Journal of Great Lakes Research

Need for harmonized long-term multi-lake monitoring of African Great Lakes

--Manuscript Draft--

Manuscript Number:	GLR-D-21-00258
Article Type:	SI: African Great Lakes 2022
Keywords:	Fisheries, Limnology, Pollution, Biodiversity, Climate change, Erosion
Corresponding Author:	Pierre-Denis Plisnier, Ph.D. University of Liege: Universite de Liege Grez-Doiceau, BELGIUM
First Author:	Pierre-Denis Plisnier, Ph.D.
Order of Authors:	Pierre-Denis Plisnier, Ph.D.
	Robert Kayanda, Ph.D.
	Sally MacIntyre, Ph.D.
	Kevin Obiero, Ph.D.
	William Okello, Ph.D.
	Anthony Vodacek, Ph.D.
	Christine Cocquyt, Ph.D.
	Hussein Abegaz, Ph.D.
	Alfred Achieng, Ph.D.
	Balagizi Akonkwa
	Christian Albrecht, Ph.D.
	Charles Balagizi, Ph.D.
	James Barasa, Ph.D.
	Rafiki Abel Bashonga
	Alexis Bashonga Bishobibiri
	Harvey Bootsma, Ph.D.
	Alberto V. Borges, Ph.D.
	Geoffrey Chavula, Ph.D.
	Dadi Tallent, Ph.D.
	Els De Keyzerr, Ph.D.
	Patrick D. Doran, Ph.D.
	Nestory Gabagambi, Ph.D.
	Robert Gatare
	Andrew Gemmell, Ph.D.
	Abebe Getahun, Ph.D.
	Lloyd Haambiya, Ph.D.
	Scott N. Higgins, Ph.D.
	Béni Hyangya, Ph.D.
	Ken Irvine, Ph.D.
	Pascal Isumbisho, Ph.D.

	Carlos Jonasse, Ph.D.
	Cyprian Katongo, Ph.D.
	Sergei Katsev, Ph.D.
	James Keyombe, Ph.D.
	Ismael Kimirei, Ph.D.
	Tchalondawa Kisekelwa, Ph.D.
	Mary Kishe, Ph.D.
	Simon Otoung A. Koding, Eng.
	Jeppe Kolding, Ph.D.
	Benjamin M. Kraemer, Ph.D.
	Peter Limbu
	Evans Lomodei
	Shigalla Mahongo, Ph.D.
	John Malala
	Stella Mbabazi
	Pascal Masilya Mulungula, Ph.D.
	Matt McCandles, Ph.D.
	Modesta Medard, Ph.D.
	Zephaniah Migeni Ajode
	Hillary D Mrosso
	Eric R. Mudakikwa
	N’sibula Mulimbwa
	Déo Mushagalusa, Ph.D.
	Fabrice Muvundja
	Angela Nankabirwa, Ph.D.
	David Nahimana, Ph.D.
	Benjamin P. Ngatunga, Ph.D.
	Ngochera Ngochera, Ph.D.
	Sharon Nicholson, Ph.D.
	Muderhwa Nshombo, Ph.D.
	Gaspard Ntakimazi, Ph.D.
	Chrispine Nyamweya, Ph.D.
	Joyce Ikwaput Nyeko, Ph.D.
	Dan Olago, Ph.D.
	Tekle Olbamo
	Catherine O'Reilly, Ph.D.
	Natacha Pasche, Ph.D.
	Harris Phiri, Ph.D.
	Nina Raasakka
	Anham Salyani
	Claver Sibomana, Ph.D.

	Greg Silsbe, Ph.D.
	Stephanie Smith
	Robert W. Sterner, Ph.D.
	Wim Thiery, Ph.D.
	Janviere Tuyisenge
	Martin Van der Knaapbj, Ph.D.
	Maarten Van Steenberger, Ph.D.
	Paul A.M. van Zwieten, Ph.D.
	Eric Verheyen, Ph.D.
	Mulugeta Wakjira, Ph.D.
	John Walakira, Ph.D.
	Oscar Ndeo Wembo, Ph.D.
	Theodore Lawrence, Ph.D.
Abstract:	To ensure the long-term sustainable use of African Great Lakes (AGL), and to better understand the functioning of these ecosystems, authorities, managers and scientists need regularly collected scientific data and information of key environmental indicators over multi-year periods to make informed decisions. Monitoring is regularly conducted at some sites across AGL while at others sites, it is rare or conducted irregularly in response to sporadic funding or short-term projects/studies. Managers and scientists working on the AGL thus often lack critical long-term data to evaluate and gauge ongoing changes. Hence, we propose a multi-lake approach to harmonize data collection modalities for better understanding of regional and global environmental impacts on AGL. Climate variability has had strong impacts on all AGL in the recent past. Although these lakes have specific characteristics, their limnological cycles show many similarities. Since different anthropogenic pressures take place at the different AGL, harmonized multi-lake monitoring will provide comparable data to address the main drivers of concern (climate versus regional anthropogenic impact). To implement harmonized long-term multi-lake monitoring, the approach will need: (1) support of a wide community of researchers and managers; (2) political goodwill towards a common goal for such monitoring; and (3) sufficient capacity (e.g., institutional, financial, human and logistic resources) for its implementation. This paper presents a preliminary state of actual monitoring of AGL and possible methodologies for their long-term, multi-lake harmonized monitoring. Key parameters are proposed. The support of national and regional authorities is necessary since each AGL is transboundary in nature.
Suggested Reviewers:	Eric Odada eodada@uonbi.ac.ke Long experience in the ecology of African Great lakes
	Richard Robarts rdrobarts@shaw.ca Good specialist that knows African lakes and monitoring state
	Walter Salzburger walter.salzburger@unibas.ch Specialist of fish biodiversity in African Great lakes
	Jan Wanink jan@wanink.nl Long experience of researches in fish ecology at Lake Victoria

To the Editors of the Journal of Great Lakes Research

Grez-Doiceau, September 11th, 2021

Dear Editors,

We would like to submit our manuscript "*Need for harmonized long-term multi-lake monitoring of African Great Lakes*". It is a full-length article that provide results of a survey dealing with monitoring and institutions related to the great African lakes (AGL). Based on this survey, it presents the opinion of a large group of authors on the need for a long-term monitoring and proposes parameters and possible ways to establish such a long-term monitoring. This is urgently needed in regards to the various challenges facing the AGL. There is presently no harmonized monitoring and time series of main parameters are a bottleneck for researchers and managers. A multi-lake monitoring would be a great advancement for the science, the advancement of our understanding of ecological functioning of those lake and would provide a strong basis for the sustainable management of those seven of the largest lakes on earth.

Each author has participated to the survey and has provided information to write the MS.
A preprint has been made available. The authors agree to update the preprint and confirm the copyright transfer should the submission be accepted.

This material has not been previously published. It is not under consideration for publication elsewhere. This publication has been approved by all authors and the responsible authorities where the work was carried out. If accepted, it will not be published elsewhere, in English or in any other language, including electronically, without the written consent of the copyright-holder.

We declare that there is any conflicts of interest.

In the name of the co-authors, I thank you for your appreciated attention.

Sincerely yours

Dr Pierre-Denis Plisnier

Need for harmonized long-term multi-lake monitoring of African Great Lakes

Journal: JOURNAL OF GREAT LAKES RESEARCH

Pierre-Denis Plisnier[a,*], Robert Kayanda[b], Sally MacIntyre[c], Kevin Obiero[d], William Okello[e], Anthony Vodacek[f], Christine Cocquyt[g], Hussein Abegaz[h], Alfred Achieng[i], Balagizi Akonkwa[j], Christian Albrecht[k,l], Charles Balagizi[m], James Barasa[i], Rafiki Abel Bashonga[n], Alexis Bashonga Bishobibiri[n], Harvey Bootsma[o], Alberto V. Borges[a], Geoffrey Chavula[p], Tallent Dadi[q], Els De Keyzer[r], Patrick J. Doran[s], Nestory Gabagambi[t], Robert Gatare[u], Andrew Gemmell[v], Abebe Getahun[w], Lloyd Haambiya[x], Scott N. Higgins[y], Béni Hyangya[z], Ken Irvine[aa,ab], Pascal Isumbisho[z,ac], Carlos Jonasse[ad], Cyprian Katongo[ae], Sergei Katsev[af], James Keyombe[ag], Ismael Kimirei[ah], Tchalondawa Kisekelwa[z, ai], Mary Kishe[ah], Simon Otoung A. Koding[aj], Jeppe Kolding[ak], Benjamin M. Kraemer[al], Peter Limbu[am], Evans Lomodei[an], Shigalla Mahongo[ap], John Malala[ag], Stella Mbabazi[aq], Pascal Masilya Mulungula[z], Matt McCandless[y], Modesta Medard[ar], Zephaniah Migeni Ajode[as], Hillary D. Mrosso[ah], Eric R. Mudakikwa[at], N'sibula Mulimbwa[n], Déo Mushagalusa[n], Fabrice Muvundja[z,au], Angela Nankabirwa[e], David Nahimana[av], Benjamin P. Ngatunga[ah], Maxon Ngochera[aw], Sharon Nicholson[ax], Muderhwa Nshombo[j,n], Gaspard Ntakimazi[av], Chrispine Nyamweya[ay], Joyce Ikwaput Nyeko[aq], Dan Olago[az], Tekle Olbamo[ba], Catherine O'Reilly[bb], Natacha Pasche[bc], Harris Phiri[bd], Nina Raasakka[be], Anham Salyani[be], Claver Sibomana[av], Greg Silsbe[bf], Stephanie Smith[bg], Robert W. Sterner[af], Wim Thiery[bh], Janviere Tuyisenge[bi], Martin Van der Knaap[bj], Maarten Van Steenberge[r,bk], Paul A.M. van Zwieten[bl], Erik Verheyen[bk,bm], Mulugeta Wakjira[bn], John Walakira[bo], Oscar Ndeo Wembo[bp,bq], Theodore Lawrence[as,y]

Affiliation of authors

[a] Chemical Oceanography Unit, Institut de Physique, University of Liège, Liège, Belgium

[b] Lake Victoria Fisheries Organization, Jinja, Uganda

[c] Department of Ecology, Evolution, and Marine Biology, University of California, Santa Barbara, USA

[d] Kenya Marine and Fisheries Research Institute, Pap-Onditi, Kenya

[e] National Fisheries Resources Research Institute, Jinja, Uganda

[f] Chester F. Carlson Center for Imaging Science Rochester Institute of Technology, Rochester, USA

[g] Research Department, Meise Botanic Garden, Meise, Belgium

[h] Fishery Development Directorate, Ministry of Agriculture, Addis Ababa, Ethiopia

[i] Department of Fisheries and Aquatic Science, University of Eldoret, Eldoret, Kenya

[j] Biology Department, Université Officielle de Bukavu, Bukavu, D.R. Congo

[k] Department of Animal Ecology and Systematics, Justus Liebig University, Giessen, Germany

[l] Department of Biology, Mbarara University of Science and Technology, Mbarara, Uganda

[m] Geochemistry Department, Goma Volcano Observatory, Goma, D.R. Congo

[n] Centre de Recherche en Hydrobiologie, Uvira, D.R. Congo

[o] School of Freshwater Sciences, University of Wisconsin-Milwaukee, Milwaukee, WI, USA

[p] Department of Civil Engineering, Malawi University of Business and Applied Sciences, Blantyre, Malawi

[q] Helmholtz Centre for Environmental Research - UFZ, Department Lake Research, Magdeburg, Germany

