10.1007/s12665-013-2915-9.
Mwanja, W.W., Akol, A., Abubaker, L., Mwanja, M., Msuku, S.B., Bugenyi, F., 2007. Status and impact of rural aquaculture practice on Lake Victoria basin wetlands. Afr. J. Ecol. 45, 165–174. https://doi.org/10.1111/j.1365-2028.2006.00691.x.
Mwanja, W.W., Nyandat, B., 2013. Challenges and issues facing small-scale producers: perspectives from Eastern Africa, in: Bondad-Reantaso, M.G., Subasinghe, R.P. (Eds.), Enhancing the Contribution of Small-Scale Aquaculture to Food Security, Poverty Alleviation and Socio-Economic Development: Report and Proceedings of an Expert Workshop. FAO, pp. 107–115.
Namulawa, V.T., Mutiga, S., Musimbi, F., Akello, S., Ngángá, F., Kago, L., Kyallo, M., Harvey, J., Ghimire, S., 2020. Assessment of fungal contamination in fish feed from the Lake Victoria Basin, Uganda. Toxins (Basel) 12, 1–19. https://doi.org/10.3390/toxins12040233.
NELSAP/GiZ, 2020. Monograph for the Sango Bay Minziro (Tanzania - Uganda) Wetland landscape. NELSAP Technical Reports: Basin Development Series 2020 - 07.
Nicholson, S.E., 1998. Historical Fluctuations of Lake Victoria and Other Lakes in the Northern Rift Valley of East Africa. In: Lehman, J.T. (eds) Environmental Change and Response in East African Lakes. Monographiae Biologicae, vol 79. Springer, Dordrecht. doi: 10.1007/978-94-017-1437-2_2.
Njagi, D.M., Routh, J., Odhiambo, M., Luo, C., Basapuram, L.G., Olago, D., Klump, V., Stager, C., 2022. A century of human-induced environmental changes and the combined roles of nutrients and land use in Lake Victoria catchment on eutrophication. Sci. Total Environ. 835, 155425. https://doi.org/10.1016/j.scitotenv.2022.155425.
Njiru, J.M., Aura, C.M., Okechi, J.K., 2019. Cage fish culture in Lake Victoria: A boon or a disaster in waiting? Fish. Manag. Ecol. 26, 426–434. https://doi.org/10.1111/fme.12283.
Njiru, J.M., Knaap, M. Van Der, Nyamweya, C.S., Marshall, B.E., 2014. Management of Lake Victoria fishery : Are we looking for easy solutions ? Aquat. Ecosyst. Health. Manag. 17, 70–79. doi: 10.1080/14634988.2014.881220.
Njiru, M., Nyamweya, C., Gichuki, J., Mugidde, R., Mkumbo, O., Witte, F., 2012. Increase in anoxia in Lake Victoria and its effects on the fishery, In: Padilla, P. (Ed.). Anoxia. InTechOpen. https://doi.org/10.5772/27461.
Ntiba, M.J., Kudoja, W.M., Mukasa, C.T., 2001. Management issues in the Lake Victoria watershed. Lakes Reservoirs: Sci. Policy Manage. Sustain. Use 6, 211–216. https://doi.org/10.1046/j.1440-1770.2001.00149.x.
Nyamweya, C.S., Sturludottir, E., Tomasson, T., Taabu-Munyaho, A., Njiru, J.M., Stefansson, G., 2017. Prediction of Lake Victoria's response to varied fishing regimes using the Atlantis ecosystem model. Fish. Res. 194, 76–83. https://doi.org/10.1016/j.fishres.2017.05.014.
Nyamweya, C.S., Natugonza, V., Taabu-Munyaho, A., Aura, C.M., Njiru, J.M., Ongore, C., Mangeni-Sande, R., Kashindye, B.B., Odoli, C.O., Ogari, Z., Kayanda, R., 2020. A century of drastic change: Human-induced changes of Lake Victoria fisheries and ecology. Fish. Res. 230, 105564. https://doi.org/10.1016/j.fishres.2020.105564.
Nyamweya, C.S., Nyaboke, H.M., Aura, C.M., Momanyi, K.N., Mlaponi, E., Odoli, C.O., Njiru, J.M., 2022. Lake Victoria's bounty: A case for riparian countries' blue economic investment. Front. Environ. Sci. 10, 1–6. https://doi.org/10.3389/fenvs.2022.952654.
Nyamweya, C., Sturludottir, E., Tomasson, T., Fulton, E.A., Taabu-munyaho, A., Njiru, J.M., Stefansson, G., 2016. Exploring Lake Victoria ecosystem functioning using the Atlantis modeling framework. Environ. Model. Softw. 86, 158–167. https://doi.org/10.1016/j.envsoft.2016.09.019.
Nyboer, E.A., Musinguzi, L., Ogutu-Ohwayo, R., Natugonza, V., Cooke, S.J., Young, N., Chapman, L.J., 2022. Climate change adaptation and adaptive efficacy in the inland fisheries of the Lake Victoria basin. People and Nature 4 (5), 1319–1338.
Nyenje, P.M., Foppen, J.W., Uhlenbrook, S., Kulabako, R., Muwanga, A., 2010. Eutrophication and nutrient release in urban areas of sub-Saharan Africa — A review. Sci. Total Environ. 408, 447–455. https://doi.org/10.1016/j.scitotenv.2009.10.020.
