Journal of Great Lakes Research 49 (2023) 102223

Contents lists available at ScienceDirect

Journal of Great Lakes Research

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

Review

Lake Tanganyika: Status, challenges, and opportunities for research collaborations

Harris Phiri [a,*], Deo Mushagalusa [b], Cyprian Katongo [c], Claver Sibomana [d], Migeni Z. Ajode [e], Nshombo Muderhwa [b,f], Stephanie Smith [e], Gaspard Ntakimazi [d], Els L.R. De Keyzer [g,h], David Nahimana [d], Pascal Masilya Mulungula [b,j], Lloyd Haninga Haambiya [i], Pascal Mwapu Isumbisho [j,k], Peter Limbu [l], Ismael Aaron Kimirei [m], Nyakorema Beatrice Marwa [n], Ritha J. Mlingi [o], Aline Munundu Mangaza [b]

[a] Department of Fisheries, P.O. Box 350100, Chilanga, Zambia
[b] Department of Biology, Centre of Research on Hydrobiology (CRH), P.O. Box 73 Uvira, Sud-Kivu Province, Democratic Republic of Congo
[c] Department of Biological Sciences, University of Zambia, P.O. Box 32379, Lusaka, Zambia
[d] Center of Research in Natural Sciences and Environment, Faculty of Sciences, University of Burundi, PO Box 20700, Bujumbura, Burundi
[e] African Center for Aquatic Research and Education, 2200 Commonwealth Blvd., Ste. 100, Ann Arbor, MI, 48105, USA
[f] Université Officielle de Bukavu, UOB, B.P.570 Bukavu, Democratic Republic of Congo
[g] Evolutionary Ecology Group (EVECO), UAntwerpen, Campus Drie Eiken, Universiteitsplein 1, 2610 Wilrijk, Belgium
[h] Laboratory of Biodiversity and Evolutionary Genomics (LBEG), KU Leuven, Charles Deberiotstraat 32, 3000 Leuven, Belgium
[i] Frankfurt Zoological Society, Nsumbu Tanganyika Conservation Programme, Nsama, Zambia
[j] Unité d'Enseignement et de Recherche en Hydrobiologie Appliquée, Institut Supérieur Pédagogique de Bukavu, Bukavu, Democratic Republic of Congo
[k] Laboratoire d'Etude des Milieux Aquatiques, Kinshasa, Democratic Republic of Congo
[l] The Nature Conservancy, Mji Mwema, Plot No. 20. P. O. Box 894, Kigoma, Tanzania
[m] Tanzania Fisheries Research Institute, Box 9750, Dar es Salaam, Tanzania
[n] Lake Tanganyika Authority Secretariat, Kigobe Sud, Avenue des Etats Unis n 17 B.P 4910 Ngagara, Bujumbura, Burundi
[o] Regional Commissioner's Office –Kigoma, Box 125, Kigoma, Tanzania

ARTICLE INFO

Communicated by Robert E. Hecky

Keywords:
Tanganyika
Stressors
Freshwater biodiversity
Research priority
Scientific community
Management
Multi-disciplinary monitoring

ABSTRACT

Lake Tanganyika is one of the most important lakes in the world because it supports millions of people who rely on its resources and its exceptional biodiversity. However, the lake currently suffers from a range of anthropogenic stressors, including water pollution and sedimentation, resource, biodiversity decline, habitat loss (both physical and functional) and climate change. Past and current research has been limited and disparate, only allowing the scientific community to gather inadequate data required to make informed policy and management plans for this lake. Based on data and knowledge derived from scientific studies and field experiences by scientists and experts working in the Lake Tanganyika basin, this paper outlines past research, present gaps, and the opportunities for collaboration to generate scientific knowledge to inform positive policy and management strategies leading to the protection of Lake Tanganyika's ecological integrity. The results of this paper draw from independent short surveys, freshwater expert meetings, and formal and informal discussions carried out to identify and prioritize specific issues and threats that need to be addressed for the conservation of biodiversity and sustainable management of the Lake Tanganyika basin. After highlighting each issue or threat, the authors propose possible management interventions; the results of this work focus heavily on the need for enhanced specific research on many issues and a larger, multi-disciplinary, long-term monitoring program to collect comprehensive information on a host of variables that will ultimately assist relevant stakeholders and key agencies in addressing these issues and threats.

* Corresponding author.
E-mail address: harrisphr@live.com (H. Phiri).

https://doi.org/10.1016/j.jglr.2023.07.009
Received 2 May 2022; Accepted 18 July 2023
Available online 10 August 2023

Background and introduction

Geomorphology

Lake Tanganyika is located within the western branch of the East African Rift Valley. It is the longest, and second deepest, freshwater lake in the world and is shared by four riparian countries: Burundi (8%), the Democratic Republic of the Congo (DRC (45%)), Tanzania (41%) and Zambia (6%). Lake Tanganyika is confined by the mountainous walls of the rift valley (Bootsma and Hecky, 2003). It extends for 676 km in a general north–south direction and averages 50 km in width. The lake covers 32,900 km^2, with a shoreline of 1,828 km, a mean depth of 570 m and a maximum depth of 1,471 m in the southern basin in DRC (Fig. 1). This lake alone contains 18,880 km^3 of water, making it the largest freshwater reservoir in Africa (Bergonzini et al., 2015) and holds 1/6 of the world's surface freshwater reserve (Nkotagu, 2008) on which over 12 million inhabitants living in the 231,000 km^2 of its watershed catchment area depend for various uses (Bootsma and Hecky, 1993; Fermon, 2007; Nkotagu 2008; Fermon, 2007). The lake consists of three major basins, the Zongwe in the southern end, Kalemie in the middle, and Kigoma in the north part (Capart, 1949; Fig. 1). Each of the three basins arose separately with the central basin forming 9–12 million years ago, the northern basin forming 7–8 million years ago, and the southern basin 2–4 million years ago (Cohen et al., 1993a; Cohen et al., 1993b; Konings, 1998). Eight major districts of the four countries are established on Lake Tanganyika's shores. These include four cities (Uvira and Kalemie in DRC, Kigoma in Tanzania and Bujumbura in Burundi) and four towns (Baraka in DRC, Rumonge in Burundi, and Mpulungu and Nsama in Zambia).

Two major rivers flow into Lake Tanganyika, the Ruzizi River, entering the north of the lake from Lake Kivu, and the Malagarasi River, entering from the eastern side in Tanzania. There are also numerous smaller rivers and streams entering the lake whose lengths are limited by the steep mountains around the lake. The Malagarasi River is older than Lake Tanganyika and was likely a headwater of the Lualaba River, the main Congo River headstream (Scheffel and Wernet, 1980; Coulter, 1991; Kullander and Roberts, 2011). Lake Tanganyika has one major outflow, the Lukuga River, which empties into the Congo River drainage. Precipitation and evaporation play greater roles in lake water level than the rivers. At least 90% of the water influx is from rain falling on the lake's surface and at least 90% of the water loss is from direct evaporation (Dettman et al., 2005). The Lake Tanganyika region experiences two seasons; a dry season between May and September or October, and a rainy season for the rest of the year (Coulter, 1991). The dry season is characterized mainly by cool and strong monsoonal southeastern winds while the rainy season is characterized by warm and mildly northeastern monsoonal winds (Coulter, 1991).

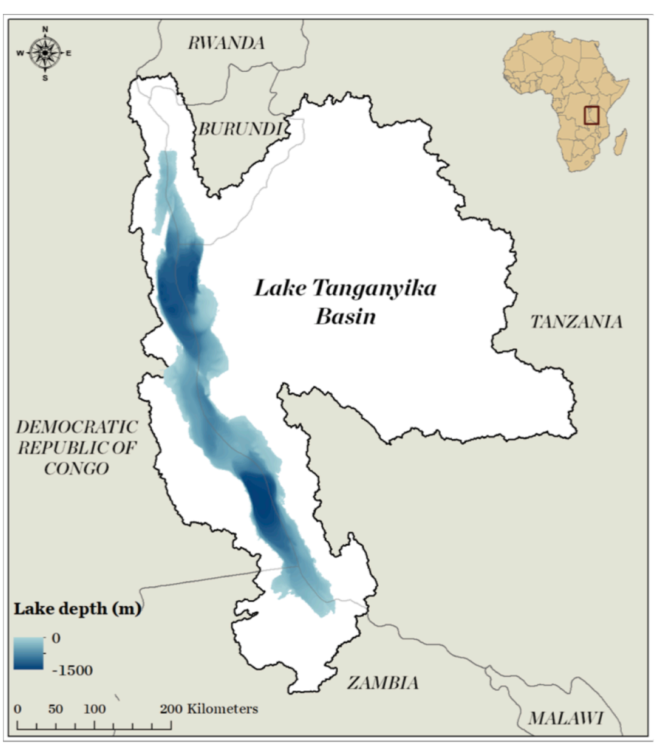

Fig. 1. Bathymetric and basin map of Lake Tanganyika.

Lake limnology and climate

Lake Tanganyika is classified as meromictic (Coulter, 1991), with well-marked thermal stratification which varies seasonally above a permanent anoxic hypolimnion. The lower depth limit of oxygen varies longitudinally with the thermocline depth from 50 to 100 m in the north to 240 m in the southern end. The strong south-easterly winds between July and September induce upwelling of nutrient-rich waters in the southern end of the lake, resulting in the mixing of the deep nutrient-rich waters with the upper nutrient-poor waters (Descy et al., 2006). These movements of nutrients along the water column are vital in maintaining the aquatic food web of the lake.

The lake's limnological characterization in part arises from seasonal meteorological changes and consequently will be impacted by global climate change in response to increasing average air temperature (see below for more details). It has been established that climate has an influence on the hydrodynamic, physicochemical, and biological parameters (in particular the plankton) and that all these phenomena are closely linked in Lake Tanganyika (Alleman et al., 2005; Bergamino et al., 2010; Capart, 1952; Descy et al., 2005). Climate warming increases the stability of the vertical stratification of the lake and decreases the depth of the mixing zone, decreasing exchanges between the different water layers of the lake and consequently resulting in a decrease in productivity in the pelagic zone (Nixon, 1988; Verburg et al., 2003; O'Reilly et al., 2003; Langenberg, 2008; Verburg and Hecky, 2009). This aspect could certainly have an impact on the ecosystem of macro- and *meso*-zooplankton as a source of food for pelagic fish (*Stolothrissa tanganicae, Limnothrissa miodon* and *Lates stappersii*) and also on the Lake Tanganyika aquatic environment as a whole (Descy et al., 2006, Descy et al., 2010).