[r] Laboratory of Biodiversity and Evolutionary Genomics, KU Leuven, Leuven, Belgium
[s] The Nature Conservancy, Lansing, Michigan, USA
[t] Tanzania Fisheries Research Institute, Kyela, Mbeya, Tanzania
[u] Livestock Department, Fisheries and Aquaculture program, Huye, Rwanda
[v] The Umvoto Foundation, Cape Town, South Africa
[w] Department of Zoological Sciences, Addis Ababa University, Addis Ababa, Ethiopia
[x] Nsumbu Tanganyika Conservation Programme, Mpika, Zambia
[y] International Institute for Sustainable Development, Winnipeg, Canada
Canada
[z] Unité d'Enseignement et de Recherche en Hydrobiologie Appliquée, Institut Supérieur Pédagogique de Bukavu, Bukavu, D.R. Congo
[aa] IHE Delft Institute for Water Education, Delft, Netherlands
[ab] Aquatic Ecology and Water Quality Management, Wageningen University, Netherlands
[ac] Laboratoire d'Etude des Milieux Aquatiques , Kinshasa, D.R. Congo
[ad] Fisheries Research Institute, Maputo, Mozambique
[ae] Department of Biological Sciences, University of Zambia, Lusaka, Zambia
[af] Large Lakes Observatory, University of Minnesota Duluth, Duluth, USA
[ag] Kenya Marine and Fisheries Research Institute, Lake Turkana Station, Lodwar, Kenya
[ah] Tanzania Fisheries Research Institute, Dar es Salaam, Tanzania
[ai] Centre de Recherche en Biodiversité, Ecologie, Evolution et Conservation, Bukavu, D.R. Congo
[aj] Lake Victoria Basin Commission, Kisumu Kenya
[ak] Department of Biological Sciences, University of Bergen, Bergen, Norway
[al] Department of Ecosystem Research, IGB Leibniz Institute for Freshwater Ecology and Inland Fisheries, Berlin, Germany
[am] The Nature Conservancy, Kigoma, Tanzania
[an] Department of Biological and Physical Science, Turkana University College, Lodwar-Kenya
[ap] Lake Victoria Fisheries Organisation, Jinja, Uganda
[aq] Directorate of Fisheries Resources, Ministry of Agriculture, Animal Industry and Fisheries, Entebbe, Uganda
[ar] WWF Seascape Programme, Dar es salaam, Tanzania
[as] African Center for Aquatic Research and Education, Ann Arbor, USA
[at] Division of Environment analytics & Lake Kivu Monitoring, Rwanda Environnemental Management Authority, Kigali, Rwanda
[au] Centre des Recherches en Environnement et Géo-Ressources, Catholic University of Bukavu, Bukavu, D.R. Congo
[av] Centre de Recherche en Sciences Naturelles et de l'Environnement, Université du Burundi, Bujumbura, Burundi
[aw] Monkey Bay Fisheries Research Station, Mangochi, Malawi
[ax] Earth, Ocean and Atmospheric Sciences Department, Florida State University Tallahassee, USA
[ay] Kenya Marine and Fisheries Research Institute, Kisumu, Kenya
[az] Institute for Climate Change and Adaptation, University of Nairobi, Nairobi, Kenya

[ba] College of Agriculture and Natural Resources, Department of Animal Health, Jinka University, Jinka, Ethiopia
[bb] Department of Geography, Geology, and the Environment, Illinois State University, Normal, USA
[bc] Limnology Center, ENAC-EPFL, Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland
[bd] Department of Fisheries, Chilanga, Zambia
[be] United Nations Environment Programme, Nairobi, Kenya
[bf] Horn Point Lab, University of Maryland Center for Environmental Science, USA.
[bg] African Center for Aquatic Research and Education, Ann Arbor, MI, USA
[bh] Department of hydrology and hydraulic engineering, Vrije Universiteit Brussel, Brussels, Belgium
[bi] Delft Institute for Water Education, Delft, Netherlands
[bj] FAO, Addis Ababa Ethiopia
[bk] Taxonomy and Phylogeny, Royal Belgian Institute for Natural Sciences, Brussels; Belgium
[bl] Aquaculture and Fisheries Group, Wageningen University, Netherlands
[bm] Department Biology- Evolutionary Ecology, Antwerp University, Antwerp, Belgium
[bn] Department of Biology, College of Natural Sciences, Jimma University, Jimma, Ethiopia
[bo] National Agricultural Research Organization, Arua, Uganda
[bp] Aquatic Biology Department, Faculty of Sciences, Université Officielle de Ruwenzori, Butembo, D.R. Congo;
[bq] Hydrobiological Department, Faculty of Sciences, University of Kisangani, Kisangani, D.R. Congo

Corresponding author: pierre-denis.plisnier@uliege.be

Abstract

To ensure the long-term sustainable use of African Great Lakes (AGL), and to better understand the functioning of these ecosystems, authorities, managers and scientists need regularly collected scientific data and information of key environmental indicators over multi-year periods to make informed decisions. Monitoring is regularly conducted at some sites across AGL while at others sites, it is rare or conducted irregularly in response to sporadic funding or short-term projects/studies. Managers and scientists working on the AGL thus often lack critical long-term data to evaluate and gauge ongoing changes. Hence, we propose a multi-lake approach to better harmonize data collection modalities for better understanding of regional and global environmental impacts on AGL. Climate variability has had strong impacts on all AGL in the recent past. Although these lakes have specific characteristics, their limnological cycles show many similarities. Since different anthropogenic pressures take place at the different AGL, harmonized multi-lake monitoring will provide comparable data to address the main drivers of concern (climate versus regional anthropogenic impact). To implement harmonized long-term multi-lake monitoring, the approach will need: (1) support of a wide community of researchers and managers; (2) political goodwill towards a common goal for such monitoring; and (3) sufficient capacity (e.g., institutional, financial, human and logistic resources) for its implementation. This paper presents a preliminary state of actual monitoring of AGL and possible methodologies for their long-term, multi-lake harmonized monitoring. Key parameters are proposed. The support of national and regional authorities is necessary since each AGL is transboundary in nature.

Keywords*:* Fisheries, Limnology, Pollution, Biodiversity, Climate change, Erosion

INTRODUCTION

The seven main African Great Lakes (AGL) consist of Lakes Albert, Edward, Kivu, Malawi/Niassa/Nyasa, Tanganyika, Turkana, and Victoria. Their basins spread across 10 riparian countries (Burundi, DR Congo, Ethiopia, Kenya, Malawi, Mozambique, Rwanda, Tanzania, Uganda and Zambia). All provide invaluable ecosystems services (e.g.: >1.5 million ton of fish/year (Lymer and Welcomme, 2012) for the rapidly growing population of > 90 million people in the region (Sterner et al., 2020). Because these AGL have existed for millions of years (Cohen et al., 1993; Tiercelin and Lezzar, 2002), they shelter an exceptional biodiversity across a large range of groups of taxa including the so-called "species-flocks" (Martens et al, 1994). This biodiversity represents a global heritage. The AGL contain >2000 fish species, including over 1800 species of cichlids, ~95% of which are endemic (Salzburger et al., 2014). Further, the AGL represent ~29% of the world's surface freshwater (Ogutu-Ohwayo et al., 2020; Shiklomanov, 1993). The lakes are also an important source of moisture contributing to precipitation regulation and regional hydrology (Balagizi et al., 2018a; Docquier et al., 2016; Thiery et al., 2015).

In the recent decades, both recurrent and emerging environmental and anthropogenic threats have been identified in the AGL (Table1). The relative importance of each of those threats is lake-specific and more information is provided in various papers presented in this issue of the JGLR.

All of the seven AGL are large with each sharing a boundary with two or more countries. Managers have a common set of concerns related to the drivers and pressures, threatening the states of the lakes' ecosystems (Atkins et al., 2011). Therefore, the use of standardized and regularly collected metrics of key interest would provide stakeholders with a greatly improved understanding of ecosystem health.

The need for, and utility of, long-term data collection has often been described and is well known within lake research (Bahlai et al., 2021; Hampton et al., 2019; Iwaniec et al., 2021; Rastetter et al., 2021). With the exception of mainly fishery surveys on Lakes Victoria and Malawi/Nyasa/Niassa (Irvine et al., 2019, 2020), monitoring programs within the AGL have often been done through short-term research projects such that there are large temporal gaps between intervals with data collection, inconsistent use of indicators, and differences in methodological approaches. Lack of Monitoring, Evaluation and Learning (MEL) personnel, and sometimes infrastructures, within fisheries departments and research institutions is accelerating the problem.

The resolution of the 2017 AGL Conference of Entebbe (>300 participants) recognized the need for timely information, robust data, and continuous monitoring to guide policy for conservation and management of the AGL aquatic and other resources (AGL, 2017; Doran et al., 2018). To address the variety of drivers and threats, and disentangle natural and anthropogenic factors, a consistent multi-lake monitoring is needed (Mudakikwa et al., 2021; Ogutu-Ohwayo and Balirwa, 2006; Plisnier et al., 2018).

A few key parameters could form a common basis for data sharing among the partners that compose a network of AGL institutions. Such a network would include institutions from each AGL country that have a mandate (or could acquire it) from their government in one or several of the environmental and anthropogenic topics related to the proposed continuous multi-lake monitoring (water, fisheries and aquaculture, climate, biodiversity, land-use, socio-economy of riparian populations using the lake's ecosystem services). A list of the various institutions, organizations and other potential stakeholders is presented in Tables 4 and 5. A subset of those institutions participating in the multi-lake monitoring network will need to be identified for efficacity but others could be called upon in case of need. Primary stakeholders who have been identified will require authorization from their national authorities to participate in the multi-lake monitoring.

The proposed monitoring network would greatly improve timely ecological understanding and provide managers with the information needed to better address and mitigate the drivers and threats, as well as to enable them to predict future changes including trade-offs, costs and benefits. Strategically, collaboration with regional and international institutions will be necessary to strengthen the continuous long-term monitoring. Such a network would boost the state of knowledge of AGL, and the sustainable long-term ecosystem services that constitute a common goal shared by all stakeholders. This necessity has already been bolstered in the African Centre for Aquatic Research and Education (ACARE)'s advisory groups based on each of the AGL (Obiero et al., 2020; Robarts and Zohary,2018).

The benefits of the multi-lake monitoring advances beyond obtaining data that can be used to assess the sustainability of ecosystems. This is also needed to determine the impacts of policies and socio-economic changes that impact lakes (for instance urbanization, livelihoods etc). This is also important for the non-academic community including local policymakers and civil society.

This paper is structured so that the first part underlines the importance of indicators based on regularly collected data and the present state of monitoring at various AGL covering climate variability and change and the anthropogenic environment. The advantages of multi-lake monitoring are then presented, including main principles and the needs for certain equipment. Practical ways for setting up a network are then proposed in addition to the selection of possible monitoring sites. We then list key parameters for priority topics (water, fisheries, meteorology, remote-sensing, biodiversity, land-use and socio-economy/human environment). The targeted frequency of observation is proposed and specific situations are addressed when capacities are not yet sufficiently available, or, inversely, particularly well-developed allowing a possible increased monitoring intensity. Important aspects of the network database are then presented, including possible regulations for data collection, use and the interest of sharing data to better support research, policy, management and AGL sustainability. This is followed by a list of institutions and organization related to the AGL in the 10 riparian countries amongst which partners of long-term, multi-lake monitoring need to be actively involved. A possible setting up of an international consortium to support the monitoring is then proposed, including a reference to a similar existing consortium, the “Charles Darwin Foundation”, in another global hotspot of biodiversity. We conclude by stressing the need for such a collaborative and harmonized continuous long-term monitoring effort, an opinion largely called for by many researchers in the region and globally.