Ochumba, P.B.O., 1987. Periodic massive fish kills in the Kenyan part of the Lake Victoria. Water Qual. Bull. 208, 93–99.
Ochumba, P.B.O., 1990. Massive fish kills within the Nyanza Gulf of Lake Victoria, Kenya. Hydrobiologia 208, 93–99. https://doi.org/10.1007/BF00008448.
Odada, E.O., Olago, D.O., Ochola, W.O. (Eds.), 2006. Environment for development: An ecosystems assessment of Lake Victoria Basin environmental and socio-economic status, trends and human vulnerabilities. United Nations Environment Programme/Pan African START Secretariat (UNEP/PASS), Nairobi, Kenya.
Odada, E.O., Ochola, W.O., Olago, D.O., 2009. Understanding future ecosystem changes in Lake Victoria basin using participatory local scenarios. Afr. J. Ecol. 47, 147–153. https://doi.org/10.1111/j.1365-2028.2008.01062.x.
Oguttu, H., Bugenyi, F.W.B., Leuenberger, H., Wolf, M., Bachofen, R., 2018. Pollution menacing Lake Victoria: Quantification of point sources around Jinja Town, Uganda. Water SA 34, 89. https://doi.org/10.4314/wsa.v34i1.180865.
Ogutu, J.O., Piepho, H.-P., Said, M.Y., Ojwang, G.O., Njino, L.W., Kifugo, S.C., Wargute, P.W., Paiva, S.R., 2016. Extreme wildlife declines and concurrent increase in livestock numbers in Kenya: what are the causes? PLoS One 11 (9), e0163249.
Okungu, J., Opango, P., 2005. Pollution loads into Lake Victoria from the Kenyan catchment, in: Mallya, G.A., Katagira, F.F., Kang'oha, G., Mbwana, S.B., Katunzi, E. F., Wambede, J.T., Azza, N., Wakwabi, E., Njoka, S.W., Kusewa, M., Busulwa, H. (Eds.), Knowledge and Experiences Gained from Managing the Lake Victoria Ecosystem. Regional Secretariat, Lake Victoria Environmental Management Project (LVEMP), Dar es Salaam, pp. 90–108.
Olokotum, M., Mitroi, V., Troussellier, M., Semyalo, R., Bernard, C., Montuelle, B., Okello, W., Quiblier, C., Humbert, J.-F., 2020. A review of the socioecological causes and consequences of cyanobacterial blooms in Lake Victoria. Harmful Algae 96, 101829. https://doi.org/10.1016/j.hal.2020.101829.
Ongeri, D.M.K., Lalah, J.O., Wandiga, S.O., Schramm, K.W., Michalke, B., 2009. Levels of toxic metals in multisectoral samples from Winam Gulf of Lake Victoria. Bull. Environ. Contam. Toxicol. 82, 64–69. https://doi.org/10.1007/s00128-008-9530-6.
Ongore, C.O., Aura, C.M., Ogari, Z., Njiru, J.M., Nyamweya, C.S., 2018. Spatial-temporal dynamics of water hyacinth, Eichhornia crassipes (Mart.) and other macrophytes and their impact on fisheries in Lake Victoria, Kenya. J. Great Lakes Res. 44, 1273–1280. https://doi.org/10.1016/j.jglr.2018.10.001.
Onyango, D.O., Opiyo, S.B., 2022. Detection of historical landscape changes in Lake Victoria Basin, Kenya, using remote sensing multi-spectral indices. Watershed Ecol. Environ. 4, 1–11. https://doi.org/10.1016/j.wsee.2021.12.001.
Opande, G.O., Onyango, J.C., Wagai, S.O., 2004. Lake victoria: The water hyacinth (*Eichhornia crassipes* [Mart.] Solms), its socio-economic effects, control measures and resurgence in the Winam Gulf. Limnologica 34, 105–109. https://doi.org/10.1016/S0075-9511(04)80028-8.
Opiyo, M.A., Marijani, E., Muendo, P., Odede, R., Leschen, W., Charo-Karisa, H., 2018. A review of aquaculture production and health management practices of farmed fish in Kenya. Int. J. Vet. Sci. Med. 6, 141–148. https://doi.org/10.1016/j.ijvsm.2018.07.001.
Osano, O., Nzyuko, D., Tole, M., Admiraal, W., 2003. The fate of Chloroacetanilide herbicides and their Degradation products in the Nzoia Basin, Kenya. AMBIO: J. Human Environ. 32, 424–427. https://doi.org/10.1579/0044-7447-32.6.424.
Osoro, E., Wandiga, S., Abongo, D., Madadi, O., Macharia, J., 2016. Organochlorine pesticides residues in water and sediment from Rusinga island, Lake Victoria, Kenya. IOSR J. Appl. Chem. 09, 56–63. https://doi.org/10.9790/5736-0909025663.
Ouma, Y.O., Shalaby, A., Tateishi, R., 2005. Dynamism and abundance of water hyacinth in the Winam Gulf of Lake Victoria: Evidence from remote sensing and