Lake Tanganyika biodiversity

Lake Tanganyika is recognized internationally as a global hotspot of biodiversity, representing some of the most diverse aquatic ecosystems in the world (Groombridge and Jenkins, 1998; Salzburger et al., 2014). There is a wide diversity of aquatic habitats in the lake, including dense macrophytes (emergent and submerged), shallow nutrient- and sediment rich plateaus near river deltas, extensive beds of empty *Neothauma tanganyicense* shells, cobble stones, rocky habitats, stromatolite congregations and large muddy areas that extend to the deepest ends of the lake. These habitats support a remarkable diversity of species, which have formed complex interrelationships and depend on the integrity of the lake ecosystem for their productivity. Estimates suggest that the lake is home to over 2000 species of flora and fauna, of which 600 are endemic to the lake (Coulter, 1991; Snoeks, 2000). Fish endemism is estimated to be as high as 56% in non-cichlids and 98% in cichlids (Poll, 1953, 1956; Brichard, 1978), and these figures seem to indicate that the speciation of the aquatic organisms has progressed in the lake during various long periods of isolation. The lake is unique in harboring endemic species clusters of bagrids, cyprinids, mastacembelids and mochokids (Coulter, 1991; Vreven, 2005; Day and Wilkinson, 2006) with at least 250 colorful and morphologically diverse cichlid fish species and 150 species of non-cichlid fish most of which live along the shores down to about 180 m depth in the southern part of the lake. Moreover, a large diversity of endemic ostracods, gastropods, shrimp, crabs (Wouters and Martens, 1994; West et al., 2003; Fryer, 2006; Marijnissen et al., 2009), as well as many other taxa can be found in Lake Tanganyika. Over 90% of the species diversity is found in the littoral and coastal areas of the lake.

Terrestrial biodiversity

The Lake Tanganyika basin is not only renowned for its aquatic biodiversity, but also its terrestrial diversity and scenic beauty. Both the Rusizi River Reserve in Burundi and the Malagarasi-Muyovozi wetlands in Tanzania are included in the Ramsar List of internationally important wetlands, harboring a wide diversity of birdlife and other animals such as crocodiles and the hippopotamus. The basin contains several forest reserves and national parks including Kigwena Forest Reserve in Burundi, Kabobo and Ngandja Natural Reserves in DRC, Gombe Stream, Katavi and Mahale Mountains National Parks in Tanzania, and Nsumbu National Park in Zambia. Gombe and Mahale have become famous as some of the few remaining habitats for chimpanzees, whereas Nsumbu is known for its rare blue duiker and the swamp dwelling sitatunga.

Habitat surveys conducted by Allison et al (2000) established that the areas adjacent to the existing terrestrial protected areas, whether they are currently protected as aquatic zones or not, contain the full range of littoral habitat types, including emergent and submerged macrophytes, stromatolite reefs, shell beds and many combinations of soft and hard substrates. These do not necessarily provide the only or best examples of such habitat types, but have the advantage of existing conservation focus and tend to be richer in biodiversity than the open areas (Table 1). Thus, the current protected areas fulfill the fundamental criterion for a protected area network that should contain good examples of diverse habitat types (and by inference the associated ecological benefits and socio-economic values) (Roberts et al, 2003; Botsford et al, 2003).

Lake Tanganyika fisheries

a) Fleet and catch

Lake Tanganyika has one of the largest inland fisheries in Africa, second in production after Lake Victoria (Hanek, 1994; Mannini et al., 1997; Reynolds, 1999). Lake Tanganyika has two overlapping fisheries, the nearshore (littoral zone) fisheries and the offshore (pelagic zone) fisheries. The largest fish biomass is found in the pelagic zone and is dominated by six species, namely, *Stolothrissa tanganicae, Limnothrissa miodon, Lates stappersii, L. angustifrons, L. mariae, and L. microlepis*. The major commercial fish stocks of the lake, *L. miodon, S. tanganicae* and *L. stappersii,* represent 98% of the total landings (by mass) of the offshore fisheries (Roest, 1992; Mölsä et al., 1999; Phiri and Shirakihara, 1999; LTA Secretariat, 2012). In 2011, the total annual fish production from the lake was estimated between 110,000 and 120,000 tonnes (LTA Secretariat, 2012). The most recent official annual catch estimates were less than 100,000 tonnes against 150,000–200,000 tonnes three decades ago (Mölsä et al., 1999; Sarvala et al., 2006; Van der Knaap, 2013).

The offshore fishery supports significant commercial activities and is of popular socio-economic interest as a vital protein source and income for the over 12 million people living in the catchment area (Hecky et al., 1981; Coulter, 1991; Roest, 1992; Aro and Mannini, 1995; LTA Secretariat, 2012; Van der Knaap et al., 2014). From the 1970 s to the 1980 s, three fisheries, the traditional, artisanal, and industrial were operational on the lake. At present the industrial fishery has completely ceased due to declining catches and competition from the artisanal fishery. The artisanal fishery is now the main commercial fishery, with the total number of people involved along the value chain estimated at 159,318 (Van der Knaap et al., 2014). Women make up an estimated 40% of the total number of operators in the fisheries sub-sector. In Burundi, DRC, and Tanzania, the artisanal fishery is composed of two types of fishing units: wooden catamarans and trimarans/apollos with 6–10 fishers respectively, that use lift nets and attract fish with light (Coenen, 1994; Coenen, and Nikomeze, 1994). In Zambia, the main fishing units consist of planked boats and seine nets supported by light boats. Fishing is done at night since most of the methods used are based on the attraction of the fish by light; this applies to lift net fishing, ring net fishing, or encircling drift net fishing. As shown in a lake-wide frame survey (LTA Secretariat, 2012), the number of fishers and active fishing boats almost doubled between 1995 and 2011 in Lake Tanganyika (Table 2) whereas catch declines were accordingly reported during the same period (LTA Secretariat, 2012; Mushagalusa et al., 2014; Van der Knaap et al., 2014).

b) State of the Fishery

Commercial fishing on Lake Tanganyika commenced in the 1960 s, targeting two distinct commercial fisheries; the inshore and pelagic (Coulter, 1991). These fisheries mainly targeted the big *Lates* species and

Table 1
Survey areas with rank order of richness in fish species, genera and families (uncorrected for differences in sampling intensity) (Allison et al., 2000). The table gives the total number of fish species, genera and families recorded in each survey area, as well as placing those sites in rank order according to the level of representation at each taxonomic level. Mahale (Tanzania) is clearly the richest area at all levels for fish with markedly fewer species being recorded at the next richest areas, which for the most part are also areas adjacent to existing national parks. In general, high species diversity is mirrored by high diversity at genus and family level. The exception is the Lufubu and Chisala River mouths (Zambia), which recorded 40% fewer species than Mahale but the same number of families (Allison et al., 2000).

Country	Survey area	Species		Genera		Family	
		Total	Rank	Total	Rank	Total	Rank
Burundi	Ruzizi NP	80	5=	48	4	9	4=
	Bujumbura Bay	44	14	34	12	7	10=
	Gitaza	62	10	39	10	7	10=
	Burundi South	80	5=	43	5=	8	7=
DR Congo	Uvira area	71	9	42	7=	8	7=
	Pemba/Bangwe/Luhanga	82	4	40	9	8	7=
Tanzania	Gombe NP	94	2	49	3	9	4=
	Kigoma Area	38	16	26	15	5	14=
	Mahale NP	128	1	54	1	11	1=
Zambia	Kalambo/Lunzua	50	13	34	12=	6	13
	Chikonde	43	15	25	16	5	14=
	Mpulungu Area	62	10=	38	11	9	4=
	Lufubu/Chisala	75	7	43	5=	11=	1=
	Katoto/Kapembwa/Kasakalawe	74	8	42	7=	7	10=
	Nsumbu NP	91	3	51	2	11	1=
	Cameron Bay	54=	12	28	14	4	16

Table 2
Comparison of the results of the 1995 and 2011 regional frame surveys (LTA, 2012).

Country	Burundi		DR Congo		Tanzania		Zambia		Total		% Change
	1995	2011	1995	2011	1995	2011	1995	2011	1995	2011	
No. landing sites	54	44	417	304	208	239	107	96	786	683	−13
No of fishers	2021	8202	26,308	51,625	12,510	26,612	4118	8420	44,957	94,859	111
Active vessels	1063	2997	9439	16,202	3951	9977	1427	2320	15,880	31,496	98
No. fishers /active vessel	1.9	2.7	2.8	3.2	3.2	2.7	2.9	3.6	2.8	3.0	6
Catamaran units	680	264	1350	2169	1194	2525	0	5	3,224	4,963	54
Apollo units[a]	0	468	23	396	0	0	0	0	23	864	3657
Planked units	543	1485	4958	7962	2834	6319	1378	1615	9,713	17,381	79
Dugout units	46	28	2382	3039	577	515	46	3	3,051	3,585	18
Metallic units	96	0	1	0	1	0	86	0	184	0	−100
Other active units[b]	14	20	1018	30	234	9	85	683	1,351	742	−45
Non active vessels	345	239	757	2179	911	1290	250	264	2,263	3,972	76
Transport vessels	29	NA	464	NA	22	NA	82	NA	597	NA	NA
Total vessels	1,408	3,236	10,196	18,381	4,862	11,267	1,677	2,584	18,143	35,468	95

[a] An Apollo is a type of Catamaran, consisting of two or three canoes and operating a larger lift net with 8 pulleys and have engines exceeding 40 HP; they are operated in Burundi and DR Congo. Apollo-type craft are not commonly used in Tanzania, although fishing craft similar to Apollos (in terms of size) are operating in Tanzania.
[b] Active vessels refers to those vessels that are actively involved in fishing.

the clupeids using gillnets and the beach seines respectively. In the 1970 s with the *Lates stappersii* fishery emerging, there was proliferation of fishing vessels and gears resulting in the introduction of diverse seine nets and lift nets. Lake Tanganyika fisheries are currently characterized by excess fishing pressure and low catch per unit of effort. These changes in the fisheries have resulted in many studies being conducted on the pelagic stocks of the lake which make up the main commercial fish resource on the lake (Coulter, 1970, 1977, 1991; Chapman, 1976; Chapman and Van Well, 1978; Mulimbwa and Shirakihara, 1994; Pearce, 1995; Tshibangu and Kinoshita, 1995; Phiri and Shirakihara, 1999; Kimirei and Mgaya, 2007; Kimirei et al., 2008).

Despite the relatively numerous studies conducted on Lake Tanganyika's fish stocks, there is no comprehensive understanding of the whole lake's fisheries because most studies were either at country-level or did not cover a wide-enough scope to influence the lake-wide management of the fisheries. For example, the migratory patterns and extent of *Lates stappersii* have, to date, not been clearly documented, although it is generally accepted that the species migrates and the stock is shared by the four riparian countries, as has been shown for the clupeid *S. tanganicae* (De Keyzer et al., 2019). Adding to the uncertainty of fish stocks and migratory patterns, the last lake-wide hydroacoustic survey was conducted in 1974 (Coulter, 1991). Recently there have been calls to conduct a lake-wide hydroacoustic survey for the pelagic stocks, but due to limited funds this has not been possible. Therefore, most of the information on the state of the pelagic fisheries resources is based on catch landing statistics, catch assessment surveys, frame surveys, and local knowledge of fishing communities and fisheries practitioners (De Keyzer et al., 2020; Marwa, Pers. Comm.). The conduct of these surveys is not consistent both in frequency and method, making it impossible to analyse the catch and effort statistics over a long period. Lake-wide hydroacoustic studies are important to better understand the occurrence and distribution of fish species, and the impact of fishing on the pelagic stocks of Lake Tanganyika. Furthermore, bio-economic surveys would help fisheries managers to better understand current open-access practices of fisheries harvest and enable potentially more sustainable practices of fisheries exploitation.