Monitoring indicators for lake managers

Lakes are continuously affected by both internal pressures and external drivers thus their management requires regularly collected scientific data to evaluate trends and spatial patterns in response to environmental changes. Such data is required to better understand these complex ecosystems of which without such information, management decisions can only be based on best guesses or quasi-scientific approaches that are unlikely to address threats in an optimal manner. Further, the lack of data from regular monitoring makes it difficult to determine the efficacy of management to address the threats.

Though there exist some short-term, high-quality data collection efforts on the AGL, coverage is spotty and time gaps between projects are often long (Fig. 1). The disruption of data acquisition may also be linked to other reasons such as civil strife or the departure of a key person in charge of collecting some data from a station. Scientists that we know working on the AGL and beyond also agree that long-term data are essential for scientific investigation and better understanding. For example, long-term data series can help identify environmental drivers for the occurrence of cyanobacterial blooms and composition in the context of climatic and anthropogenic pressure (Le Moal et al., 2021).

AGL respond to climate variability and in turn affect the climate of the surrounding terrestrial environment. The lakes respond to atmospheric and oceanic variability on annual and interannual time scales as well as, over much longer periods (Barker, 2006; Bergonzini et al., 2004; Birkett et al., 1999; Burnett et al., 2011; Cohen et al., 2006; Gownaris et al., 2018; MacIntyre, 2013; Mercier et al., 2002; Mudakikwa et al., 2021; Nicholson, 2017; Olaka et al., 2010; Plisnier,1997, 1998; Smith and Semazzi, 2014; Thiery et al., 2015, 2016). Long-term environmental data, including the meteorological and biogeochemical data from the surrounding environs as well as within lake data, are essential also to support the development and evaluate models of lake hydrology, hydrodynamics, and ecosystems, which are critical for sustainable management (e.g. mixing regimes (Delandmeter et al., 2018; Kranenburg et al., 2020; Thiery et al., 2014a, 2014b); disentangling the impact of bottom-up drivers versus top- down drivers in fisheries (Kolding et al., 2008); dynamics of invasive species (van Zwieten et al., 2015). Validated models also lead to better forecasting of long-term changes related to human activities or climate, including changes in fisheries and lake level. Such models are also useful for guiding management decisions by predicting the ecosystem response to various management scenarios. Harmonized continuous multi-lake monitoring is a necessity in order to achieve those objectives.

Current state of monitoring in the AGL

A preliminary survey by ACARE-IISD conducted between February and March 2021 (Appendix S1) involved a variety of aquatic experts from institutions, organizations and universities active in the AGL region. Responses on current monitoring were received from 64 African Great Lakes experts.

The results indicated that some lakes have no field stations (Lake Edward and Lake Albert) or regular monitoring sites while others implement routine monitoring activities for a sub-set of indicators (such as for fisheries), or a wider set of indicators during short-term projects or studies. Available information does not allow detailed statistics of the situations, but a map (figure 3) gives an indication of the present state of the situation concerning research stations and long-term monitoring activities. When monitoring takes place, it mainly focuses on fisheries and rarely limnological measurements on a continuous basis.

On Lake Victoria, a harmonized fisheries monitoring among riparian countries is taking place in the frame of the Lake Victoria Fisheries Organization (LVFO) and various Standard Operating Procedures (SOPs) have been set up (LVFO, 2016). LVFO monitors various aspects including fisheries, limnology and, socio-economics though with some gaps. Furthermore, the Lake Kivu Monitoring Programme collaborates with various institutions/universities in Rwanda and DR Congo to conduct a multidisciplinary regular monitoring program of Lake Kivu. Similarly, in Malawi, continuous fisheries monitoring is taking place. Recently installed automated lake buoys provide a platform for monitoring weather parameters and underwater currents measurements. Other monitoring activities are taking place at other lakes but there is no central clearinghouse documenting these efforts.

It was indicated that in various sites on AGL, many activities depend on sporadic funding and/or foreign donor support, which results in irregular and ineffective monitoring. This highlights that lack of adequate funding is one of the main obstacles for long-term monitoring. Several institutions indicated that they have the capacity to conduct monitoring activities if funding is available.

Although various historical observations were made since the end of the 19th century (e.g., Beadle, 1932; Beauchamp, 1939; EAFRO, 1951; Lowe-McConnell, 1997; Moore, 1899; Talling, 1956; Worthington, 1930; etc.), in general in the AGL, there is little baseline data available to assess environmental and anthropogenic stressors. In addition to the setting up of continuous monitoring of key parameters, the collection and rescue of historical data is essential and their accessibility to researchers is very much needed.

Monitoring Themes

In recognition of these urgent needs for sustained data collection on the AGL, we propose a long-term, networked and harmonized approach. In regard to the various environmental and anthropogenic threats on AGL (Bootsma and Hecky, 2003; Hecky et al., 1994; 2010; Kolding, 1995; Kolding et al., 2008; Lung'ayia et al., 2001; Mgaya and Mahongo, 2017; Njiru et al., 2012; Odada and Olago, 2006; Ogutu-Ohwayo et al., 1997), the proposed multi-lakes monitoring is designed to support an ecosystem approach to management. Six main themes/topics are relevant to the harmonized multi-lake monitoring: climate, limnology, fisheries, land-use, biodiversity and socio-economy/human environment (Figure 2 and Table 2):

Climate has a strong impact on the stratification and productivity of African lakes (Barker, 2006; Cohen et al., 2006; Kraemer et al., 2021; Olaka et al., 2010). Therefore, it is essential that meteorological data are continuously collected at each lake. Seasonal changes and particularly trade winds induce an annual limnological cycle of AGL including upwelling, internal waves in stratified lakes and nutrient mixing (Eccles, 1962; Coulter, 1988; MacIntyre, 2013; Naithani et al., 2002; Patterson et al., 2000; Plisnier et al., 1999; Talling, 1966;). An understanding of the regional impact of climate on the AGL in a multi-lake approach, as proposed here, will allow better understanding of how this has an impact on fluctuating fisheries (Kolding and van Zwieten,2012) and ecological conditions linked to particular events such as fish kills and planktonic blooms (Ochumba and Kibaara, 1989). Human pressure also plays a role with important fisheries and land-use impacts on increased sedimentation, particularly affecting the coastal environment and its biodiversity (Bootsma and Hecky, 2003; Hecky et al., 1994; Kolding, 1995; Kolding et al., 2008; Mgaya and Mahongo, 2017; Njiru et al., 2012). The human environment, including various activities such as aquaculture, is also part of the proposed monitoring themes. The acquired data should be able to make significant progress in better understanding AGL ecological cycles and addressing the threats indicated above.

Two methodological aspects are also important and would provide common services to all partners:

- Remote sensing (lake wide parameters, land-use in the lake basins, meteorology)
- Open-source database setup and management

Modeling (fisheries, ecosystems, hydrodynamics, lake level changes etc.) could be undertaken in the longer-term based on the critical indicators that will be selected. In a first step, modeling may address the impact of local climate on the AGL (Lam et al., 2003; Musinguzi et al., 2017; Naithani et al., 2012). In a second step, modeling and teleconnections may link local conditions with global indicators (Indian Ocean dipole, ENSO etc.) that could provide a significant prediction value (Behera et al., 2005; McGlue et al., 2020; Saji et al., 1999). The multi-lake monitoring themes thus open wide perspectives for modeling and forecasting key topics related to AGL ecosystem services, among which are fisheries and water level changes.

Advantages of a harmonized multi-lakes monitoring

Added value results from monitoring the AGL using a harmonized, consistent, multi-lakes approach: acquired experience gained from one lake may have a leveraging effect for a better understanding of other lakes and comparative studies, as freshwater systems have fundamental similarities. Many threats (as listed above) are common to the lakes that are shared by different countries and communities. Common field, analytical, and data management methods would allow information to be more broadly shared and compared. For example, balancing the sustainability of fish stocks with fisheries catch data would be easier with agreed upon approaches and metrics.

These two other important aspects need to be highlighted with respect to multi-lake monitoring:

(1) The various limnological cycles show strong regional similarities and climate patterns linked particularly to trade winds. For example, a southern upwelling is observed at the south of Lake Tanganyika and Lake Malawi/Nyasa/Niassa, while the thermoclines of both lakes are tilted toward the north (Coulter, 1963, 1991; Eccles, 1974). A secondary upwelling has been detected at the northern end of both lakes: around September/October (derived from physical-chemical measurements for the period 1993-1995) at Lake Tanganyika (Plisnier et al, 1999; Plisnier and Coenen, 2001); and in October (remote sensing observations in 1993) at Lake Malawi/Nyasa/Niassa (Patterson and Kachinjika, 1995). North to south downwelling of the thermocline at the onset of the trade winds occurs in L. Victoria as well, and it is not yet clear whether the arrival of cooler water near the bottom to the north at the end of the trade winds is due to relaxation of the tilted thermocline or due to flow of cooler, denser water from the south where evaporation is greater (MacIntyre et al., 2014). These flows are critical for oxygenation of the lower water column and sustained habitat for fish. Important internal waves (seiches) have been observed at Lakes Tanganyika and Malawi/Nyasa/Niassa and also in other AGL (Eccles, 1974; MacIntyre, 2013; Spigel and Coulter, 1996). Simultaneous monitoring would strongly reinforce the links between atmospheric-hydrodynamical processes and ecological responses of AGL including eutrophication, phytoplankton blooms, changes in anoxia and fish kills and would provide a strong

basis for important applications including forecasting the abundance of the main fish stocks and lake levels change with concomitant changes in nutrient loading and depth of mixing.

(2) Similar types of anthropogenic pressure have been observed at the different lakes (overfishing, deforestation, increased sedimentation, pollution, etc.) (Irvine et al., 2019). Since the average population density linked to anthropogenic pressure is different among lakes (43 persons/km^2 at Lake Tanganyika (Xu et al., 2020) compared with 495 persons/km^2 in the Lake Kivu area (Imasiku and Ntagwirumugara, 2020), the multi-lakes monitoring approach offers a strong opportunity to compare the threats that AGL face and to better identify causal factors (Fig.2). This comparison would help managers to select the most appropriate adaptation or management measures favorable to the sustainable use of AGL ecosystems services (Kolding and van Zwieten, 2012).

Although hydrodynamic cycles in relation to climate show similarities, the lakes display also differences in relation to their latitude and depth impacting their thermal stratification and oxygenation (Katsev et al., 2017; Spigel and Coulter, 1996). Those differences will be instructive in the framework of the multi-lake comparison.

The Laurentian Great Lakes can serve as an example of a coordinated international monitoring effort (Burlakova et al, 2018). An agreement between USA and Canada coordinates the monitoring of different programs that each focus on a main area of research: limnological parameters including physical processes, underwater light, and water chemistry; fish and plankton biology; atmospheric deposition; invasive species; coasts and wetlands. There are almost 100 buoys deployed across the Laurentian Great Lakes, owned by companies, universities, and government agencies. Most of these buoys have a variety of different sensors, and their data are publicly available online. There is also a program coordinated by NOAA for remote sensing of the lakes, including toxic algal blooms prediction (www.epa.gov/great-lakes-monitoring).

Multi-lake monitoring: main principles and equipment

Long-term monitoring needs to focus on a few key parameters or indicators only to ensure its maintenance and sustainability (>>40 years) at all stations. The proposed parameters below are based on their importance, ease of implementation and, in particular, “low cost” and robustness. The goal is the acquisition of consistent time series data without gaps in a harmonized way at the seven lakes to allow status and trend evaluations, responses to perturbations, and inter-lake comparisons. Monitoring additional parameters is possible in relation to the long-term availability of qualified staff in charge of instruments calibration and quality data acquisition. The objective is to ensure a sustainable continuous and accessible high-quality data collection. This objective requires that only a few key parameters be monitored (unlike an intense monitoring that can take place during short-term project). An additional consideration is data quality, which requires trained staff, high quality instruments, effective data management, and a quality control quality assurance (QA/QC) protocol that includes regular auditing.