seasonal-climate data. Int. J. Environ. Stud. 62, 449–465. https://doi.org/10.1080/00207230500197011.

Outa, J.O., Kowenje, C.O., Avenant-Oldewage, A., Jirsa, F., 2020. Trace elements in crustaceans, mollusks and fish in the Kenyan part of Lake Victoria: Bioaccumulation, bioindication and health risk analysis. Arch. Environ. Contam. Toxicol. 78, 589–603. https://doi.org/10.1007/s00244-020-00715-0.

Perga, M., Frossard, V., Jenny, J., Alric, B., Arnaud, F., Berthon, V., Black, J.L., Domaizon, I., Giguet-covex, C., Kirkham, A., Magny, M., Manca, M., Marchetto, A., Millet, L., Paillès, C., Pignol, C., Poulenard, J., Reyss, J., Rimet, F., Sabatier, P., Savichtcheva, O., Sylvestre, F., Verneaux, V., 2015. High-resolution paleolimnology opens new management perspectives for lakes adaptation to climate warming. Front. Ecol. Evol. 3, 1–17. https://doi.org/10.3389/fevo.2015.00072.

Petty, C., Ngoleka, S., Cornforth, R., Achiro, E., Acidri, J., Ainslie, A., Owuor, J., Walker, G., 2022. Adaptation planning: An integrated approach to understanding vulnerability in the Lake Victoria Basin. Front. Climate 3. https://doi.org/10.3389/fclim.2021.782534.

Pietroiusti, R., Vanderkelen, I., Thiery, W., 2022. Was the 2020 Lake Victoria flooding linked to anthropogenic climate change? An event attribution study, in: EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022. Vienna.