Post-harvest handling and marketing

The shoreline of Lake Tanganyika has many fish landing sites that constitute the first level of fish transactions. Most of the fish catches on the lake are dried (65%) and smoked by the fishermen themselves. Fish processing is artisanal and rudimentary. Clupeids (*L. miodon* and *S. tanganicae*), are the main species processed through drying on the sand. In some cases, the fish are dried on racks or tarpaulins, which increases the quality of the finished product and add value by about 25%, and decreases losses through breakage. Fish drying encounters serious problems during the rainy season due to decreased drying conditions and lack of storage facilities. Smoking mainly involves *Lates* and some large-sized fish of littoral cichlids, and the methods used are rudimentary and consume a lot of wood. The fish is mainly sold fresh in areas located near the production centers because of the low electricity coverage of the area. Inland, the products are marketed mainly as dried and smoked fish, except in Zambia and Burundi where the marketing of fresh fish is considerably higher due to acceptable freezing facilities and relatively good roads. Generally, dried or smoked fish account for over 80% of the total produce of Lake Tanganyika. Moreover, intra-regional fish trade is facilitated by lake transport (LTA Secretariat, 2012).

Environment and population

Lake Tanganyika provides essential sources of livelihood and income opportunities to the growing human population, estimated to be over 12 million living within its basin with the annual growth rate between 2.9 and 3.1% (Table 3) in the riparian countries (Odada et al., 2004). These populations depend directly and indirectly on the lake's resources. For example, fish from the lake are estimated to account for up to 40 percent of total protein supply in the region, but per capita fish supplies are steadily declining because of increasing human populations leading to continuous high pressure on fisheries resources. The lake also provides other socio-economic services such as a permanent source of drinking water, and water for domestic use, as well as industrial and agricultural development.

Table 3
Socioeconomic Statistics for Lake Tanganyika Riparian Nations ().

Item	Burundi	DR Congo	Tanzania	Zambia
Population growth rate (%/year)	3.1	3.2	3.0	2.9
Population density (person/km^2)	422.5	21	36	13
Adult literacy (%)	46	59	78	76
Per Capita (US$/year)	261	581	1122	1305
School enrolment (% of school age population)	51	78	67	89
Life expectancy (years)	61	60	65	63
Percent of population without access to:				.
Safe water	48	32	34	62
Health services	20	NA	7	25
Sanitation	49	NA	14	29

Adapted from Odada et al. (2004)

The total number of fishermen operating on the lake is estimated at 94,886 and there are about 31,496 active boats, of which only a few (12%) have engines (Van der Knaap et al., 2014). Traditional and artisanal fishing units are manufactured locally by carpenters who possess the relevant skills. The fishermen are largely small-scale and artisanal in nature and therefore use a broad spectrum of fishing gear, including destructive gear (West, 2001). The state agencies responsible for issuing fishing licenses are not adequately equipped or staffed to effectively conduct their task; fisheries laws and rules are disparate due to unharmonized laws among the four riparian countries.

All four riparian countries of Lake Tanganyika have low levels of economic development, with average gross national incomes (GNIs) per capita of US$755 (World Bank, 2020b; World Bank, 2020a). Agriculture, livestock raising, processing of fish products, and mining are the main industries in the Lake Tanganyika basin. The lake plays a crucial role in travel and trading between riparian countries thus contributing to economic development of the African Great Lakes region. Poverty, overcrowding and lack of environmental education in some areas, combined with regional insecurity are the ultimate causes of destructive behaviors against the environment leading to the destruction of critical habitats in the Lake Tanganyika basin (West, 2001).

In an effort to address the various challenges faced by Lake Tanganyika, specifically those caused by disparate approaches of each of the four countries, the riparian states established the Lake Tanganyika Authority (LTA) through "the convention on the sustainable management of Lake Tanganyika''. The objective of the convention is to ensure the protection and conservation of the biological diversity and the sustainable use of the natural resources of Lake Tanganyika and its basin by the contracting states on the basis of integrated and co-operative management. In 2010, the LTA developed the Strategic Action Programme (SAP) for Sustainable Management of Lake Tanganyika and it was later reviewed in 2011. The SAP identified the intensification of human activities as the main driver of the threats to the biological richness of the Lake Tanganyika basin (LTA Secretariat, 2011).

Challenges facing the lake tanganyika basin ecosystem

The Lake Tanganyika ecosystem and the services it provides to the riparian communities are threatened by, among others, overexploitation of fish stocks; declining biodiversity; sedimentation caused by deforestation; informal settlements and unsustainable agricultural practices–especially on steep-sloping landscapes; indiscriminate dumping of urban sewage as well as mining and industrial wastewater; climate change; and nutrient pollution from agricultural lands and atmospheric deposition. These human induced threats are driven by activities of people who either do not understand the implications of their actions; or do not have any alternative option to their actions due to poverty; or do not realise the importance of environmental health. Collectively, these threats have detrimental consequences to the water quality of the lake and by extension to the survival of the unique endemic fish species flocks and other biodiversity, especially in the littoral habitats where species diversity is most spectacular. Below are the overall summaries of the threats to the Lake Tanganyika ecosystem.

Land use and habitat destruction

The Lake Tanganyika basin has witnessed increased development activities, which have led to increased demand for land and other natural resources within the ecosystem. Changes in anthropogenic land use have negatively impacted the environment and ecosystems (Alin et al., 2002). The shores of the lake feature a few densely inhabited population-centers, where anthropogenic impacts peak. In the littoral zones, where there is higher biodiversity on the lake, pollution, gravel and sand extraction, and increased sedimentation pose serious threats to aquatic plant and animal communities (Hori et al., 1993; Cohen et al., 1993a; Cohen et al., 1993b; Detenbeck et al., 1999; Allison et al., 2000).

Numerous studies have demonstrated the contribution of land-use change to erosion and sediment-loading patterns in lakes (Alin et al., 1999; Cisternas et al., 2001; Dearing et al., 1987; O'Hara et al., 1993). In their study, Alin et al. (2002) demonstrated the combined influence of land-use change and climate events on the ecology of Lake Tanganyika using paleorecords in a paired watershed approach. Similarly, another study in southern Lake Tanganyika concluded that there was a correlation between land clearance and levels of sediments from river discharge into the lake (Sichingabula, 1999). Both reports and a study by Britton et al., (2017) illustrated that the presence of protected areas such as national parks or forest reserves minimized habitat disruptions in the lake basin. However, there has not been any comprehensive monitoring of the land use changes that have taken place within the basin.

Unsustainable fisheries

Fisheries and related activities in the region around the lake support the livelihoods of millions of people and serve as a main source of animal protein and income. The increasing demand for fish for local consumption and for sale to distant markets has increased fishing pressure to the extent that the sustainability of the lake fisheries is threatened (LTA Secretariat, 2011). These problems affect both the commercial offshore fisheries and the artisanal activities of the near-shore fisheries. The unplanned settlements along the coast and the basin, the use of inappropriate fishing techniques and gear in prohibited sites, post-harvest losses, and outdated regulations and their weak application mean that the fish are becoming a declining commodity across the lake basin (Mushagalusa et al., 2020). The fish stocks, which are shared among the four riparian countries (De Keyzer et al., 2019), require harmonized and consistent management at all levels to mitigate the effects of unsustainable fishing practices and pressure. These approaches will require a consistent and harmonized data collection system in order to inform strategic interventions.

The riparian countries of Lake Tanganyika are implementing a number of measures to monitor and control fishing activities, which include mesh size restrictions, closed areas and seasons, observation of lunar breaks, licensing, and assessment of catches. However, due to inadequate resources, these measures are not effective and not regularly enforced. A holistic and inclusive management approach, which includes stakeholders in each of the four countries, needs to be implemented to effectively address these challenges.

On 16 December 2021, the Conference of Ministers of the LTA endorsed the Regional Charter on Sustainable Management of Fisheries as the regulatory tool with the harmonized specific management measures focusing on three commercial pelagic fish species of Lake Tanganyika and committing to enforcing its implementation (LTA Secretariat, 2021). The Charter was adopted and endorsed by the riparian states. However, the successful implementation of the Charter will require a robust monitoring regime in order to provide social and scientific evidence of progress at national and regional levels.

There are also national and international NGOs and agencies involved in the management of fisheries and protection of biodiversity, as well as providing advisory support to socio-professional organizations. These institutions have different competencies in environmental protection activities such as the development of catchment areas and community forestation, thereby complementing governments' efforts to manage the Lake Tanganyika basin albeit not adequate to reverse the trends for the moment.

Erosion and sedimentation

Deforestation has greatly accelerated erosion rates in the basin, leading to loss of nutrient-rich topsoil and sedimentation. Eroded sediments accumulate in the near-shore areas of the lake where habitats are altered and primary production is disturbed, negatively affecting aquatic species richness, densities and ecology. About 40% to 60% of lands that were originally forest areas in the central basin of the Lake, and nearly 100% in the northern basin, have been cleared. Most of these lands have been cleared for firewood, charcoal, slash-and-burn agriculture, or pasture. This has contributed to increased soil erosion and runoff of sediment into Lake Tanganyika (Azanga et al., 2016). Sedimentation affects breeding spots for fish, particularly the rocks on which eggs are laid. Deposition of sediment in the lake also increases turbidity, which reduces transparency and negatively affects photosynthetic rates for phytoplankton. Sedimentation further negatively impacts aquatic organisms by reducing the functioning of the environment, disturbing nutrient dynamics in the lake, and by physically harming aquatic fauna for example by blocking filtering apparatus (Cohen et al., 1993a; Cohen et al., 1993b) and nesting-sheltering systems of the benthic life.

Water pollution

Water pollution has been pinpointed as one of the main challenges for Lake Tanganyika (Nkotagu, 2008) and is exacerbated by human population growth (Nkurunziza, 1998). The surface waters of Lake Tanganyika are polluted by various harmful contaminants from diverse sources, such as the discharge of domestic wastewater (Kapepula et al., 2020), rapid industrialization, use of chemical pesticides and fertilizers in agriculture (Manirakiza et al., 2002), and erosion and sedimentation (Cohen et al., 1993a; Cohen et al., 1993b; Eggermont and Verschuren, 2003). Agricultural expansion has been accompanied by an increase in the use of agrochemicals such as artificial fertilizers, pesticides, and herbicides. In addition, domestic and industrial waste is increasingly causing pollution of ground and surface water in urbanized areas. Aquatic pollution causes biodiversity and habitat loss, reduced fish catches and increases human health problems. Further and detailed studies are needed regarding pollution origins and effects on the lake.

Beside the water pollution from wastewater and sedimentation, there is also pollution by plastics, mainly mineral water bottles and plastic bags. In the absence of a system of recycling and/or collection (reuse) of these plastics in the border towns of Lake Tanganyika in the four riparian countries, the lake becomes a public dumpsite, where all non-biodegradable waste ends up. There is evidence of negative effects of plastic ingestion on fishes under laboratory conditions (Azevedo-Santos et al., 2021). Plastics colonised by bacteria and algae in water produces odors that lead fish to involuntarily ingest them, and this may lead to bioaccumulation and amplification of microplastics in their muscles (Akhbarizadeh et al., 2018; Su et al., 2018; Bellasi et al., 2020; Gamarro Garrido et al., 2020). The contaminated fish is then consumed by humans, a phenomenon that has been highlighted in Lake Victoria (Khan and Biginagwa, 2018) and that deserves to be investigated in Lake Tanganyika. Additionally, plastic bags whose lifespan is at least 400 years blanket the substrate of the lake, reducing their natural functions of supporting the living communities of the lake (https://goecopure.com/plastic-waste-impacts/).