Short-term monitoring is often more intense, and many parameters are measured more frequently. This is not detailed here although it remains essential for specific studies. It is recommended that short-term projects implementing a monitoring program take place simultaneously on more than one lake as much as possible in order to increase the possible comparison between lakes.

The proposed multi-lakes monitoring specifies continuous measurements and a network approach. It requires comparable parameters and methods of monitoring (fisheries, limnology, biodiversity…) while considering as much as possible the currently applied methodologies at the different lakes where continuous monitoring is carried out. Standardization of methods is important and it should be pursued as much as possible.

The monitoring sites are linked to the presence of research stations (infrastructure and staff) nearby the lakes (Irvine et al., 2016). Remote sensing will extend the spatial scale of investigation for the whole region. This topic is detailed below.

It is essential that research stations that are part of the multi-lake monitoring program are located on the shoreline or as close as possible to the lake (at least one station per country and per lake). In the absence of such stations, the countries are encouraged to install them, with possible support from government allocations or donors, in regards to the importance of the lake for the national economy and all exceptional characteristics detailed above. Additional to the staff, each research station needs electricity, water supply and long-term national support related to the mandate of the institution in charge.

Critical equipment and facilities required for a basic monitoring program are presented in (Table 3). In some of the existing stations, it is probable that part of the necessary equipment which; for most of it, is basic, is presently available. An inventory will have to be made of monitoring equipment present in the institutions and additional or spare equipment could be provided by the multi-lake monitoring program depending on the available financial support. For the long-term, a cost sharing (country financing & LT monitoring program) is needed to maintain or replace the targeted equipment. Boats, laboratories, vehicles, etc. are expected to exist at the partner institutions but a budget for maintenance related to the LT monitoring is necessary. Computers and internet connections are critical in addition to quick access to duplicate instruments, spare parts, and consumables such as bottles, containers, ethanol, formalin, fuel, etc. which is related to a "no gaps" objective in time series collection of indicator data. Maintenance of equipment is also crucial.

Mooring method presents an option for the continuous collection of water parameters (particularly temperature) throughout the water column and possibly automated buoys with additional sensors for other important water quality variables and meteorological recording. An ideal location at the northern and southern ends of the larger lakes would allow the real-time collection of data to track the seasonal upwelling events critical to nutrient cycles and fisheries and to link these events to changing meteorological conditions. The safe installation and proper maintenance (biofouling, calibration, etc.) of automatic buoys instruments are, however, necessary for their long-term use and cost effectiveness.

PROCESS FACILITATION

ACARE-IISD may facilitate communication and connect the different partners who will carry out the long-term monitoring, in partnerships with local and international freshwater and fisheries experts. The objective is to harmonize methods among lakes, implement or strengthen the present, long-term monitoring and help to develop it where there is little or none presently. More information is presented at www.agl-acare.org and www.africangreatlakesinform.org/.

A network of freshwater experts on the AGL, with each clustered on a lake as an advisory group, has been established by ACARE (AGL Advisory Groups) with regular monthly and annual meetings. Its role is to exchange information about each lake and to strengthen science, research, and education on the AGL. Such a network increases collaboration opportunities for research and services that managers can call upon if they wish (e.g. sampling and analytical protocols, taxonomic identification, training, quality check, data sharing prerequisites, etc.). This network consists of individual researchers and managers.

SETTING UP THE MULTI-LAKES MONITORING FRAMEWORK

Setting up of a long-term multi-lake monitoring programme is a process involving many partners (individuals, lake users, institutions, funders, managers). Proposed implementation steps are summarized in Figure 4.

(1) Information on each institution related to the management of the AGL is needed. A list including mandated and non-mandated institutions (by their national authorities) is presented in Table 5 (national institutions) and Table 6 (regional institutions). Long-term monitoring is generally implemented by institutions that are mandated by their governments. However, institutions that could usefully be involved in the long-term monitoring could be involved and seek such a mandate from their governments. This is generally linked to a financial support, an authority in some fields (regulations) and a wider dissemination of reports.

(2) Detailed information on current monitoring activities is then needed (methods, frequency, sites, etc.) in order to base the proposed monitoring methods as much as possible on existing methods and possibly on intercalibration (Poikane et al., 2015).

(3) If an institution agrees to join the network of the multi-lakes monitoring programme, then the cooperation could be formalized by signing an agreement to participate in the network. This agreement would specify what information may be shared, as well as the contributions of the parties. Specific data sharing policies exist in various countries and data sharing should be evaluated by the authorities as to the benefits it provides. A general agreement could previously be agreed upon at a high level such as the African Union Development Agency (AUDA) or other multi-national institutions.

(4) Harmonization sessions will then be organized on site with the staff who would be designated in each institution for the monitoring to discuss e.g. field manuals, instruments, methodologies, reporting, database, quality control. In addition, in the case of moored thermistor array or buoys, it would be important to also meet and communicate with fisher organizations, the riparian communities and the security forces about the objectives of collecting data with those instruments, so that the buoys could be adequately deployed and safely maintained.

The database (see below) needs to be operational before the multi-lakes monitoring activities are initiated. The remote sensing component should also reach an advanced stage of implementation before the beginning of the operational phase of the monitoring.

To ease implementation, the multi-lake monitoring could address fisheries, water and meteorological aspects in the first phase of the networking. Biodiversity, land-use, and socio-economic aspects could be added during a second phase.

MONITORING SITES

A few sites (two to five) at each lake are targeted for field monitoring (including at least one site per country). Many of those sites correspond to existing research stations with relevant staff (about 13) while other research stations remain to be installed (7). Some nearby universities could be tasked to conduct regular monitoring activities. Other relevant regional authorities like Water Boards may have stations in the basin that could monitor land-use/erosion and tributaries. Remote sensing could extend the monitoring to a wider area of the lakes and their water basins.

The monitoring sites (also including sites for automatic buoys) are ideally situated at the northern and southern ends of the lakes. This strategy enables capturing the influence of the changing direction of the trade winds (SE and NE) and the resultant upwelling of the thermocline on various lakes. At the deep lakes, the seasonal change of trade winds and the release of tilting of the thermocline activates internal waves (Coulter, 1963; Eccles, 1974; MacIntyre et al., 2002; Spigel and Coulter, 1996). These oscillations of water layers affect the supply of deep, nutrient-rich waters via upwelling to the euphotic surface zone, enabling increased growth of plankton and supply of food to sustain the fisheries in these lakes. Since most lakes have a North-South orientation, a high frequency monitoring of thermal structure at the northern and southern ends is advisable. This approach was applied at Lake Tanganyika with automatic buoys in southern and northern positions (Huttula et al., 2006; Huttula and Sarvala, 2012). Internal waves influenced the limnology of the upper layers (Chitamwebwa, 1999; Langenberg et al., 2003; Naithani et al., 2003; Plisnier et al, 1999). Although these results have illustrated the critical role of the trade winds and resultant internal waves in deep elongated stratified lakes, between year variability in phytoplankton and zooplankton abundance due to El Niño-Southern Oscillation (ENSO) induced variability in duration and magnitude of the trade winds in Lakes Victoria and Kivu (Cozar et al., 2012; Sarmento et al., 2012). Thus, it is critical to investigate the impact of trade winds on lakes' hydrodynamics as a key driver of ecological variability (Delandmeter et al., 2018; Docquier et al., 2016; Naithani et al., 2012) and establish the links between ENSO cycles, with the intensity and frequency of their cycles varying with climate warming (Nakamura et al., 2009; Wolff et al., 2011), and primary productivity and diversity and abundance of fish. It has been shown that ENSO is correlated to the abundance cycles of pelagic fish at Lake Tanganyika (Plisnier, 1997, 1998).

For large lakes, a monitoring research station in their central area is advised to acquire information lakewide.

Important information for the monitoring of fisheries includes recording fish catches corresponding to a defined fishing effort (example: catches by a standard type lift net unit fishing during one night). Such a catch assessment survey (CAS) may be implemented at different geographical scale with various frequencies. A monthly CAS is proposed nearby the research stations. An example of a simple long-term monitoring of a fish community is from Lake Kariba, where a site on the lake nearby the research station in Zimbabwe has been sampled (bi)weekly with a fleet of gillnets almost without interruption since 1960 (Kolding et al., 2003).

For the monitoring of biodiversity, the long-term monitoring considers only a few key taxa at sites that are situated fairly near research stations (maximum of a few hours travel). More investigations need specialists during short-term projects as indicated below and in appendix S1.

For land-use, the calibration sites should also be situated in close-by regions near the field stations of the network, in order to be reachable without much effort. Those sites need to represent as much as possible the various characteristics of the region including erosion sites and at least one tributary to monitor changes of sediments loads.

The socio-economic surveys would be carried out in the nearby areas of the research stations mainly unless special surveys would require a wider spatial investigation.

MULTI-LAKES MONITORING PARAMETERS

The harmonized, long-term, multi-lake monitoring that is proposed includes only a limited number of key indicators or parameters as presented in the below summary Table 4. At some sites, many of those parameters are already measured. For such sites, the present list provides a proposed frequency of sampling and methodology which will enable harmonization.

Limnological parameters

- Water temperature (WT) is an essential parameter as it is linked to the physiology of the organisms in the lakes and to the physical stability and mixing of the lakes. Its monitoring is essential to understand controls on nutrient (N, P, Si) supply in euphotic layers and resultant changes in lake productivity.

- Coastal surface WT measurements (mandatory)

  Recording of WT at the surface near the coast every day at the same time at each station. This will be completed using thermistors placed in safe coastal sites.

- Pelagic WT profile measurements (mandatory)

  Recording of a vertical temperature profile (including the thermocline) of WT in the pelagic area every 15 days (ideally) or every month. Profiling requires a larger-size boat for safe navigation and a temperature probe or a profiler such as CTD.

- Buoy for in-situ near continuous WT measurements (optional)

  A buoy would be equipped with thermistors fixed at various depths to record temperature frequently (every 30 min). Some commercially available buoys are available with winches that raise and lower instruments. Even if a buoy is installed near a research station, the measurement of temperature profiles every 15 days or every month would remain mandatory since loggers can fail or be displaced. Commercially available buoys using winches need regular maintenance while thermistor arrays suspended from buoys and using inductive modems or batteries are self-contained for a year or more. Winch operation would facilitate cleaning of sensors to reduce biofouling, but this feature must be weighed again the usually much larger cost and a higher failure rate or moored arrays. Use of buoys is indicated as optional although a network of automatic buoys would be ideal if their safety could be ensured. These data facilitate evaluation of hydrodynamic models of lakes and their coupling with ecosystem models.

- Remote sensed water temperature readings (to be "ground-truthed").

➢ <u>Pelagic specific conductivity</u> (C) profile (optional).

Specific conductivity can be a good indicator of mixing because of strong vertical difference of conductivity particularly in deep lakes. Calculation of stability requires this parameter in well-mineralized lakes such as Lake Kivu. Because profilers (CTDs) include conductivity sensors, this measurement can be done simultaneously with the WT measurements and at the same depths.

➢ <u>Water transparency</u>

For assessing changes in the concentrations of particles associated with growth of algae or erosion/resuspension or changes in dissolved substances with chromophoric properties, water transparency measurement is a fundamental limnological parameter. Measurement of water transparency enables evaluation of the depth to which primary production can occur. Water transparency is commonly measured using a Secchi disk (SD). In Lake Tanganyika, and probably in most or all AGL, SD transparency in the pelagic zone is correlated with phytoplanktonic concentration (Coulter, 1963; Silsbe et al., 2006). However, in near-shore regions near the mouth of rivers, suspended sediments may contribute.