Poste, A.E., Muir, D.C.G., Guildford, S.J., Hecky, R.E., 2015. Bioaccumulation and biomagnification of mercury in African lakes: The importance of trophic status. Sci. Total Environ. 506–507, 126–136. https://doi.org/10.1016/j.scitotenv.2014.10.094.

PRB, 2021. World Population Data Sheet.

Pringle, R.M., 2005. The origins of the Nile perch in Lake Victoria. Bioscience 55, 780–787. https://doi.org/10.1641/0006-3568(2005)055[0780:TOOTNP]2.0.CO;2.

Ribbe, N., Arinaitwe, K., Dadi, T., Friese, K., von Tümpling, W., 2021. Trace – element behaviour in sediments of Ugandan part of Lake Victoria : results from sequential extraction and chemometrical evaluation. Environ. Earth Sci. 80, 1–14. https://doi.org/10.1007/s12665-021-09554-1.

Rutaisire, J., Char-Karisa, C., Shoko, A., Nyandat, B., 2010. Aquaculture for increased fish production in East Africa. Afr. J. Trop. Hydrobiol. Fish. 12. https://doi.org/10.4314/ajthf.v12i1.57379.

Sayer, C.A., Máiz-Tomé, L., Akwany, L.O., Kishe-Machumu, M.A., Natugonza, V., Whitney, C.W., Omondi, R., Nshutiyayesu, S., Kabuye, C.S., 2018a. The importance of freshwater species to livelihoods in the Lake Victoria Basin. In: Freshwater Biodiversity in the Lake Victoria Basin: Guidance for Species Conservation, Site Protection, Climate Resilience and Sustainable Livelihoods. International Union for Conservation of Nature, Gland, pp. 136–151. https://doi.org/10.2305/IUCN.CH.2018.RA.2.en.

Sayer, C.A., Máiz-Tomé, L., Darwall, W.R.T., 2018b. Freshwater biodiversity in the Lake Victoria Basin: Guidance for species conservation, site protection, climate resilience and sustainable livelihoods. IUCN, Int. Union Conserv. Nature. https://doi.org/10.2305/IUCN.CH.2018.RA.2.en.

Scheren, P.A.G.M., Zanting, H.A., Lemmens, A.M.C., 2000. Estimation of water pollution sources in Lake Victoria, East Africa: Application and elaboration of the rapid assessment methodology. J. Environ. Manag. 58 (4), 235–248.

Shoko, A., Lamtane, H.A., Wetengere, K., Kajitanus, O.O., Msuya, F., Mmochi, A., Mgaya, Y., 2011. The status and development of aquaculture in Tanzania, East Africa. In: International Conference on Ecosystem Conservation and Sustainable Development (ECOCASD), pp. 85–97.

Sitoki, L., Gichuki, J., Ezekiel, C., Wanda, F., Mkumbo, O.C., Marshall, B.E., 2010. The environment of Lake Victoria (East Africa): current status and historical changes. Int. Rev. Hydrobiol. 95, 209–223. https://doi.org/10.1002/iroh.201011226.

Ssebugere, P., Sillanpää, M., Kiremire, B.T., Kasozi, G.N., Wang, P., Sojinu, S.O., Otieno, P.O., Zhu, N., Zhu, C., Zhang, H., Shang, H., Ren, D., Li, Y., Zhang, Q., Jiang, G., 2014. Polychlorinated biphenyls and hexachlorocyclohexanes in sediments and fish species from the Napoleon Gulf of Lake Victoria, Uganda. Sci. Total Environ. 481, 55–60. https://doi.org/10.1016/j.scitotenv.2014.02.039.

Ssegane, H., Tollner, E.W., Veverica, K., 2012. Geospatial modeling of site suitability for pond-based Tilapia and *Clarias* farming in Uganda. J. Appl. Aquac. 24, 147–169. https://doi.org/10.1080/10454438.2012.663695.

Stutzman, E., Molnar, J., Atukunda, G., Walakira, J., 2017. Understanding the role of fish farmer associations as intermediaries for the commercialization of aquaculture in Uganda. Fish. Aquac. J. 08. https://doi.org/10.4172/2150-3508.1000214.