Biological invasions

Invasive species pose a serious threat to the biodiversity and productivity of the Lake Tanganyika basin. Several invasive plants and fish have already been identified, and there is real concern about the likely introduction of additional invasive species in the basin, either as a result of lack of awareness or deliberate introduction (e.g., through aquaculture). Some invasive freshwater fishes are known to readily hybridize with indigenous congeneric species, driving loss of unique and irreplaceable genetic resources. Between 2013 and 2016, it was revealed that newly discovered evolutionarily significant populations of Korogwe tilapia (*Oreochromis korogwe*) from southern Tanzania are threatened by hybridization with the larger invasive Nile tilapia (*Oreochromis niloticus*). These studies also provide genetic evidence of *O. korogwe-niloticus* hybrids in three southern lakes and demonstrate heterogeneity in the extent of admixture across the genome (Blackwell et al., 2021). Thus, these newly discovered and phenotypically unique cichlid populations are already threatened by hybridization which may result in the loss of the species. Furthermore, there are unconfirmed reports of some sightings of hybrids between *Oreochromis tanganicae* and *O. niloticus* in Zambia (Mpulungu town) and the north of DRC. Cage aquaculture was introduced in Mpulungu, Zambia in 2014, and there are plans to introduce the same on the Tanzanian side of the lake. This poses a high risk of local eutrophication and possibly introduction of alien species. It will be necessary to closely monitor such developments around the lake using a lake-wide framework, preferably through the LTA.

The water hyacinth (*Eichhornia crassipes*) is present and invasive in wetlands and swampy shorelines around Bujumbura and other parts of the Burundi and DRC (Uvira) shorelines of Lake Tanganyika. This is an invasive plant which was introduced in the late 1990 s and has spread widely to the detriment of other aquatic plants and animals (including fish), and people. There are no records of invasion of the lakeshores by this introduced plant species in Tanzania and Zambia, but this water weed is present in other water bodies of all the four riparian countries – as well as in upland wetlands and lakes in Burundi and Rwanda. *E. crassipes* is capable of spreading across the lake and to establish in suitable sites, but does not seem to have done so yet (IUCN, 2012). Increased spread of the weed has the potential to result in the loss of critical fish habitats thereby resulting in reduced productivity in the littoral zone of the lake. Ballast water discharges from the ships across the lake is a potential pathway for the spread of the water hyacinth.

A comprehensive mapping of high-risk areas prone to alien species' invasions in the Lake Tanganyika basin to identify potential hot spots and thus create an effective early warning system is a necessity. This will help in the development of management strategies and avoid unnecessary introductions in the region.

Biodiversity decline and habitat modification

A wide diversity of aquatic habitats (e.g., river mouths and deltas, empty shell beds, cobble stones, rocky habitats and crevices, sandy and muddy areas) in Lake Tanganyika support a remarkable diversity of species which have formed complex interrelationships and depend on the integrity of the lake ecosystem for their productivity. Unsustainable anthropogenic land use negatively impacts the lake's environment and ecosystem. The shores of the lake feature a few densely inhabited human population-centres, where anthropogenic impacts peak. Soil erosion, sediment transport and runoff of pesticides used for agriculture have also been identified as sources of pollution that may seriously affect the lake's biodiversity. Increased rate of conversion of forests to agricultural land is a threat to biodiversity in the lake's basin. Vital habitats for wildlife have disappeared in large parts of the basin and only few relatively pristine areas remain. Sediments impact negatively on primary productivity by reducing light penetration and thereby affecting the trophic system and destroying habitats of aquatic species.

Recent initiatives for oil exploitation are progressing in the East African Great Lakes region, posing substantial threats to the lakes and their fauna and flora as well as to fisheries production and clean water provision. In 2013, for example, six of the top-ten global discoveries of hydrocarbon deposits were made in this part of Africa (Davison et al, 2014). All countries in the area have developed plans to open exploration blocks, and in some cases competitive bidding for these blocks is ongoing in Rift Valley lakes. An oil spill in these lakes would be a global catastrophe for biodiversity. An eventual accident might deal a final blow to these ecosystems that have already been rendered fragile by anthropogenic and environmental stressors such as overfishing, deforestation, and global warming (Verheyen et al., 2016).

Climate change

Global lake warming results in additional pressure on the terrestrial and aquatic ecosystems and has the potential to cause significant degradation to the environment. Hulme et al (2001) predicted an increase of 1.3–1.7 °C in mean air temperature in the Great Lakes region of East Africa. The Lake Tanganyika ecosystem has warmed over the last century in response to climate change (Kraemer et al., 2015; Plisnier et al., 2018), which has resulted, globally, in an increase in the average air temperature. Temperatures have increased by 0.2 °C at 1000 m in depth since 1913, while water surface temperatures have increased by about 1.3 °C (Verburg et al. 2003, Verburg and Hecky 2009) and at depth of 600 m, an increase of 0.31 °C has been recorded between 1938 and 2003 (Plisnier, 1997, 2000; O'Reilly et al., 2003; Verburg et al., 2003). Data of *in situ* temperature from the top 100 m of the water column demonstrated that long-term temperature trends in Lake Tanganyika depend strongly on depth, season, and latitude (Kraemer et al., 2015). There are many possible effects of global climate change on the ecosystem of Lake Tanganyika (Naithani et al., 2011). It has been suggested that any changes in the air temperature, wind speed, precipitation, and incoming solar radiation possibly induced by increasing greenhouse gasses and climate change will directly influence lakes and other water bodies. The influence can cause changes in the physical (water temperature, stratification and transparency), chemical (nutrient loading and oxygen) and biological (structure and functioning of the ecosystem) components of the Lake (Naithani et al., 2011; Cohen et al., 2016; Plisnier et al., 2018). If no actions are taken to address the growing negative effects of climate change, it is expected that socio-economic development will stall or reverse, and problems associated with poverty and food-shortages will increase. Ultimately, this could lead to increased conflicts over natural resources, resulting in further compromise of the social stability and security in the region.

Identifyiing research priorities

This paper was written by scientists who belong to the Lake Tanganyika–Science Advisory Group (LT–SAG), which was formed during the African Great Lakes Stakeholder Network Workshop held in Entebbe, Uganda in 2019. The LT–SAG is an independent group made up of freshwater experts knowledgeable about Lake Tanganyika and drawn from the four riparian countries. The LT–SAG also has advisors from other global institutions, including experts from the Netherlands, Switzerland, Belgium, Canada and the USA, and is administered and facilitated by the African Centre for Aquatic Research and Education (ACARE), which plays the role of secretariat for the LT-SAG. In preparing this paper, a core team of three experts was formed by the LT-SAG, while other members submitted their contributions to the core team for compilation.

Online survey

In November 2020, ACARE conducted a survey to determine the environmental, conservation and management challenges that members of LT–SAG, ACARE Board of Directors, and other stakeholders such as LTA, thought were the priorities that the Lake Tanganyika and global research community should focus on. The respondents were involved in an independent online 32-question survey that asked them to identify the most critical issues affecting the African Great Lakes on which they work, prioritize those issues and state how to address them. The survey included ten (10) thematic areas as follows: Disease; Oil/Petroleum Extraction; Invasive Species; Human Population Growth; Insufficient Skills and Knowledge; Biodiversity Decline; Climate Change; Fishery Health; Land Use/Habitat Destruction; and Pollution. The respondents were given a link to the survey and asked to pick any three (3) thematic areas that they thought were their top priorities and to rank them from 1 to 3. A total of ten (n = 10) survey respondents, all scientists/researchers, accepted to participate in the survey. Details of the questions are included in Electronic Supplementary Material (ESM) Appendix S1.

Results from this survey are summarized in Fig. 2 and are discussed in this paper in relation to the Lake Tanganyika Strategic Action Programme (LT–SAP). The top five (5) broad priority areas for research on Lake Tanganyika were: land use/habitat destruction, fishery health, pollution, biodiversity decline and climate change. It should be noted that many of the issues are interconnected and this was reflected in the survey responses. Therefore, the research priorities are informed by this preliminary survey notwithstanding the fact that only 10 scientists/researchers participated in the survey as mentioned above.

Literature review

The next step was a review of the literature on Lake Tanganyika that is relevant to the four priority areas. The core team of lead authors, all

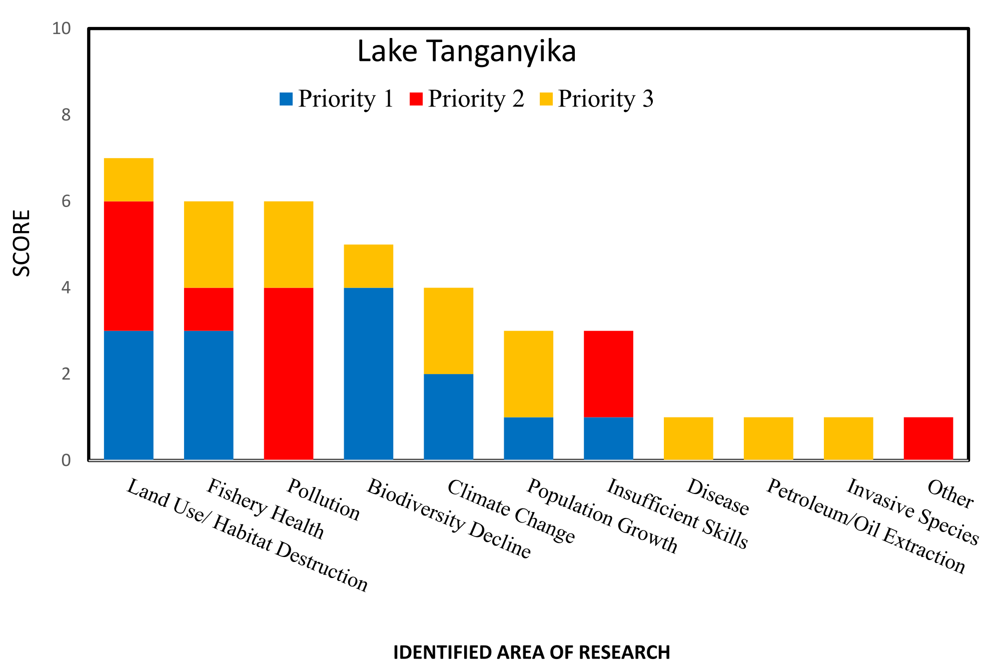

Fig. 2. Prioritization of issues to be addressed by research on Lake Tanganyika (N = 10).

contributing authors, made submissions. The review highlights the status quo of each priority area, identifies the challenges and proposes research activities that would address these challenges. What this means is there is a need to focus on understanding the causes and potential solutions for the issues listed since the survey responses noted that many of these issues are interconnected. There is still a need to deeply analyze how these problems are interconnected so that specific solutions can leverage each other to achieve more efficient and effective outcomes. In the sections below, we address the five top-ranked issues and priorities on Lake Tanganyika and give an overview of how strengthening these areas can help in making evidence-based decisions in the management of the basin.

Specific research priorities

Using data and knowledge derived from scientific studies and field experiences, the Lake Tanganyika SAP identified and prioritized threats and solutions for the conservation of the biodiversity and sustainable management of natural resources in the Lake Tanganyika basin. But, to adequately reflect the changes in magnitude and nature of threats to biodiversity and natural resources, the SAP requires regular updating by all stakeholders, including scientists. Based on the SAP, the authors' own investigations and information from literature, the following issues and priorities with adverse impacts on its biodiversity and natural resources need urgent attention in the short to medium term to preserve the ecological integrity of Lake Tanganyika and the development of its basin: (i) Land Use and Habitat Destruction, (ii) Fishery Health, (iii) Pollution, (iv) Biodiversity Decline and, (v) Climate Change. Table 4 summarises the identified issues and the suggested research priorities for Lake Tanganyika.