Since nutrients (N and P particularly) are quickly used for primary production in tropical waters, the measurement of SD is an ideal proxy for plankton abundance and nutrient availability that may thus be measured less frequently such as during short-term projects/studies. Since a SD is cheap to build and easy to operate, it is an ideal parameter for long-term monitoring. When more sophisticated approaches are used (e.g. profiles of photosynthetically active radiation, PAR) the use of a SD is still encouraged to allow comparisons over time and between sites. If sensors are available for the measurement of PAR and calculation of the diffuse attenuation coefficient (k_d), regression equations between SD and k_d can be obtained as k_d is essential for both hydrodynamic and water quality models.

- Coastal SD measurements (mandatory)

  Recording of water transparency using the SD near the coast every week on the same day in the morning at each lake. However, a daily frequency of SD measurement is advisable if possible since this parameter may change rapidly in some deep lakes in relation to e.g. internal waves and planktonic blooms. SD measurement generally requires only a small boat to reach a lake depth corresponding to the maximal transparency that can be observed near the coast at the sampling site.

- Pelagic SD measurements (mandatory)

  Recording of water transparency using the SD in the pelagic area every 15 days (ideally) or every month. This requires a larger size boat (same trip as for WT profiles).

  Profiles of underwater irradiance – When available, or if the instruments can be shared between sites, profiles of photosynthetically available radiation should be obtained to create regressions with Secchi Depth and as needed for physiological studies of phytoplankton and for modeling.

➢ Lake level (mandatory)

Daily recording of lake levels is a simple measurement that is useful for various applications (navigation, constructions along the shores including harbors, hydrological modeling etc.). This measurement may complete information acquired from RS measurements.

➢ Occasional sampling

- Planktonic bloom samples (optional)

When a particularly strong planktonic bloom is observed, it is highly recommended to take a sample every day as long as the bloom lasts (phytoplankton/zooplankton) for measurement of chlorophyll a and to send it at a specialized laboratory for species determination unless it could be done locally. Storage (with preservation) is also an option until further determination could be done.

- Water sample (optional/mandatory)

In case of any suspected form of pollution, a sample should be taken for analysis to a specialized laboratory where the complete list of chemical and microbiological elements and pollutants are tested. A detailed list of those laboratories needs to be established for the region. In case of strong pollution events, such sampling and analysis would be mandatory.

➢ Additional parameters (where feasible):

Weekly or 15-day routine chlorophyll *a* measurement is highly recommended to understand how the lakes change in response to atmospheric forcing and for ground-truthing the data collected by remote sensing. This could start during a short-term project and could be implemented on a regular basis according to each station capacity.

The use of multiparameter probes is feasible across all the AGL, though require resources and capacity to ensure proper maintenance, calibration, and record keeping. Great care must be taken in selection, as some are not well-engineered. Those in use by the oceanographic community are generally of higher quality and accuracy than those typically sold to limnologists. While the needs of individual sites may vary, in addition to WT and conductivity, sensors for dissolved oxygen (optically measured) and pH are recommended. Other sensors such as turbidity, colored dissolved organic matter (CDOM), and chlorophyll fluorescence may be appropriate for specific stations.

Macro-nutrients such as phosphorus and nitrogen, in addition to chlorophyll *a*, represent important indicators to assess the potential productivity of the lakes. However, for deep tropical lakes the hypolimnion waters are always very rich in nutrients and epilimnion water often poor because of their fast use for photosynthesis. The main driver of productivity is the mixing of water that enables those nutrients to reach the euphotic layer.

Other parameters such as silica, calcium, turbidity, dissolved CO_2 and methane, etc. may be important in some lakes but require significant infrastructure and trained staff for analysis. We encourage measurement of key nutrient parameters only if their long-term sustainable monitoring can be assured. Parameters to be measured should be sustainable without putting the main program at risk.

Fisheries parameters

- Catch assessment survey (CAS) (mandatory)

  CAS should take place regularly and preferably covering seasonality. The monthly monitoring of catch rates (= catch per unit of effort (CPUE)) would allow better understanding of fish capture fluctuation in relation to the environmental variability and changes in fisheries (mandatory). A weekly monitoring would be ideal if the capacity of a station can sustain it. At the same time, other than information on catches, information on fishing efforts (boats, gears…) is collected. Less frequent CAS surveys are much less informative. It they are done, they should take place at least every year or two years (as a bare minimum). CAS include sampling of catch rates and the activity patterns (e.g. numbers of days per month spent fishing) of fishing units.

- Frame surveys (FS) (mandatory)

  In a sampling system the "Total annual catch" is calculated by multiplying the average CPUE and Activity pattern (obtained through CAS) of fishing units with the total number of fishing units, the fishing effort. Thus, information on total fishing effort is needed in combination with wider CAS surveys (CPUE, Activity pattern) to calculate the total catch (main fish species) of a lake. Frame surveys includes the number of landing sites, boats, fishing gears, processing facilities, and fisheries related service found near the landing sites. These data can also be the basis for socio-economic analyses. A frame survey is advised every 3 to 4 years and more frequently if possible. Field investigation could be supported by satellite and possibly by drone images.

- Size of fish (mandatory)

  Management efforts in most AGL are related to the size of fish caught, and sampling of size of fish is therefore crucial. New developments in fisheries science put "size" central in the assessments of fish stocks and communities, as size is related to many life-history parameters in fish (Andersen, 2019; Shin et al., 2005; van Zwieten et al., 2016). A random sample of catches (main fish species) is needed. This could be measured at the same time as the monthly CAS near the research stations.

- Biomass/stock assessments (optional)

  Abundance and distribution of key fish species are important parameters that are often lacking in many AGL. Fisheries independent surveys such as hydroacoustic and trawl/gillnet surveys among others are key to monitor the status of the main key fish species. Such surveys could ideally be integrated into the multi-lakes monitoring at all stations. This should be done within an Ecosystem Approach to Fisheries Management (EAFM) (Downing et al., 2014; Garcia et al., 2003, 2016; Garcia and Cochrane, 2005; Natugonza et al., 2019; Njiru et al., 2018; Nyamweya et al, 2016). This requires additional information and might be mandatory according to institutions capacities.

- Other fisheries monitoring (optional)

For institutions with sufficient capacities, additional investigations could include biological analysis of main species, including life-history characteristics as feeding (trophic level) and reproductive behaviour of fish (migration, breeding and nursery habitats) and fish cohort studies.

Meteorology

- Automated weather stations (AWS) (mandatory)

The monitoring of meteorological conditions is essential. With technological advancements, AWS are becoming cheaper and of better quality and observations close to the lake shores (and ideally on the lake in association with automated monitoring buoys) are necessary. The main parameters to record include air temperature, precipitation, rain intensity, wind speed and direction, relative humidity, incoming shortwave and long wave radiation and atmospheric pressure. Remote sensing may also collect regular meteorological data for the entire AGL region including their basins. An AWS measuring the four components of solar radiation (incoming shortwave, outgoing shortwave, incoming longwave and outgoing longwave would be advisable). However, the outgoing terms are only required if the AWS is deployed on the lake. Otherwise, the outgoing terms can be calculated. It is important to note that rainfall over most lakes exceeds the amount of precipitation in the catchment. For that reason, separate monitoring of rainfall over the lake is highly advisable. The official meteorological network remains the recommended reference. Data sharing with the official network is strongly encouraged for stations situated in the lake basins.

Remote sensing

Satellite remote sensing (RS) data with the appropriate spatial, spectral, and temporal scales are available for the AGL and can provide important long-term consistent data over the AGL and their watersheds. Current operational earth observing satellites that provide free data in near real-time include Moderate Resolution Imaging Spectrometer (MODIS) Aqua and Terra, Visible Infrared Imaging Radiometer Suite (VIIRS), Landsat 8, and Sentinel 1, 2, and 3. Other related satellite derived data are processed and made available online for data products such as lake level and precipitation (e.g., Global Reservoirs and Lakes Monitor (G-REALM) and Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)). New satellite sensors and sensor constellations are continually being added to the list of potential resources. Emerging opportunities for acquiring RS data of the AGL and their watersheds include drone platforms to carry hyperspectral imagers, thermal sensors, and synthetic aperture radar.

- Key data that RS can monitor include Chl-a concentration, algal blooms, surface temperature and turbidity. Other data products derived from RS include physical variables such as lake level, wind, waves, precipitation, solar insolation and cloud cover; and biogeochemical variables such as surface layer suspended solids concentration and dissolved colored organic matter concentration. Land use information is also targeted to better identify land use impacts on water quality, erosion and sediments reaching or leaving the lakes. Precipitation monitoring from satellite platforms can supplement and extend measurements made at weather stations.

Creating data products for the AGL requires validation of existing algorithms or development of lake-specific algorithms. Very little RS validation data has been collected in the AGL region so the data products in many cases are known to produce biased or inaccurate data. Lack of validation data is a known issue for atmospheric compensation, water color and derived products, water level, and local and regional precipitation, to name a few. Lake specific remote sensing algorithms require data for development and validation. While limnological field data play a key role in monitoring lakes, various sensing systems on buoys can provide a link between field and satellite data for more rapid development and validation of algorithms. These sensors have the capacity to measure light spectra of lake water absorption, scattering, reflectance, lake surface temperature and fluorescence. Their capacity to measure atmospheric properties for good atmospheric compensation of the satellite signals is also needed. Finally, there must be capacities in the region to process remote sensing data and to provide adequate measurements to validate data products. Emerging online tools like Google Earth Engine now provide free cloud-based computing and streamlined access to RS data that eases otherwise costly data infrastructure requirements (Gomes et al., 2020). Capacity development in drone technology and data processing is also required as access to drone sensing expands.

Biodiversity

The AGL are exceptional for their biodiversity (Darwall et al., 2011). However, this may be seriously reduced due to various factors: invasive species, habitat destruction, fisheries targeting some rare species (ex: aquarium fishing), pollution, high sedimentation rates and other threats (Irvine et al., 2019).

- Changes from the baseline (mandatory)

  Indicating the presence/absence of some key taxa and communities are indicative of the habitat health (e.g. the rock-cichlid communities in the major large lakes). Those key taxa and communities need to be easily identifiable by para-taxonomists (trained non-taxonomists) and they should also be easy to sample, for instance using dipnets or other fishing gears. Observation from snorkeling and diving observations would even be better. This survey is targeting only key fish species and communities (every 2 years; mandatory) as well as their habitats as the riparian vegetation (every 5 years; mandatory) with attention to possible introduced species, such as *Eichhornia crassipes*. This should be done at biodiversity rich areas near the research stations (often coastal sites). The reference collection left by taxonomists will be useful for the monitoring teams. Other taxonomic groups require specialists during short term projects. Important fish biodiversity information could be collected also from the CAS in collaboration with the fishermen (Ticheler et al., 1998).

Other surveys related to biodiversity monitoring are the baseline and the intermittent (Appendix S1) that take place only during short-term projects and thus are not part of the present long-term monitoring proposal. National and international taxonomists experts are needed to implement those surveys, at the same time training potential staff members with interest in taxonomic studies. Future efforts could be expanded to additional well-studied taxonomic groups that are responsive to water quality conditions and food abundance, including mollusks and birds.