The World Bank, 2016. Reviving Lake Victoria by restoring livelihoods. https://www.worldbank.org/en/news/feature/2016/02/29/reviving-lake-victoria-by-restoring-livelihoods [WWW Document].

Tibihika, P.D., Curto, M., Alemayehu, E., Waidbacher, H., Masembe, C., Akoll, P., Meimberg, H., 2020. Molecular genetic diversity and differentiation of Nile tilapia (*Oreochromis niloticus*, L. 1758) in East African natural and stocked populations. BMC Evol. Biol. 20, 1–20. https://doi.org/10.1186/s12862-020-1583-0.

UNEP, 2006. Lake Victoria Basin Environment Outlook: Environment and Development. UNEP, Nairobi.

Veldhuis, M.P., Ritchie, M.E., Ogutu, J.O., Morrison, T.A., Beale, C.M., Estes, A.B., Mwakilema, W., Ojwang, G.O., Parr, C.L., Probert, J., Wargute, P.W., Hopcraft, J.G. C., Olff, H., 2019. Cross-boundary human impacts compromise the Serengeti-Mara ecosystem. Science 1979 (363), 1424–1428. https://doi.org/10.1126/science.aav0564.

Verschuren, D., Johnson, T.C., Kling, H.J., Edgington, D.N., Leavitt, P.R., Brown, E.T., Talbot, M.R., Hecky, R.E., 2002. History and timing of human impact on Lake Victoria, East Africa. J. Royal Soc. 269 (1488), 289–294.

Walakira, J K Hang'ombe, B M Mugimba, K K Sserwada, M., Mwansa, S., Kakwasha, K., Chimatiro, S., 2018. Fish trade in Africa and its implication to aquatic biosecurity in the Great Lakes region, Sixth International Conference of the Pan African Fish and Fisheries Association (PAFFA6). PAFFA, Mangochi, Malawi.

Wasige, J.E., Groen, T.A., Smaling, E., Jetten, V., 2012. Monitoring basin-scale land cover changes in Kagera Basin of Lake Victoria using: Ancillary data and remote sensing. Int. J. Appl. Earth Obs. Geoinf. 21, 32–42. https://doi.org/10.1016/j.jag.2012.08.005.

Williams, A.E., Duthie, H.C., Hecky, R.E., 2005. Water hyacinth in Lake Victoria: Why did it vanish so quickly and will it return? Aquat. Bot. 81, 300–314. https://doi.org/10.1016/j.aquabot.2005.01.003.

Wilson, J.R.U., Ajuonu, O., Center, T.D., Hill, M.P., Julien, M.H., Katagira, F.F., Neuenschwander, P., Njoka, S.W., Ogwang, J., Reeder, R.H., Van, T., 2007. The decline of water hyacinth on Lake Victoria was due to biological control by Neochetina spp. Aquat. Bot. 87, 90–93. https://doi.org/10.1016/j.aquabot.2006.06.006.

Witte, F., Wanink, J.H.H., Ligtvoet, W., Van Oijen, M.J.P.J.P., Goldschmidt, T., Goudswaard, P.C.C., Ligtvoet, W., Van Oijen, M.J.P.J.P., Wanink, J.H.H., Ligtvoet, W., Van Oijen, M.J.P.J.P., Goldschmidt, T., Goudswaard, P.C.C., Goldschimidt, T., Goudswaard, P.C.C., Ligtvoet, W., Oijen, M.J.P.V., Wanink, J.H.H., Ligtvoet, W., Van Oijen, M.J.P.J.P., Goldschmidt, T., Goudswaard, P.C.C., 1992. Species extinction and concomitant ecological changes in Lake Victoria. Netherlands J. Zool. 42, 214–232. https://doi.org/10.1163/156854291X00298.

World Agroforestry Centre, 2006. Improved Land Management in the Lake Victoria Basin: Final Report on the TransVic project. ICRAF Occasional Paper No. 7. Nairobi.

World Bank, 1996. Kenya, Tanzania, Uganda - Lake Victoria Environmental Management Project, in: World Development Sources, WDS 1996. World Bank, Washington, DC.