Land use and habitat destruction

Currently there is no comprehensive land use map for the Lake Tanganyika basin. Available land use maps only cover the part of Congo (Azanga et al., 2016). In order to fully understand the interaction among the various interests in the basin, a comprehensive basin-wide land use map will be of great value. This will help to identify and gazette critical habitats for aquatic and terrestrial flora and fauna conservation. The methods used in generating the map will include the use of GIS technologies, remote sensing, satellite imagery and any other technologies or methods that will be technically and financially feasible. Ground truthing could be conducted in some selected areas identified as biodiversity hotspots. The output of this activity could be a comprehensive basin-wide land use map indicating where the critical and vulnerable habitats (use zones) are located and their level of vulnerability in time and space. The land use mapping would be followed by the development of long-term multidisciplinary monitoring studies or projects on land-use practices (soil occupation, fishing activities, urban expansion and related activities) to track their impact on the aquatic and terrestrial ecosystems of the Lake Tanganyika basin. The results from these studies could better inform the integrated management plans for the basin and contribute to the improvement of critical aquatic and terrestrial habitats' protection, restoration and management and subsequently enhance integrated development planning within the Lake Tanganyika basin.

To halt the negative impacts of sedimentation resulting from deforestation, Allison et al. (2000) advanced some specific management practices that should be considered to reduce sedimentation in the lake basin:

- Manage tree cutting and initiate reforestation programmes. This should be undertaken and concentrated in the upstream section of the catchment where maximum erosion normally occurs and using appropriate tree species that do not result in the depletion of groundwater resources that sustain surface water flows during the dry season.
- Find the best use of the available soil, indicating the necessity of selecting the most suitable farming practices according to climate, soil, and the needs for the human population. For example, the practice of terraced farming on sloping lands on the hills along the lakeshore and rivers. This was recognized to have given good results of soil management elsewhere in other basins and should be evaluated in the Lake Tanganyika basin.
- Reduce or prevent stream bank cultivation where erosion can be severe.
- Find alternatives to charcoal as a source of energy.
- Impose stricter building regulations designed to reduce erosion by establishing minimum vegetation buffer zones (need for harmonization of legislations around the lake).

The application of these management methods requires either formulation or amendment of laws and legislation, and improved enforcement. Long-term monitoring and research on climate, soil erosion and sedimentation in the littoral areas and their implication on benthic biodiversity need to be prioritized on Lake Tanganyika. This must be combined with the studies on land-use, soil use and socio-demographic patterns in the basin.

These efforts, once implemented, should focus on the biodiversity and resource management in some key protected areas on each country's shoreline with the integration of local communities, and education and research agencies with the support of international financing agencies (e.g. World Bank, African Development Bank and European Union).

Fisheries health

There is a great uncertainty on the sustainability of the Lake Tanganyika pelagic fishery considering its high sensitivity to climate change, decreased primary production (Verburg et al., 2003) and possible overfishing (Sarvala et al., 2006) as well as the increasing vulnerability of the littoral zones to sedimentation, land use/habitat destruction, pollution and unsuitable fishing practices along the coasts. To effectively manage the fisheries, there will be a need to improve on the collection, collating and analysis of the pelagic fisheries information. Lake-wide survey data of fish stock and fisheries dynamics for at least five annual cycles will enable the government agencies to establish a harmonized long-term data collection approach in the four riparian countries.

Since the first ACARE meeting (Entebbe, November 2019) and through many other interactions, experts and scientists active in the four riparian countries (Center for Research in Hydrobiology-Uvira, University of Burundi, Department of Fisheries, Zambia, University of Zambia, Tanzania Fisheries Research Institute and LTA) and their colleagues from partner institutions have come together to develop a common vision for research on the lake. To sustain and to regularly apply research results and expert advice, there could be joint actions between all actors at the lake, especially lake managers, decision makers and fishers' communities to ensure that future generations will still have access to fish and other lake resources in a sustainable manner. The LTA will use the existing networking mechanisms within the riparian countries to promote dialogue between users, scientists and managers for better management and implementation of regulations and good fishing practices in order to accelerate the recovery of fish stocks in the lake.

Pollution

Although the main sources of pollution on Lake Tanganyika have been identified, waste production per habitat and per year, waste nature, collection, treatment and management, and immediate effects on

Table 4
Proposed plan for supporting and implementing the identified long-term priority research in the Lake Tanganyika Basin.

		Most Critical Aspects	Research Needed	Resources Required	Timeframe (Duration)	Missing information to inform good policy formulation and management	Recommended solutions to address the issue
1st issue	Land Use/ Habitat Destruction	Management of the whole Lake Tanganyika watershed	Regional Land use map Multidisciplinary research on soil occupation and related consequences Baseline study on land use regulations in the basin	Monitoring equipment; Capacity building for institutions and scientists; Financial and technical support	≫10 years	Updated land use map for the Lake Tanganyika basin	Develop basin-wide integrated management plan Find experts from the riparian countries to make a proposal in collaboration with LTA and submit to Partners for support Alternative fuels for cooking and space-efficient agriculture Develop ecosystem-based and collaborative management strategies
2nd Issue	Loss of Biodiversity	Information on critical habitats and related activities. Loss of biodiversity Sedimentation	Fishing activities and other land use practices Species inventory Identify biodiversity hotspots (Key Biodiversity Areas) Sediment load and budget of the catchement	Monitoring equipment; Capacity building for institutions and scientists; Financial and technical support	≫10 years	Information on critical habitats and related activities. Updated IUCN Red list for Lake Tanganyika Regional land use map	Develop species inventory monitoring tool Develop regional integrated management plan
3rd Issue	Fishery Health	Stock decline Inadequate and disparate data that does not ensure sustained investigations of the fisheries dynamics and their causes Overfishing High pressure on fisheries Governance and Management	Identification of spawning areas; estimation of effective population sizes (stocks-recruitments). Regular and harmonized Limnological surveys Regular and harmonized Catch Assessment Surveys Regular Frame Surveys Development of standard CAS programme Training for national researchers Understanding of fish migration patterns Governance for better management and better implementation of regulations	Remuneration for scientists; procurement of boats and fuels, and other consumables (tubes, ethanol, etc), and equipment (microscopes, etc) Hydro-acoustic survey equipment; Data storage portals at national and regional stations; training institutions and expertise; multi-disciplinary information necessary to study, understand and address legislation. A regional or international support to national research teams willing to conduct harmonized fish surveys.	≫10 years	Fisheries statistics (catch, number of fishermen, techniques used, Catch per unit effort) and biology of target species (population structure, feeding habits, spawning areas, life history traits) Systematic monitoring in the riparian countries Inventory of species on the lake Lake-wide fish stock assessment Updated biodiversity mapping on status of biodiversity and fisheries	Build national capacity to conduct appropriate research and finance research (Training in research and resource mobilization) Regular and consistent Catch Assessment surveys, frame surveys, fish biology investigations, stock assessments, fish migration studies and hydroacoustic surveys. Install a network in the frame of a long-term monitoring programme Conduct studies on the state of fisheries (inclusive of national research institutions) Mobilisation of resources (LTA to take lead)
4th Issue	Pollution	Domestic and industrial waste, and pollution around major towns on the lakeshore (Bujumbura, Kigoma, Uvira, Kalemie, Mpulungu) Biological Pollution and alien invasive species in the lake's basin	Pollution studies off the main cities on the lake (Bujumbura, Kigoma) by local centers of research. Regular monitoring of the status of invasive species in the lake and its basin Development of industrial and domestic	Laboratory space; water, soil and air quality monitoring equipment and related reagents; Remuneration for scientists;	≫10 years	1) Long-term series data on the amounts and composition of pollutants entering the lake;2) Data on the water quality (quality and quantity, dynamics) .	Development of regional proposal by national lead institutions (CRNSE in Burundi, TAFIRI in Tanzania, CRH in Congo and LTRU in Zambia) Develop better sewage systems (not leading into the lake) , communication with population about good waste management

(*continued on next page*)

Table 4 (*continued*)

		Most Critical Aspects	Research Needed	Resources Required	Timeframe (Duration)	Missing information to inform good policy formulation and management	Recommended solutions to address the issue
		Household and industrial waste management	waste management technologies				
5th Issue	Climate Change	Impact of climate change on the Tanganyika ecosystem Adaptation to Climate Change	Climate monitoring and modelling Synthesis and consolidation of country NAPAs	Weather monitoring equipment	≫10 years	Consistent climate monitoring data	Set up sustainable climate monitoring mechanism Develop early-warning systems Support the implementation of a basin-wide climate adaptation programmes (based on NAPAs) Develop ecosystem based adaptation plans

biodiversity are poorly investigated in the lake basin. Long-term research to understand these issues systematically will be useful for water management. Further studies based on the bio-accumulation or biomonitoring can help reveal the levels of this pollution using some indicator biota (e.g., eubacteria, algae, benthic macro-invertebrate, plankton, fish, etc.).

Biodiversity decline in the Lake Tanganyika basin

a) Terrestrial biodiversity

Considering the importance of terrestrial biodiversity in the Lake Tanganyika basin, it will be important to conduct an inventory of the terrestrial flora and fauna as well as design a feasible and consistent monitoring programme in order to establish their relationship with the anthropogenic activities and the variable climatic conditions. This will help to create a baseline that can be used for monitoring purposes in future terrestrial biodiversity surveys.

b) *Freshwater biodiversity*

Presently, fishing communities report the perceived historical decline in fisheries biodiversity of mainly the important commercial fish species. Their perceptions are based on their observation of the declining catches and population sizes of commercial fish species such as the *Lates* species (*L. stappersii, L. mariae, L. angustifrons* and *L. microlepis),* clupeid species *(S. tanganicae* and *L. miodon),* and large cichlid species among others, to levels that cannot withstand commercial fish exploitation or even for adequate food supply purposes. Lake Tanganyika is also known for having an ornamental fishery, exploiting and exporting fish species from genera such as *Altolamprologus*, *Cyprichromis*, *Eretmodus*, *Julidochromis*, *Lamprologus*, *Neolamprologus*, *Tropheus* and *Xenotilapia*, which are popular aquarium fish due to their bright colors and patterns, and interesting behaviors. However, in spite of the general acknowledgement of an existing ornamental fishery on the lake, there has been very limited information on its impact around the lake. The overall impact of human activities on the benthic fauna and their related macrophytes is hardly monitored as there seems to be no consistent records of these activities.

To establish the status of the lake's biodiversity, there will be a need to conduct a lake-wide habitat mapping and species inventory to establish a baseline, which will then be used to monitor the aquatic biodiversity of Lake Tanganyika basin.