Land use

Within the AGL catchment, the increased population contributes to land-use changes including wetland conversion and deforestation for agriculture as well as urbanisation. Wetland conversion or degradation and agricultural practices (e.g. cultivation on steep slopes) may induce an accumulation of silt affecting transparency, turbidity, and dissolved oxygen, as well as increased nutrient loading resulting in eutrophication, increase of pesticides and other agrochemicals in water and sediments (Getenga et al., 2004; Madadi et al., 2005; Musa et al., 2011; Osano et al., 2003; Thenya et al., 2006).

The monitoring of land use includes maps (RS) of the whole lakes' watershed. ESA CCI Land cover provides some of this information at the global scale. Field observations at some sites are necessary for calibration of RS informationnear each research station. The objective is to check on the field a diversity of land surfaces corresponding to RS acquired information.

The following information is targeted every 2 or 3 years in a few localized sites only.

- Surface use for agriculture, pasture, fallow land, savanna, forest, etc.
- Surface use on exposed soil by slope categories
- Erosion and landslides or gully hazard risk assessment
- Population density

Quantification of land use impact on the lakes can be based on the measurement of suspended sediment concentration in rivers (Donohue et al., 2003). This measurement would target one river per calibration-site if it can be done frequently. This and possible additional measurements related to rivers (level, nutrients etc.) will be discussed in a next stage with local institution in relation to the existing network and institutions capacities.

Socio-economy/human environment

Socio-economic indicators target mainly (but not exclusively) key information linked to the human pressure on fished ecosystems and associated fish products in the value chain:

- Fishermen (population statistics, income)
- Fish abundance, size and prices at the market (main species)
- Aquaculture statistics (number of cages, fish species)
- Specific surveys (variable topics related to fisheries, lake and human population)

These are additional indicators to monitor the anthropogenic impact on the resources and the environment, however, they do not not target a full-size investigation of socio-economy at an AGL. The key indicators that are targeted are coherent with the objective of increased understanding of AGL and allow detailing various man activities related to lakes and some primary effects of anthropogenic pressure linked to key indicators (CPUE, catch, size) sampled for fisheries assessment purposes (Kolding et al., in prep.). Specific surveys will allow documenting questions related to the anthropogenic environment including health, trade routes, traditional knowledge, fatalities, conflicts among fishermen (especially at regional level) etc. During some periods such as every year or two years, different topics could be addressed. Selection of key socio-economic indicators could follow a dedicated process designed to identify indicators that allow assessments of importance to local communities and governments (Liberati et al., 2020).

ADAPTABLE MONITORING AT SOME SITES

The description above corresponds to the "standard monitoring" with a level of intensity that is likely to be achievable at most sites. However, a preliminary survey identified two other cases:

(1) Sites with no lake monitoring stations: It is proposed that at these sites, a reduced monitoring program could be implemented with a lower frequency of measurements until a monitoring station (infrastructure, staff) is installed within a specific timeframe. Such less-intensive monitoring could be implemented by partner institutions ideally situated in the region. For example, at Lakes Albert and Edward (D.R. Congo and Uganda) and at Lake Turkana in Ethiopia there are no stations with permanent staff presently. In these cases, institutions/universities situated in the region (< 300 km for example) could monitor some parameters at a lower frequency than the rest of the network such as once or twice per year. The list of parameters for a reduced monitoring program needs to be discussed with partners to fit local possibilities, needs.

(2) Sites with enhanced capacity (staff, laboratory etc.): It is proposed that at sites with capacity above the network average, a more intense monitoring (with more parameters) could be implemented. Members of the Lake Victoria Basin Commission at Lake Victoria indicated such a possibility during the recent IISD-ACARE survey. Some lake-specific monitoring parameters could be added (e.g., CO_2 and CH_4 at Lake Kivu) if they could sustainably be monitored.

DATA MANAGEMENT

The most common water quality evaluation methods are i) in-situ data analysis based on data generated from direct measurements in the water systems and laboratory analysis, ii) water quality modelling, and iii) remote sensing/satellite imagery (World Water Quality Alliance, 2021). Overall, there is a reliance on in-situ data collected via either grab samples for laboratory analysis or in-situ water quality measurements (such as data loggers). Grab samples have a limited temporal detail in data, while data loggers often have a lack of spatial detail due to the cost of the equipment. This is exacerbated by valid concerns around data sharing by data owners (United Nations, 2021). As a result, there is a need to promote data sharing between institutions and countries at transboundary lakes.

New monitoring data will need processing (quality checking, flagging, integration into a usable and unique database providing various tools for data retrieval) and a safe long-term storage. Also, it would be appropriate to gather historical monitoring data as a baseline for comparisons and evaluation of changes taking place at the AGL.

To enhance data sharing and information access, ACARE and University of Nairobi's open-source African Great Lakes Information Platform (www.africangreatlakesinform.org) could be a common database for all partners. It will allow each partner to upload and retrieve information. Importantly, uploaded information needs to be checked for quality before being fully integrated into the database. The management of such a central database needs to be discussed and agreed upon by all partners. The Great Lakes Observing System (https://glbuoys.glos.us/) and the open database on Swiss lakes (www.datalakes-eawag.ch) could provide a model

An upgrade/ initiation of localized databases at research stations in the different partner states would be carried out in the framework of training or harmonization sessions.

The exchange of collected information among partners is a key point for enabling a better understanding of interannual variability of many lakes through comparative data. For lake levels, comparable data at some lakes (Stager et al., 2007) indicates that large-scale climate fluctuations impact the AGL region. Sharing data is easier when partners appreciate the benefit that it brings not only to the network but also to individual researchers. Accessible shared data needs the development of a common data-management system, with agreed upon data types and formats that allow for better collaboration between organizations/institutions/countries (Poikane et al., 2015; United Nations, 2021). A common database with agreed Standard Operating Procedure will allow each partner to decide what data can be shared, while publication priority regulations after several years of data collection ensure that appropriate credits are given for the hard work of scientists who have collected the data. Long-term data will help short-term projects with data while short-term projects data could facilitate the general database once collected data have been published.

Some regulations should be set up for data accessibility to a wider community as this is expected to multiply the interest of the monitoring in addition to the optimal use of the information and an increased support from various organizations. An example is the GEMS/Water Data Policy (gemstat.org) which allows data providers to select from three different levels of data sharing. This standard protocol ensures data providers retain data ownership and recognition

Sharing of data could multiply the database size by seven (at the lake level) and by as much as the number of monitoring sites (~20). Comparing time-series data increases the scientific benefits of collected data by giving them a wider perspective for interpretation, leading each participant, each institution and indeed each country to a win-win collaboration. Undoubtedly, this is expected to boost science and benefit managers in their efforts toward the long-term sustainable management of the lakes.

INSTITUTIONAL FRAMEWORK OF THE AGL

A preliminary survey (Appendix S2), in the framework of the ACARE-ISSD freshwater experts network, has allowed the gathering of information on institutions in each AGL country in relation to fisheries, water quality, biodiversity, land use/erosion, climate and socio-economy (Table 5 a,b,c). It investigated if those institutions were active for the lakes, for their basins or both.

For the long-term monitoring (>> 40 years), implementing institutions need the official mandate from their governments (Table 5). Other institutions that are interested in AGL but not mandated (such as universities for example) are often involved during short-term monitoring made possible by the funding of short-terms projects often covering a few years at most. Many members of these non-mandated institutions have indicated their willingness to be involved in long-term monitoring (e.g. various universities in D.R. Congo seem to be the only institutions situated near some lakes with the required human capacities to presently implement a monitoring).

Several regional institutions identified in the AGL region are presented in Table 6. These institutions would be ideal to help with the implementation of the multi-lake monitoring in their partners countries. Harmonized fishery monitoring between Kenya, Tanzania and Uganda is currently taking place on Lake Victoria in the framework of the Lake Victoria Fisheries Organization (LVFO), an institution of the East African Community (EAC). The LVFO convention was amended in 2016 to expand the scope to cover all EAC Partner States and is mandated to cover all waterbodies. To add on, the Republic of Burundi has joined the membership while The Republic of Rwanda and South Sudan are still in the process of fulfilling the requirement of depositing the instrument of accession with the Director General of FAO (This organization is a depository of all Regional Fisheries Management bodies legal instruments in the world as provided in the UN charter of the FAO, CAP 102. LVFO as one of the Regional Fisheries Management bodies, its Convention is deposited there. Therefore, any changes to the convention and membership must be requested through the Director General of FAO. For any country to join LVFO, it must submit instrument of accession to FAO). This means that five countries (riparian of the seven Great Lakes) are part of the same political union where an institution has already started to implement a harmonized monitoring activity.

For Lake Tanganyika basin, the Lake Tanganyika Authority launched a preliminary initiative related to a long-term monitoring about a decade ago (Plisnier and Marijnissen, 2010). At Lake Kivu, exists the monitoring program (Lake Kivu Monitoring Program, LKMP) owned by the Rwandan Government, supported by a strong collaboration with Congolese institutions (Institut Supérieur Pédagogique de Bukavu and Goma Volcanological Observatory), a framework under which ongoing collaborative capacity building projects are being implemented.

Identifying the key institutions will be important since it would not be possible to involve all the AGL-related institutions in the harmonized long-term monitoring. In addition to the institutions in Table 6, it is interesting to recognize the existence of the Regional Centre for Mapping of Resources for Development (RCMRD), as an inter-governmental organization established in 1975 and currently has contracting Member States in the Eastern and Southern Africa Regions. RCMRD provides Spatial Decision Support Systems, GIS Application in the Management of Natural Resources, Flood Prediction & Modeling and has been very instrumental in supporting LVFO to develop satellite and mapping based services. LVFO and RCMRD have running MOU and implemented a several activities including water quality monitoring and forest cover mapping.

For the successful implementation of the proposed long-term, multi-lake monitoring, an agreement and active support of each of the national authorities will be necessary and desirably backed by multi-national authorities.

AN INTERNATIONAL CONSORTIUM

Although the need for monitoring is widely recognized, local government often do not have sufficient funds to support while international funding is rarely available for long-term projects. As Lovett et al. (2007), we urge government agencies and other funding institutions to make greater commitments to increasing the amount and long-term stability of funding for environmental monitoring programs. The benefit for AGL management and research is huge in regards to costs.

What would be the expected costs? If the needed new research stations (seven out of twenty) are funded separately, the costs would concern:

(1) Initial equipment and harmonization sessions.
(2) Functioning costs related to monitoring (staff, boat's fuel and oil, maintenance).
(3) Remote sensing component: initial procedures, training and operating team.
(4) Database: setting up and operating team.
(5) Reporting.

In relation with the importance of the AGL, the needed data from monitoring require an innovative approach for funding. One possibility is the development of a trust with sufficient funds so that the earnings from the trust are used to provide long-term support (self-sustaining). Another approach is that a great number of participants (and/or a few main donors) join a consortium (with regular subscriptions) to support the cost of the monitoring.

Given the primary importance of the AGL ecosystems globally, there is no doubt that various institutions will consider being actively involved to participate in the sustainable use of these major resources. This consortium (possibly called "Friends of AGL") could involve a great number of stakeholders (international agencies as FAO and World fish, UNEP, UNDP, WMO, research agencies, multilateral and bilateral cooperation agencies, universities, NGOs, foundations, public funding etc.) interested in the AGL ecosystems, their long-term sustainability, research, biodiversity, preservation of natural sites etc. Such support by this consortium would be continuous and could override the problem of short-term projects funding that are by essence restricted to a few years of data collection only. Funding by enterprises that do have commercial interest in the AGL should however be excluded.

Such a consortium exists for another world biological hotspot: the Galapagos Islands. The "Charles Darwin Foundation" has developed inter-institutional agreements with many governmental institutes, national and international universities, and private organization. It promotes the causes of joint research projects, facilitation of research amongst many other topics related to this other exceptional environment. (www.darwinfoundation.org/en/other-institutions). This consortium could be an example of what is proposed here for the AGL multi-lake continuous monitoring.