Climate change

Overall, it is agreed that Climate change impacts on the trophic dynamics of lakes and oceans (Barange and Perry, 2009; Mohammed and Uraguchi, 2013). Although the effects of climate change observable in Lake Tanganyika basin do not all have immediate causes originating in its watershed, actions such as stopping deforestation, charcoal making and poor soil management (Alin et al., 2002; Donohue et al., 2003; Azanga et al., 2016) would contribute in some way to its mitigation. However, environmental monitoring of Lake Tanganyika is often lacking or not based on harmonised methods among the riparian countries (Plisnier et al., this issue). Long-term monitoring observations are essential to guide management measures to adapt to climate change and decrease, whenever possible, unfavourable human impact on the Lake Tanganyika environment. A regionally standardised long-term monitoring programme is therefore necessary for Lake Tanganyika. Setting up a long-term integrated monitoring programme is also a goal of the LTA as mandated by its member states and working in collaboration with various stakeholders including the LT–SAG and ACARE, The Nature Conservancy (TNC), United Nations Food and Agriculture Organization (FAO) and the European Union (EU). This initiative could also benefit from the Lake Tanganyika scientific drilling project, which will conduct drill-samplings with a view to test the response of African climate to fundamentally important reorganizations of the Earth System (Russell et al., 2020). The initiative will further contribute to the realization of a regional long-term climate information database as envisioned by Plisnier et al. (this issue). Ultimately, the national climate adaptation programmes of action in the riparian countries would benefit from data collected and synthesized through the research collaborations.

Conclusion

The Lake Tanganyika ecosystem is under threats from global and local environmental challenges including climatic change, water pollution, unsustainable fishing practices and biodiversity loss, driven largely by the rapid changes in land use and the ever-growing demand for the lake's resources. The present paper is a review of the scientific studies that have been conducted on Lake Tanganyika over the past seventy years. The paper has highlighted the important knowledge generated over the decades and the gaps that still need to be filled to adequately inform evidence-based management strategies. The last lake-wide research projects conducted on Lake Tanganyika, Lake Tanganyika Research (LTR) Project and the Lake Tanganyika Biodiversity Project (LTBP) of which findings need to be updated, considering the time lapse since their implementation. We therefore propose the establishment and implementation of a long-term, Regional Integrated Environmental Monitoring Programme (RIEMP) on Lake Tanganyika. This was first suggested in 2010 (Plisnier and Marijnissen, 2010) but has not been established to date. A long-term monitoring programme will be of utmost importance and will contribute to assessing changes in biodiversity as a function of environmental parameters. Subsequently, it will be useful to all stakeholders and assist in the protection of the lake's biodiversity and other natural resources. Future actions will require that substantial amounts of financial and human resources are mobilised under the coordination of the LTA Secretariat and national institutions, and that strong partnerships continue to be built with a range of international and national organisations. The governments of the riparian countries are expected to generate a substantial part of the funding for future SAP implementation, partly through innovative financing arrangements (e.g., use of economic instruments and incentives), and government allocation to the core budgets. An important priority will be the development of national institutions' capacity and investments into mainstream national and regional programmes on each of the issues and priorities affecting the ecological integrity of Lake Tanganyika. Both ACARE and LT–SAG in collaboration with stakeholder institutions in riparian countries must work together to establish a common baseline of facts and analysis of the problem in the form of a transboundary program to address Lake Tanganyika issues. That would facilitate prioritization of the most urgent interventions to enable the development of detailed proposals and/or measures to address identified priorities.

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.

Acknowledgements

This work was carried out by scientists active on Lake Tanganyika in the four riparian countries and grouped into the Lake Tanganyika Science Advisory Group with the support of African Center for Aquatic Research and Education staff. Our thanks to all those who contributed with information during the discussions and redaction phases of this work. We thank the authors and organisations who accepted to use their data in this study. We thank particularly Dr. Pierre-Denis Plisnier and Professor Ken Irvine for relevant comments and contributions during the internal revision of the manuscript and the three anonymous reviewers for helping us improve this manuscript. The map used in this paper was provided by The Nature Conservancy's Africa Program.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jglr.2023.07.009.

References

Akhbarizadeh, R., Moore, F., Keshavarzi, B., 2018. Investigating a probable relationship between microplastics and potentially toxic elements in fish muscles from northeast of Persian Gulf. Environ. Pollut. 232, 154–163.

Alin, S.R., Cohen, A.S., Bills, R., Gashagaza, M.M., Michel, E., Tiercelin, J.-J., Martens, K., Coveliers, P., Mboko, S.K., West, K., Soreghan, M., Kimbadi, S., Ntakimazi, G., 1999. Effects of landscape disturbance on animal communities in Lake Tanganyika, East Africa. Conservation Biology: The Journal of the Society for Conservation Biology 13 (5), 1017–1033.

Alin, S.R., O'Reilly, C.M., Cohen, A.S., Dettman, D.L., Palacios-Fest, M.R., McKee, B.A., 2002. Effects of land-use change on aquatic biodiversity: a view from the paleorecord at Lake Tanganyika. East Africa. Geology 30 (12), 1143–1146.

Alleman, L.Y., Cardinal, D., Cocquyt, C., Plisnier, P.-D., Descy, J.-P., Kimirei, I., Sinyinza, D., André, L., 2005. Silicon isotopic fractionation in Lake Tanganyika and its main tributaries. J. Great Lakes Res. 31 (4), 509–519.

Allison, E. H., Paley, R., Cowan, V. J., and West, K. (2000). Biodiversity assessment and conservation in Lake Tanganyika Bioss Final Technical Report. Lake Tanganyika Biodiversity Project (RAF/92/G32 (En)).

Aro, E. and P. Mannini (1995), Results of Fish Population Biology 1995 Studies on Lake Tanganyika during July 1993-June 1994. FAO/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/FIN—TD/38 (En): 104p.

Azanga, E., Majaliwa, M., Kansiime, F., Mushagalusa, N., Karume, K., Tenywa, M.M., 2016. Land-use and land cover, sediment and nutrient hotspot areas changes in Lake Tanganyika Basin. African Journal of Rural Development (AFJRD) 1 (1), 75–90.

Azevedo-Santos, V.M., Brito, M.F.G., Manoel, P.S., Perroca, J.F., Rodrigues-Filho, J.L., Paschoal, L.R.P., Gonçalves, G.R.L., Wolf, M.R., Blettler, M.C.M., Andrade, M.C., Nobile, A.B., Lima, F.P., Ruocco, A.M.C., Silva, C.V., Perbiche-Neves, G., Portinho, J. L., Giarrizzo, T., Arcifa, M.S., Pelicice, F.M., 2021. Plastic pollution: a focus on freshwater biodiversity. AMBIO A Journal of the Human Environment. Royal Swedish Academy 50 (7), 1313–1324.

Barange, M. and Perry, R.I. (2009). Physical and ecological impacts of climate change relevant to marine and inland capture fisheries and aquaculture. In K. Cochrane, C. De Young, D. Soto and T. Bahri (eds). Climate change implications for fisheries and aquaculture: overview of current scientific knowledge. FAO Fisheries and Aquaculture Technical Paper. No. 530. Rome, FAO. pp. 7–106.

Bellasi, A., Binda, G., Pozzi, A., Galafassi, S., Volta, P., Bettinetti, R., 2020. Microplastic contamination in freshwater environments: a review, focusing on interactions with sediments and benthic organisms. Environments 7 (4), 30.

Bergamino, N., Horion, S., Stenuite, S., Cornet, Y., Loiselle, S., Plisnier, P.-D., Descy, J.-P., 2010. Spatio-temporal dynamics of phytoplankton and primary production in Lake Tanganyika using a MODIS based bio-optical time series. Remote Sens. Environ. 114 (4), 772–780. https://doi.org/10.1016/j.rse.2009.11.013.

Bergonzini, L., Williamson, D., and Albergel, J. (2015). Planche 2 - L'hydrologie et la limnologie autour du lac Tanganyika. In: Atlas des Pays du Nord-Tanganyika. CAZENAVE-PIARROT A., NDAYIRUKIYE S., VALTON C. (coord.) - Atlas des Pays du Nord-Tanganyika. Marseille, IRD Éditions, 144 pages.

Blackwell, T., Ford, A.G.P., Ciezarek, A.G., Bradbeer, S.J., Gracida Juarez, C.A., Smith, A. M., Ngatunga, B.P., Shechonge, A., Tamatamah, R., Etherington, G., Haerty, W., Di Palma, F., Turner, G.F., Genner, M.J., 2021. Newly discovered cichlid fish biodiversity threatened by hybridization with non-native species. Mol. Ecol. 30 (4), 895–911.

Bootsma, H.A., Hecky, R.E., 1993. Conservation of the African great lakes: a limnological perspective. Conservation Biology: The Journal of the Society for Conservation Biology 7 (3), 644–656.

Bootsma, H.A., Hecky, R.E., 2003. A comparative introduction to the biology and limnology of the African Great Lakes. J. Great Lakes Res. 29, 3–18.

Botsford, L.W., Micheli, F., Hastings, A., 2003. Principles for the design of marine reserves. Ecol. Appl. 13 (sp1), 25–31.

Brichard, P., 1978. Fishes of Lake Tanganyika. Neptune City, N.J., USA.

Britton, A.W., Day, J.J., Doble, C.J., Ngatunga, B.P., Kemp, K.M., Carbone, C., Murrell, D. J., 2017. Terrestrial-focused protected areas are effective for conservation of freshwater fish diversity in Lake Tanganyika. Biol. Conserv. 212, 120–129.

Capart, A., 1952. Exploration hydrobiologique du lac Tanganika, 1946–1947: résultats scientifiques. Le milieu géographique et géophysique, Institut royal des sciences naturelles de Belgique.

A. Capart Sondages et carte bathymétrique. Institut royal des sciences naturelles de Belgique 1949.

Chapman, D.W., 1976. Acoustic estimates of pelagic ichthyomass in Lake Tanganyika with an inexpensive echo sounder. Trans. Am. Fish. Soc. 105 (5), 581–587.

Chapman, D.W., Van Well, P., 1978. Observations on the biology of *Luciolates stappersi* in Lake Tanganyika (Tanzania). Trans. Am. Fish. Soc. 107 (4), 567–573.

Cisternas, M., Araneda, A., Martinez, P., Perez, S., 2001. Effects of historical land use on sediment yield from a lacustrine watershed in central Chile. Earth Surf. Proc. Land. 26 (1), 63–76.

Coenen, and Nikomeze. (1994). Lake Tanganyika Catch assessment surveys, Burundi, 1992-93. LTR Newsletter.

Coenen., 1994. Lake Tanganyika fisheries: an update. LTR Newsletter.

Cohen, A.S., Bills, R., Cocquyt, C.Z., Caljon, A.G., 1993a. The impact of sediment pollution on biodiversity in Lake Tanganyika. Conservation Biology: The Journal of the Society for Conservation Biology 7 (3), 667–677.

Cohen, A.S., Soreghan, M.J., Scholz, C.A., 1993b. Estimating the age of formation of lakes: an example from Lake Tanganyika. East African Rift system. Geology 21 (6), 511–514.

Cohen, A.S., Gergurich, E.L., Kraemer, B.M., McGlue, M.M., McIntyre, P.B., Russell, J.M., Simmons, J.D., Swarzenski, P.W., 2016. Climate warming reduces fish production and benthic habitat in Lake Tanganyika, one of the most biodiverse freshwater ecosystems. PNAS 113 (34), 9563–9568.

Coulter, G.W., 1970. Population changes within a group of fish species in Lake Tanganyika following their exploitation. J. Fish Biol. 2 (4), 329–353.

Coulter, G.W., 1977. Approaches to estimating fish biomass and potential yield in Lake Tanganyika. J. Fish Biol. 11 (5), 393–408.