CONCLUSIONS

The main African Great Lakes (AGL) and their basins provide invaluable resources and ecosystem services to populations of 11 countries: Burundi, D.R. Congo, Ethiopia, Kenya, Malawi, Mozambique, Rwanda, South Sudan, Tanzania, Uganda, and Zambia. Various anthropogenic and environmental pressures and drivers threaten the AGL in the fields of water quality, fisheries, climate change, biodiversity, land use and socio-economics related to anthropic pressure particularly. Managers and researchers need a set of ongoing indicators to evaluate trends in environmental changes to better understand those complex ecosystems. Presently, long-term, continuous data sets are few and existing data often remain inaccessible to researchers. This situation is not favorable for a scientific approach to management as managers often lack the necessary information needed for sustainable environmental and fisheries management.

The present manuscript proposes a few key parameters to be monitored and that could form a common basis to inform managers and decision makers for the sustainable management of the AGL. The objective is also the acquisition of consistent time series of data in a harmonized way for the seven lakes. Multi-lake monitoring presents multiple advantages to improve the understanding of the AGL's ecological functioning which is essential to address the various threats that are all related in one way or another to the lake ecosystems and the impacts of climate and/or regional anthropogenic pressures and drivers.

To reach the AGL multi-lake, continuous monitoring objective, two to five stations per lake (depending on its size) would be necessary (total: ~20 stations). The information would be collected locally near those stations but a remote sensing service as a common service for the entire AGL monitoring network would spatially increase the information collected.

In the AGL, the mixing of water and the associated availability of nutrients in the upper zone where light can support photosynthesis is essential to understand their productivity. In addition to the field monitoring, a network of automatic buoys with sensors (mainly thermistors, possibly including meteorological measurements) could collect important data to allow the increased understanding of the lakes' hydrodynamics in relation to climate variability and change. It is expected that this could be followed by modeling of important topics including forecasting of: fisheries production, eutrophication, and water level changes.

Steps toward such a long-term monitoring network for the African Great Lakes have been proposed (here above) and discussed during various ACARE-IISD meetings. The main institutions will be asked to participate in the monitoring network. Their national authorities are aware of the importance of the AGL and could authorize their participation. Regional organizations could be helpful to set up and possibly coordinate the proposed multi-lake monitoring that concerns so many countries sharing the same lake problems.

Each partner of the multi-lake monitoring network acknowledges that it is essential to collect and exchange data. Therefore, increased information, available to each country and network partners, is expected to boost the knowledge of the AGL and provide managers of each country with the necessary and best information on which to better base their management decisions in the various fields related to the sustainable use of ecosystem services provided by the AGL.

AGL challenges are huge and need a variety of specialists in a range of disciplines (taxonomy, hydrodynamics, remote sensing, climate science, fisheries ecology, social sciences etc.). Key for this is the collaboration with the national, regional and international community that will strengthen the network. It is anticipated that a support will be brought by an international consortium (international agencies, universities, NGOs…) interested in the AGL ecosystems. Such a consortium could be built with the help of ACARE that has already developed a network of freshwater experts on the African Great Lakes who meet regularly monthly and annually to exchange information and data.

Lakes are effective sentinels for climate change because they are sensitive to climate, respond rapidly to change, and integrate information about changes in the catchment (Adrian et al., 2009). Their value for paleo-climate reconstruction is well established (Cohen, 2018; Johnson and Odada, 1996; Johnson et al., 2002). Lake levels may be considered as an index of the global hydrological cycle (Street-Perrott and Harrison, 1984). Given the importance of AGL, among the largest lakes in the world, they thus present a considerable interest as indicator of past and present ecological changes on earth.

The authors of this paper, many with decades of experience in the region, have unanimously agreed on the vital importance of long-term data series, and have detailed essential aspects (principles, parameters, steps) to develop the multi-lake harmonization of long-term monitoring of the AGL as needed to support the sustainable use of the AGL in providing essential resources and services for > 90 million inhabitants in the region.

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

Many thanks to all AGL experts, particularly from AGL countries, who contributed with ideas and other information during discussions to develop a harmonized long-term monitoring plan for this long-term monitoring proposal. We also thank the ACARE and the IISD for supporting this work and a preparatory survey. The setting up of a network of advisory groups at each lake by ACARE-IISD has greatly facilitated the preparation of the present proposal.

1. REFERENCES

AGL, 2017. Resolution of the African Great Lakes Conference: Conservation and development in a changing climate (Entebbe, Uganda), 5th May 2017.

Adrian, R., O'Reilly, C.M., Zagarese, H., Baines, S.B., Hessen, D.O., Keller, W., Livingstone, D.M., Sommaruga, R., Straile, D., Van Donk, E., Weyhenmeyer, G.A., Winder, M., 2009. Lakes as sentinels of climate change. Limnol. Oceanogr. 54, 2283–2297. https://doi.org/10.4319/lo.2009.54.6_part_2.2283.

Andersen, K.H., 2019. Fish ecology, evolution and exploitation: a new theoretical synthesis. Princeton University Press, Princeton and Oxford.

Atkins, J.P., Burdon, D., Elliott, M., Gregory, A.J., 2011. Management of the marine environment: Integrating ecosystem services and societal benefits with the DPSIR framework in a systems approach. Mar. Pollut. Bull. 62, 215–226. https://doi.org/10.1016/j.marpolbul.2010.12.012.

Bahlai, C.A., Hart, C., Kavanaugh, M.T., White, J.D.,Ruess, R.W., Brinkman, T.J., Ducklow, H.W , Foster, D.R., Fraser, W.R., Genet, H., Groffman, P.M., Hamilton, S.K., Johnstone, J.F., Kielland, K., Landis, D.A., Mack, M.C., Sarnelle, O., Thompson, J.R., 2021. Cascading effects: insights from the U.S. Long Term Ecological Research Network. Ecosphere 12, e03430. https://doi.org/10.1002/ecs2.3430.

Bakibinga-Ibembe, J.D., Said, V.A., & Mungai, N.W., 2011. Environmental laws and policies related to periodic flooding and sedimentation in the Lake Victoria Basin (LVB) of East Africa. Afr. J. Environ. Sci. Technol. 5, 367–380.

Balagizi, C.M., Kasereka, M.M., Cuoco, E., Liotta, M., 2018a. Influence of moisture source dynamics and weather patterns on stable isotopes ratios of precipitation in Central-Eastern Africa. Sci. Total. Environ. 628–629, 1058-1078. https://doi.org/10.1016/j.scitotenv.2018.01.284.

Balagizi, C.M., Kies, A., Kasereka, M., Tedesco, D., Yalire, M., McCausland, W., 2018b. Natural hazards in Goma and the surrounding villages, East African Rift System. Nat. Hazards 93, 31–66. https://doi.org/10.1007/s11069-018-3288-x.

Bärenbold, F., Boehrer, B., Grilli, R., Mugisha, A., von Tümpling, W., Umutoni, A., Schmid, M., 2020. No increasing risk of a limnic eruption at Lake Kivu: Intercomparison study reveals gas concentrations close to steady state. PloS one 15, e0237836. https://doi.org/10.1371/journal.pone.0237836.

Barker, P.A., 2006. The impact of climate change on East African lakes: Cyclical changes and contingent events. Verh. Internat. Verein. Theor. Angew. Limnol. 29, 1854–1856. https://doi.org/10.1080/03680770.2006.11903011.

Beadle, L. C., 1932. Scientific results of the Cambridge Expedition to East African Lakes, 1930-1. –4. The waters of some East African Lakes in relation to their fauna and flora. Zool. J. Linn. Soc. – Lond. 38(258), 157–211. https://doi.org/10.1111/j.1096-3642.1932.tb00699.x.

Beauchamp, R.S.A., 1939. Hydrology of Lake Tanganyika. Int. Revue ges. Hydrobiol. 39, 316–353. https://doi.org/10.1002/iroh.19390390303.

Behera, S.K., Luo, J.-J., Masson, S., Delecluse, P., Gualdi, S., Navarra, A., Yamagata, T., 2005 Paramount Impact of the Indian Ocean Dipole on the East African Short Rains: A CGCM Study. J. Clim. 18, 4514–4530. https://doi.org/10.1175/JCLI3541.1.

Bergonzini, L., Richard, Y., Petit, L., Camberlin, P., 2004. Zonal circulations over the Indian and Pacific Oceans and the level of lakes Victoria and Tanganyika. Int. J. Climatol. 24, 1613–1624. https://doi.org/10.1002/joc.1089.

Birkett, C., Murtugudde, R., Allan, T., 1999. Indian Ocean climate event brings floods to East Africa's lakes and the Sudd Marsh. Geophys. Res. Lett. 26, 1031–1034. https://doi.org/10.1029/1999GL900165.

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 (Suppl. 2), 3–18. https://doi.org/10.1016/S0380-1330(03)70535-8.

Bompangue, N.D., Giraudoux, P., Plisnier, P.-D., Mutombo Tinda, A., Piarroux, M., Sudre, B., Horion, S., Muyembe Tamfum, J.-J., Kebela Ilunga, B., Piarroux, R., 2011. Dynamics of Cholera Outbreaks in Great Lakes Region of Africa, 1978–2008. Emerg. Infect. Dis. 17, 2026–2034. https://doi.org/10.3201/eid1711.110170.

Burlakova, L.E., Hinchey, E.K., Karatayev, A.Y, Rudstam, L.G. , 2018. U.S. EPA Great Lakes National Program Office monitoring of the Laurentian Great Lakes: insights from 40 years of data collection. J. Great Lakes Res. 44, 535–538. https://doi.org/10.1016/j.jglr.2018.05.017.

Burnett, A.P., Soreghan, M.J., Scholz, C.A., Brown, E.T., 2011. Tropical East African climate change and its relation to global climate: A record from Lake Tanganyika, Tropical East Africa, over the past 90+ kyr. Palaeogeogr. Palaeoclimatol.Palaeoecol. 303, 155–167. https://doi.org/10.1016/j.palaeo.2010.02.011.

Chitamwebwa, D.B.R., 1999. Meromixis, stratification and internal waves in Kigoma waters of Lake Tanganyika. Hydrobiologia 407, 59–64. https://doi.org/10.1023/A:1003716914421.

Cohen, A.S., Soreghan, M.J. and Scholz, C.A. 1993. Estimating the age of formation of lakes: an example from Lake Tanganyika, East African Rift system. Geology 21, 511–514. https://doi.org/10.1130/0091-7613(1993)021<0511:ETAOFO>2.3.CO;2.

Cohen, A.S., Lezzar, K.E., Cole, J., Dettman, D., Ellis, G.S., Gonneea, M.E., Plisnier, P.-D., Langenberg, V., Blaauw, M., Zilifi, D., 2006. Late Holocene linkages between decade-century scale climate variability and productivity at Lake Tanganyika, Africa. J. Paleolimnol. 36, 189–209. https://doi.org/10.1007/s10933-006-9004-y.

Cohen, A.S., 2018. The past is a key to the future: Lessons paleoecological data can provide for management of the African Great Lakes. J. Great Lakes Res. 44, 11421153. https://doi.org/10.1016/j.jglr.2017.10.001.

Coulter, G.W., 1963. Hydrological changes in relation to biological production in southern Lake Tanganyika. Limnol. Oceanogr. 8, 463–477. https://doi.org/10.4319/lo.1963.8.4.0463.

Coulter G. W., 1988. Seasonal hydrodynamic cycles in Lake Tanganyika. Verh. Internat. Verein. Theor. Angew. Limnol. 23, 86– 89. https://doi.org/10.1080/03680770.1987.11897907.