Coulter, G. W. (1991). Lake Tanganyika and its life. With contributions from J.J. Tiercelin, A.Mondeguer, R.H. Spigel and R.E. Hecky (G. W. Coulter (ed.); p. 3). Oxford university press and British Museum (Natural History).

Davison, I., Steel, I., Taylor, M., Beirne, E.O., Faull, T., 2014. Exploration in the East African rift system. GeoExPro 11(5):26–31. http://www.geoexpro.com/ articles/2014/11/exploration-in-the-east-african-rift-system.

Day, J.J., Wilkinson, M., 2006. On the origin of the *Synodontis* catfish species flock from Lake Tanganyika. Biol. Lett. 2 (4), 548–552.

De Keyzer, E.L.R., De Corte, Z., Van Steenberge, M., Raeymaekers, J.A.M., Calboli, F.C.F., Kmentová, N., Mulimbwa, T.N., Virgilio, M., Vangestel, C., Masilya, P., Volckaert, F.A.M., Vanhove, M.P., 2019. First genomic study on Lake Tanganyika sprat *Stolothrissa tanganicae*: a lack of population structure calls for integrated management of this important fisheries target species. BMC Evol. Biol. 19 (6), 1–15. https://doi.org/10.1186/s12862-018-1325-8.

De Keyzer, E.L.R., Masilya Mulungula, P., Alunga Lufungula, G., Amisi Manala, C., Andema Muniali, A., Bashengezi Cibuhira, P., Bashonga Bishobibiri, A., Bashonga Rafiki, A., Hyangya Lwikitcha, B., Hugé, J., Itulamya, C., Huyghe, C.E.T., Itulamya Kitungano, C., Janssens de Bisthoven, L., Kakogozo Bombi, J., Kamakune Sabiti, S., Kiriza Katagata, I., Kwibe Assani, D., Lubunga Dunia, P., Lumami Kapepula, V., Lwacha, F., Mazambi Lutete, J., Shema Muhemura, F., Milec, L.J.M., Milenge Kamalebo, H., Mulimbwa N'Sibula, T., Mushagalusa Mulega, A., Muterezi Bukinga, F., Muzumani Risasi, D., Mwenyemali Banamwezi, D., Kahindo N'djungu, J., Nabintu Bugabanda, N., Ntakobajira Karani, J.-P., Raeymaekers, J.A.M., Riziki Walumona, J., Safari Rukahusa, R., Vanhove, M.P.M., Volckaert, F.A.M., Wembo Ndeo, O., Van Steenberge, M., 2020. Local perceptions on the state of the pelagic fisheries and fisheries management in Uvira, Lake Tanganyika, DR Congo. J. Great Lakes Res. 46 (6), 1740–1753.

Dearing, J.A., Håkansson, H., Liedberg-Jönsson, B., Persson, A., Skansjö, S., Widholm, D., El-Daoushy, F., Hakansson, H., Liedberg-Jonsson, B., Skansjo, S., 1987. Lake sediments used to quantify the erosional response to land use change in Southern Sweden. Oikos 50 (1), 60.

Descy, J-P., Plisnier, P-D., Leporcq, B., Sténuite, S., Pirlot, S., Stimart, J., Gosselain, V., Stoyneva, P., Deleersnijder, E., Naithani, J., Chitamwebwa, D., Chande, A., Kimirei, I., Sekadende, B., Mwaitega, S., Muhoza, S., Sinyinza, D., Makasa, L., Lukwesa, C., Zulu, I., and Phiri, H. (2006) Climate variability as recorded in Lake Tanganyika. Global changes, ecosystems and biodiversity SPSD2, research project EV/13/02. Final report (2001-2005). Belgian Science Policy.

Descy, J.-P., Hardy, M.-A., Stenuite, S., Pirlot, S., Leporcq, B., Kimirei, I., Sekadende, B., Mwaitega, S.R., Sinyenza, D., 2005. Phytoplankton pigments and community composition in Lake Tanganyika. Freshw. Biol. 50 (4), 668–684.

Descy, J.-P., Tarbe, A.-L., Stenuite, S., Pirlot, S., Stimart, J., Vanderheyden, J., Leporcq, B., Stoyneva, M.P., Kimirei, I., Sinyinza, D., Plisnier, P.-D., 2010. Drivers of phytoplankton diversity in Lake Tanganyika. In: Naselli-Flores, L., Rossetti, G. (Eds.), Fifty Years After the "'Homage to Santa Rosalia'": Old and New Paradigms on Biodiversity in Aquatic Ecosystems. Springer, Netherlands, pp. 29–44.

Detenbeck, N.E., Galatowitsch, S.M., Atkinson, J., Ball, H., 1999. Evaluating perturbations and developing restoration strategies for inland wetlands in the Great Lakes basin. Wetlands 19 (4), 789–820.

Dettman, D.L., Palacios-Fest, M.R., Nkotagu, H.H., Cohen, A.S., 2005. Paleolimnological investigations of anthropogenic environmental change in Lake Tanganyika: VII. Carbonate isotope geochemistry as a record of riverine runoff. J. Paleolimnol. 34 (1), 93–105.

Donohue, I., Duck, R.W., Irvine, K., 2003. Land use, sediment loads and dispersal pathways from two catchments at the southern end of Lake Tanganyika, Africa: implications for lake management. Environ. Geol. 44 (4), 448–455.

Eggermont, H., Verschuren, D., 2003. Impact of soil erosion in disturbed tributary drainages on the benthic invertebrate fauna of Lake Tanganyika, East Africa. Biological Conservation 113 (1), 99–109.

Fermon., 2007. Étude de l'état des lieux de la partie nord du lac Tanganyika dans le cadre du Programme Pêche d'Action Contre la Faim en République Démocratique du Congo. Action Against Hunger, USA.

Fryer, G., 2006. Evolution in ancient lakes: radiation of Tanganyikan atyid prawns and speciation of pelagic cichlid fishes in Lake Malawi. Hydrobiologia 568 (S1), 131–142.

Gamarro Garrido, E., Ryder, J., Elvevoll, E.O., Olsen, R.L., 2020. Microplastics in fish and shellfish – a threat to seafood safety? J. Aquat. Food Prod. Technol. 29 (4), 417–425.

Groombridge, B., Jenkins, M., 1998. Freshwater biodiversity: a preliminary global assessment. IUCN, Cambridge, UK, p. 104p.

Hanek, G. (1994). Management of Lake Tanganyika fisheries. FAO/FINNIDA Research for the Management of the fisheries on Lake Tanganyika GCP. RAF/271/FIN-TD/25 (En): 21 pp.

Hecky, R.E., Fee, E.J., Kling, H.J., Rudd, J.W.M., 1981. Relationship between primary production and fish production in Lake Tanganyika. Trans. Am. Fish. Soc. 110 (3), 336–345.

Hori, M., Gashagaza, M.M., Nshombo, M., Kawanabe, H., 1993. Littoral fish communities in Lake Tanganyika: Irreplaceable diversity supported by intricate interactions among species. Conservation Biology: The Journal of the Society for Conservation Biology 7 (3), 657–666.

Hulme, M., Doherty, R., Ngara, T., New, M., Lister, D., 2001. African climate change: 1900–2100. Climate Res. 17, 145–168.

Iucn, 2012. Guide to some invasive plants affecting Lake Tanganyika. IUCN ISI and Lake Tanganyika Authority, Nairobi, Kenya, p. 64p.

Kapepula, L., Ndikumana, T., Dieu-Donn, M., Luis Alconero, P., Tamungang, N.E.B., Tarimo, I., Van der Bruggen, B., 2020. Qualitative and quantitative analysis of the pollutant load of effluents discharged Northwestern of Lake Tanganyika, in the Democratic Republic of Congo. Afr. J. Environ. Sci. Technol. 14 (11), 361–373.

Khan, M., Biginagwa., 2018. Microplastics in inland African waters: Presence, sources, and fate. Annual Report, Freshwater Fisheries Centre, Christchurch.

Kimirei, I.A., Mgaya, Y.D., 2007. Influence of environmental factors on seasonal changes in clupeid catches in the Kigoma area of Lake Tanganyika. Afr. J. Aquat. Sci. 32 (3), 291–298.

Kimirei, I.A., Mgaya, Y.D., Chande, A.I., 2008. Changes in species composition and abundance of commercially important pelagic fish species in Kigoma area, Lake Tanganyika. Tanzania. Aquatic Ecosystem Health and Management 11 (1), 29–35.

Konings, A.D., 1998. Tanganyika cichlids in their natural habitat. Cichlid Press.

Kraemer, B.M., Hook, S., Huttula, T., Kotilainen, P., O'Reilly, C.M., Peltonen, A., Plisnier, P.-D., Sarvala, J., Tamatamah, R., Vadeboncoeur, Y., Wehrli, B., McIntyre, P.B., Bohrer, G., 2015. Century-long warming trends in the upper water column oF Lake Tanganyika. PLoS One 10 (7).

Kullander, S.O., Roberts, T.R., 2011. Out of Lake Tanganyika: endemic lake fishes inhabit rapids of the Lukuga River. Ichthyological Exploration of Freshwaters 22 (4), 355–376.

Langenberg, V.T., 2008. On the Limnology of Lake Tanganyika. Thesis Wageningen University, The Netherlands.

Manirakiza, P., Covaci, A., Nizigiymana, L., Ntakimazi, G., Schepens, P., 2002. Persistent chlorinated pesticides and polychlorinated biphenyls in selected fish species from Lake Tanganyika, Burundi, Africa. Environmental Pollution 117 (3), 447–455.

Mannini, P., Aro, E., Katonda, I., Kassaka, B., Mambona, C., Milindi, G., Paffen, P., and Verburg, P. (1997). Pelagic fish stocks of Lake Tanganyika: Biology and exploitation. Research for the Management of the Fisheries on Lake Tanganyika GCP. RAF/271/FIN-TD/53 (En).

Marijnissen, S.A.E., Michel, E., Cleary, D.F.R., 2009. Ecology and conservation status of endemic freshwater crabs in Lake Tanganyika, Africa. Biodiversity 18, 1555–1573.

Mohammed, E.Y., Uraguchi, Z.B., 2013. Impacts of Climate Change on Fisheries: Implications for food security in Sub Saharan Africa. Global Food Security. Nova Science Publishers, Inc., In Hanjira, M. A.

Mölsä, H., Reynolds, J.E., Coenen, E.J., Lindqvist, O.V., 1999. Fisheries research towards resource management on Lake Tanganyika. Hydrobiologia 407, 1–24.

Mulimbwa, N., Shirakihara, K., 1994. Growth, Recruitment and Reproduction of Sardines (*Stolothrissa tanganicae* and *Limnothrissa miodon*) in Northwestern Lake Tanganyika. Tropics 4 (1), 57–67.

Mushagalusa, C.D., Nshombo, M., Lushombo, M., 2014. Littoral fisheries on Cichlidae (Pisces) from the northwestern part of Lake Tanganyika, East Africa. Aquat. Ecosyst. Health Manag. 17 (1), 41–51.

Mushagalusa, C.D., De Keyzer, E.L.R., Badesirhe, K.M., Heeren, S., Hugé, J., Janssens de Bisthoven, L., Kavuye, M.S., Kmentová, N., Marwa, B., Mulimbwa, N.T., Munundu, M.A., Muterezi, B.F., Mwangaza, B.-S.-F., Nabintu, B.N., Raeymaekers, J., Tusanga, S., Van Steenberge, M., Vanhove, M.P.M., Verheyen, E., Masilya, M.P., 2020. Un œil critique sur la pêche au Lac Tanganyika: les générations futures auront-elles encore du poisson? / A critical look at fishing in Lake Tanganyika: will future generations still have access to fish? Policy Brieff, CEBioS.

Naithani, J., Plisnier, P.-D., Deleersnijder, E., 2011. Possible effects of global climate change on the ecosystem of Lake Tanganyika. Hydrobiologia 671 (1), 147–163.

Nixon, S.W., 1988. Physical energy inputs and the comparative ecology of lake and marine ecosystems. Limnol. Oceanogr. 33 (4part2), 1005–1025.

Nkotagu, H.H., 2008. Lake Tanganyika ecosystem management strategies. Aquat. Ecosyst. Health Manag. 11 (1), 36–41.

Nkurunziza, F. (1998). Thème: Le Peuplement humain dans la partie burundaise du Bassin Versant du Lac Tanganyika.

O'Hara, S.L., Street-Perrott, F.A., Burt, T.P., 1993. Accelerated soil erosion around a Mexican highland lake caused by prehispanic agriculture. Nature 362 (6415), 48–51.

O'Reilly, C.M., Alin, S.R., Plisnier, P.-D., Cohen, A.S., McKee, B.A., 2003. Climate change decreases aquatic ecosystem productivity of Lake Tanganyika. Africa. Nature 424 (6950), 766–768.

Odada, E.O., Olago, D.O., Kulindwa, K., Ntiba, M., Wandiga, S., 2004. Mitigation of environmental problems in Lake Victoria, East Africa: causal chain and policy options analyses. Ambio 33 (1–2), 13–23.

Pearce, M.J., 1995. Effects of exploitation on the pelagic fish community in the south of Lake Tanganyika. In: Pitcher, T.J., Hart, P.J.B. (Eds.), The Impact of Species Changes in African Lakes. Springer, Netherlands, pp. 425–441.

Phiri, H., Shirakihara, K., 1999. Distribution and seasonal movement of pelagic fish in southern Lake Tanganyika. Fish. Res. 41 (1), 63–71.

Plisnier, P.-D., 1997. Climate, limnology and fisheries changes of Lake Tanganyika. FAO, Rome, Italy.

Plisnier, P.-D., 2000. Recent climate and limnology changes in Lake Tanganyika. SIL Proceedings, 1922-2010 27 (5), 2670–2673.

Plisnier, P-D, and Marijnissen, S.A.E. (2010) Lake Tanganyika Regional Integrated Environmental Monitoring Programme, Institutional Needs Assessment. UNDP/GEF Project on Lake Tanganyika, Report LTRIEMP/PCU/C1/2010, April 2010.

Plisnier, P.-D., Kayanda, R., MacIntyre, S., Obiero, K., Okello, W., Vodacek, A., Cocquyt, C., Abegaz, H., Achieng, A., Akonkwa, B., Albrecht, C., Balagizi, C., Barasa, J., Abel Bashonga, R., Bashonga Bishobibiri, A., Bootsma, H., Borges, A.V., Chavula, G., Dadi, T., De Keyzer, E.L.R., Doran, P.J., Gabagambi, N., Gatare, R., Gemmell, A., Getahun, A., Haambiya, L.H., Higgins, S.N., Hyangya, B.L., Irvine, K., Isumbisho, M., Jonasse, C., Katongo, C., Katsev, S., Keyombe, J., Kimirei, I., Kisekelwa, T., Kishe, M., Otoung, A., Koding, S., Kolding, J., Kraemer, B.M., Limbu, P., Lomodei, E., Mahongo, S.B., Malala, J., Mbabazi, S., Masilya, P.M., McCandless, M., Medard, M., Migeni Ajode, Z., Mrosso, H.D., Mudakikwa, E.R., Mulimbwa, N., Mushagalusa, D., Muvundja, F.A., Nankabirwa, A., Nahimana, D., Ngatunga, B.P., Ngochera, M., Nicholson, S., Nshombo, M., Ntakimazi, G., Nyamweya, C., Ikwaput Nyeko, J., Olago, D., Olbamo, T., O'Reilly, C.M., Pasche, N., Phiri, H., Raasakka, N., Salyani, A., Sibomana, C., Silsbe, G.M., Smith, S., Sterner, R. W., Thiery, W., Tuyisenge, J., Van der Knaap, M., Van Steenberge, M., van Zwieten, P.A.M., Verheyen, E., Wakjira, M., Walakira, J., Ndeo Wembo, O., Lawrence, T., 2023. Need for harmonized long-term multi-lake monitoring of African Great Lakes. J. Great Lakes Res. 49 (6), 101988 https://doi.org/10.1016/j.jglr.2022.01.016.

Plisnier, P.-D., Nshombo, M., Mgana, H., Ntakimazi, G., 2018. Monitoring climate change and anthropogenic pressure at Lake Tanganyika. J. Great Lakes Res. 44 (6), 1194–1208.

Poll, M., 1953. Poissons Non Cichlidae. Resultats scientifiques. Exploration hydrobiologique du Lac Tanganika (1946–1947). Inst R Sci Nat Belg.

Poll, M., 1956. Poissons Cichlidae. Resultats scientifiques. Exploration hydrobiologique du Lac Tanganika (1946–1947). Inst R Sci Nat Belg.

Reynolds, J.E., 1999. Lake Tanganyika framework fisheries management plan. FAO, Rome, Italy.

Roberts, C.M., Andelman, S., Branch, G., Bustamante, R.H., Castilla, J.C., Dugan, J., Halpern, B.S., Lafferty, K.D., Leslie, H., Lubchenco, J., McArdle, D., Possingham, H. P., Ruckleshaus, M., Warmer, R.W., 2003. Ecological criteria for evaluation of candidate sites for marine reserves. Ecol. Appl. S199–S215.

Roest, F.C., 1992. The pelagic fisheries resources of Lake Tanganyika. SIL Communications, 1953-1996 23 (1), 11–15.

Russell, J.M., Barker, P., Cohen, A., Ivory, S., Kimirei, I., Lane, C., Leng, M., Maganza, N., McGlue, M., Msaky, E., Noren, A., Park Boush, L., Salzburger, W., Scholz, C., Tiedemann, R., Nuru, S., 2020. ICDP Workshop on the Lake Tanganyika Scientific Drilling Project: a late Miocene-present record of climate, rifting, and ecosystem evolution from the world's oldest tropical lake. Sci. Drill. 27, 53–60.

Salzburger, W., Van Bocxlaer, B., Cohen, A.S., 2014. Ecology and evolution of the African Great Lakes and their faunas. Annu. Rev. Ecol. Evol. Syst. 45 (1), 519–545.

Sarvala, J., Langenberg, V.t., Salonen, K., Chitamwebwa, D., Coulter, G.W., Huttula, T., Kanyaru, R., Kotilainen, P., Makasa, L., Mulimbwa, N., Mölsä, H., 2006. Fish catches from Lake Tanganyika mainly reflect changes in fishery practices, not climate. SIL Proceedings, 1922-2010 29 (3), 1182–1188.

Scheffel, R.L., Wernet, S.J., 1980. Natural Wonders of the World. Reader's Digest Association. Inc, United States of America.

Secretariat, L.T.A., 2011. Strategic Action Programme for the Protection of Biodiversity and Sustainable Management of Natural Resources in Lake Tanganyika and its Basin. Bujumbura, Burundi, p. 141p.

Secretariat, L.T.A., 2021. Regional Charter of the member states of the Lake Tanganyika Authority providing for measures for sustainable management of fisheries in Lake Tanganyika and its basin. LTA, Bujumbura, Burundi.

LTA Secretariat. (2012). Report on Regional Lakewide Fisheries Frame Survey on Lake Tanganyika 2011 (LTA/TECH DOC/2012/01).

H. Sichingabula Special study on sediment discharge and Its consequences (SedSS). United Nations Development Programme/Global Environment Facility (UNDP/GEF) 1999.

Snoeks, J., 2000. How well known is the ichthyodiversity of the large East African lakes? Adv. Ecol. Res. 31, 17–38.

Su, L., Cai, H., Kolandhasamy, P., Wu, C., Rochman, C.M., Shi, H., 2018. Using the Asian clam as an indicator of microplastic pollution in freshwater ecosystems. Environ. Pollut. 234, 347–355.

Tshibangu, K.K., Kinoshita, I., 1995. Early life histories of two clupeids, *Limnothrissa miodon* and *Stolothrissa tanganicae*, from Lake Tanganyika. Japanese Journal of Ichthyology 42 (1), 81–87.

Van der Knaap, M., 2013. Comparative analysis of fisheries restoration and public participation in Lake Victoria and Lake Tanganyika. Aquat. Ecosyst. Health Manag. 16 (3), 279–287.

Van der Knaap, M., Katonda, K.I., De Graaf, G.J., 2014. Lake Tanganyika fisheries frame survey analysis: assessment of the options for management of the fisheries of Lake Tanganyika. Aquat. Ecosyst. Health Manag. 17 (1), 4–13.

Verburg, P., Hecky, R.E., 2009. The physics of the warming of Lake Tanganyika by climate change. Limnol. Oceanogr. 54 (6part2), 2418–2430.

Verburg, P., Hecky, R.E., Kling, R., 2003. Ecological consequences of a century of warming on Lake Tanganyika. Science 301, 505–507.

Verheyen, E., Abila, R., Akoll, P., Albertson, C., Antunes, D., Banda, T., Bills, R., Bulirani, A., Manda, A.C., Cohen, A.S., Cunha-Saraiva, F., Derycke, S., Donohue, I., Du, M., Dudu, A.M., Egger, B., Fritzsche, K., Frommen, J.G., Gante, H.F., Zimmermann, H., 2016. Oil extraction imperils Africa's Great Lakes. Science 354 (6312), 561–562.

Vreven, E.J., 2005. Mastacembelidae (Teleostei; Synbranchiformes) subfamily division and African generic division: an evaluation. J. Nat. Hist. 39 (4), 351–370.

West, K., Michel, E., Todd, J., Brown, D., Clabaugh, J., 2003. The gastropods of Lake Tanganyika: Diagnostic key, classification and notes on the fauna. Centre for African Wetlands Ghana, on Behalf of International Association of Theoretical and Applied Limnology.

West, K. (2001). Resultats et constats tires de l'initiative de conservation du PNUD/GEF (RAF/92/G32) qui a eu lieu au Burundi, en Republique Democratique du Congo, en Tanzanie et en Zambie. Lake Tanganyika Biodiversity Project.

World Bank, 2020b. World Development Indicators (2020), population growth (annual %). retrieved from. https://data.worldbank.org/indicator/SP.POP.GROW.

World Bank. (2020). World Development Indicators (2020), GNI per capita, Qtlas method (current US$). World Bank. Retrieved 2020, from https://data.worldbank.org/indicator/NY.GNP.PCAP.CD.

Wouters, K., Martens, K., 1994. Contribution to the knowledge of the Cyprideis species flock (Crustacea: Ostracoda) of Lake Tanganyika, with the description of three new species. Bulletin de l'Institut Royal Des Sciences Naturelles de Belgique, Entomologie 18 (6), 1555–1573.