Coulter, G.W. (Ed.), 1991. Lake Tanganyika and its life. Oxford University Press, London. https://doi.org/10.1002/aqc.3270010210.

Cózar, A., Bruno, M., Bergamino, N., Úbeda, B., Bracchini, L., Dattilo, A.M., Loiselle, S.A., 2012. Basin-scale control on the phytoplankton biomass in Lake Victoria, Africa. PLoS One 7, e29962. https://doi.org/10.1371/journal.pone.0029962.

Darwall, W.R.T., Smith, K.G., Allen, D.J., Holland, R.A, Harrison, I.J., Brooks, E.G.E. (Eds.), 2011. The Diversity of

Life in African Freshwaters: Under Water, Under Threat. An analysis of the status and distribution of freshwater species throughout mainland Africa. IUCN, Cambridge, United Kingdom and Gland, Switzerland.

Deirmendjian, L., Descy, J.-P., Morana, C., Okello,W., Stoyneva-Gärtner, M.P., Bouillon, S., Borges, A.V., 2021. Limnological changes in Lake Victoria since the mid-20th century. Freshw. Biol. 66, 1630–1647. https://doi.org/10.1111/fwb.13780.

Delandmeter, P., Lambrechts, J., Legat, V., Vallaeys, V., Naithani, J., Thiery, W., Remacle, J.-F., Deleersnijder, E., 2018. A fully consistent and conservative vertically adaptive coordinate system for SLIM 3D v0.4 with an application to the thermocline oscillations of Lake Tanganyika. Geosci. Model Dev. 11, 1161–1179. https://doi.org/10.5194/gmd-11-1161-2018, 2018.

Docquier, D., Thiery, W., Lhermitte, S., van Lipzig, N., 2016. Multi-year wind dynamics around Lake Tanganyika. Clim. Dyn. 47, 3191–3202. https://doi.org/10.1007/s00382-016-3020-z.

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. Env. Geol. 44, 448–455. https://doi.org/10.1007/s00254-003-0779-0.

Doran, P. J., Medard, M., Apse, C.D., 2018. The 2017 African Great Lakes Conference: Conservation and development in a changing climate. J. Great Lakes Res. 44, 1137–1141. https://doi.org/10.1016/j.jglr.2018.10.009.

Downing, A.S., van Nes, E.H., Balirwa, J.S., Beuving, J.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. Ecology and Society, 19(4), 31. https://doi.org/10.5751/ES-06965-190431.

East African Fisheries Research Organization, 1951. Hydrology and algology. Annual Report 1950. Government Printer, Nairobi.

Eccles D.H. 1962 An internal wave in Lake Nyasa and its probable significance in the nutrient cycle. Nature, 194, 832–833. https://doi.org/10.1038/194832a0.

Eccles, D.H., 1974. An outline of the physical limnology of Lake Malawi (Lake Nyasa). Limnol. Oceanogr. 19, 730–742. https://doi.org/10.4319/LO.1974.19.5.0730.

Gabagambi, N.P., Skorping, A., 2018. Spatial and temporal distribution of *Ligula intestinalis* (Cestoda: Diphyllobothriidea) in usipa (*Engraulicypris sardella*) (Pisces: Cyprinidae) in Lake Nyasa. J. Helminthol. 92, 410: 410–416. https://doi.org/10.1017/S0022149X17000724.

Gabagambi, N.P., Skorping, A., Chacha, M., Kihedu, K.J., Mennerat, A.,2020. Life history shifts in an exploited African fish following invasion by a castrating parasite. Ecol. Evol. 10, 13225–13235. https://doi.org/10.1002/ece3.6917.

Garcia, S.M., Zerbi, A., Aliaume, C., Do Chi, T., Lasserre, G., 2003. The ecosystem approach to fisheries. Issues, terminology, principles, institutional foundations, implementation and outlook. FAO Fisheries Technical Paper, Food and Agriculture Organization of the United Nations, Rome.

Garcia, S.M., Cochrane, K.L., 2005. Ecosystem approach to fisheries: a review of implementation guidelines. ICES J. Mar. Sci 62, 311–318. https://doi.org/10.1016/j.icesjms.2004.12.003.

Garcia, S. M., Rice, J., Charles, A., 2016. Bridging fisheries management and biodiversity conservation norms: potential and challenges of balancing harvest in ecosystem-based frameworks. ICES J. Mar. Sci. 73:1659–1667. https://doi.org/10.1093/icesjms/fsv230.

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, 335–343. https://doi.org/10.1007/s00128-003-9107-3.

Gomes, V.C.F., Queiroz, G.R., Ferreira, K.R., 2020. An overview of platforms for big earth observation data management and analysis. Remote Sens. 12, 1253. https://doi.org/10.3390/rs12081253.

Gownaris, N.J., Rountos, K.J., Kaufman, L., Kolding, J., Lwiza, K.M.M., Pikitch, E.K., 2018. Water level fluctuations and the ecosystem functioning of lakes. J. Great Lakes Res. 44, 1154–1163. https://doi.org/10.1016/j.jglr.2018.08.005.

Glaser, S.M., Hendrix, C.S., Franck, B., Wedig, K., Kaufman, L., 2019. Armed conflict and fisheries in the Lake Victoria basin. Ecol. Soc. 24, 25. https://doi.org/10.5751/ES-10787-240125.

Haambiya, L., Kaunda, E., Likongwe, J., Kambewa, D., Chama, L., 2015. Co-management driven enforcement of rules and regulations on Lake Tanganyika, Zambia. Int. J. Fish. Aquat. Stud. 2(6), 73–80.

Hampton, S.E., Scheuerell, M.D., Church, M.J., Melack, J.M., 2019. Long- term perspectives in aquatic research. Limnol. Oceanogr. 64, S2-S10. https://doi.org/10.1002/lno.11092.

Heather-Clark, S., de Jong, A., 2007. Strategic Environmental and Social Overview of Lake Albert, Uganda. Lake Overview Report, Environmental Resources Management, South Africa (Pty) Ltd.

Hecky, R.E., Bugenyi, F.W.B., Ochumba, P., Talling, J.F., Mugidde, R., Gophen, M., Kaufman, L., 1994. Deoxygenation of the deep water of Lake Victoria, East Africa. Limnol. Oceanogr. 39: 1476–1481. https://doi.org/10.4319/lo.1994.39.6.1476.

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 (Suppl. 1), 19–42. https://doi.org/10.1111/j.1365-2427.2009.02374.x.

Huttula, T., Huttunen, O., Podsetchine, V., Peltonen, A., Kotilainen, P., Mölä, H., 2006. Hydrodynamics and thermal regime of Lake Tanganyika. Verh. Internat. Verein. Limnol. 29, 1174–1177. https://doi.org/10.1080/03680770.2005.11902869.

Huttula, T., Sarvala, J., 2012. Tanganyika Lake: Strong in hydrodynamics, diverse in ecology. In: Bengtsson, L., Herschy, R.W., Fairbridge, R.W. (Eds.), Encyclopedia of Lakes and Reservoirs. Springer, Dordrecht, pp. 776–782. https://doi.org/10.1007/978-1-4020-4410-6_168.

Imasiku, K., Ntagwirumugara, E., 2020. An impact analysis of population growth on energy-water-food-land nexus for ecological sustainable development in Rwanda. Food Energy Secur. 9, e185. https://doi.org/10.1002/fes3.185.

Irvine, K., Castello, L., Junqueira, A., Moulton, T., 2016. Linking ecology with social development for tropical aquatic conservation. Aquat. Conserv. Mar. Freshw. Ecosyst. 26, 917–941. https://doi.org/10.1002/aqc.2706.

Irvine, K., Etiegni, C.A., Weyl, O.L.F., 2019. Prognosis for long-term sustainable fisheries in the African Great Lakes. Fish. Manag. Ecol. 26, 413–425. https://doi.org/10.1111/fme.12282.

Iwaniec, D.M., Gooseff, M., Suding, K.N., Samuel Johnson, D., Reed, D.C., Peters, D.P.C., Adams, B., Barrett, J.E., Bestelmeyer, B.T., Castorani, M.C.N., Cook, E.M., Davidson, M.J., Groffman, P.M., Hanan, N.P., Huenneke, L.F., Johnson, P.T.J. , McKnight, D.M, Miller, R.J., Okin, G.S., Preston, D.L., Rassweiler, A., Ray, C.,. Sala, O.E., Schooley, R.L., Seastedt, T., Spasojevic, M.J., Vivoni, E.R., 2021. Connectivity: insights from the U.S. Long Term Ecological Research Network. Ecosphere 12, e03432. ttps://doi.org/10.1002/ecs2.3432.

Jane, S.F., Hansen, G.J.A., Kraemer, B.M., Leavitt, P.R., Mincer, J.L.,North, R.L., Pilla, R.M., Williamson, C.E., Woolway, R.I., Arvola, L., Chandra, S., DeGasperi, C.L., Diemer, L., Dunalska, J., Erina, O., Flaim, G., Grossart, H., Hambright, K.D., Hein, C., Hejzlar, J., Janus, L.L., Jenny, J., Jones, J.R., Knoll, L.B., Leoni, B., MacKay, E., Matsuzaki, S.S., McBride, C., Müller-Navarra, D.C., Paterson, A.M., Pierson, D., Rogora, M., Rusak, J., Sadro, S., Saulnier-Talbot, E., Schmid, M., Sommaruga, R., Thiery, W., Verburg, P.,Weatherz, K.C., Weyhenmeyer, G.A., Yokota, K., Rose, K.C., 2021. Widespread deoxygenation of temperate lakes. Nature 594, 66–70. http://dx.doi.org/10.1038/s41586-021-03550-y.

Johnson, T.C., Odada, E.O., (Eds.) 1996. The Limnology, Climatology and Paleoclimatology of the East African Lakes. Gordon and Breach Publishers, Amsterdam. https://doi.org/10.1201/9780203748978.

Johnson, T.C., Brown, E.T., McManus, J., Barry, S., Barker, P., Gasse, F., 2002. A high-resolution paleoclimate record spanning the past 25,000 years in southern East Africa. Science 296(5565), 113132. https://doi.org/10.1126/science.1070057.

Kanangire, C.K, Matano, A.S., Ally-Said, Dida, G.O., & Anyona, D., 2018. A systematic review of effects of emerging pollutants on human health and livelihoods of population living in the Lake Victoria basin of Kenya. Technical report, UNESCO-IHP International Initiative on Water Quality.

Katsev, S., Aaberg, A.A., Crowe, S.A., Hecky, R.E., 2014. Recent warming of Lake Kivu. PloS One 9, e109084. https://doi.org/10.1371/journal.pone.0109084.

Katsev, S., Verburg, P., Llirós, M., Minor, E.C., Kruger, B.R., Li, J., 2017. Tropical meromictic lakes: specifics of meromixis and case studies of Lakes Tanganyika, Malawi, and Matano. In: Gulati, R.D., Zadereev, E., Degermendzhi, A.G. (Eds.), Ecology of Meromictic Lakes. Ecological Studies 228, Springer International Publishing, pp. 277–323. https://doi.org/10.1007/978-3-319-49143-1.

Kolding, J., 1995. Changes in species composition and abundance of fish populations in Lake Turkana, Kenya. In: Pitcher, T.J., Hart, P.J.B. (Eds.), Impact of species changes in African lakes. Chapman and Hall Fishand Fisheries Series 18, Springer, Dordrecht, pp. 335–360. https://doi.org/10.1007/978-94-011-0563-7_16.

Kolding, J., Musando, B., Songore, N., 2003. Inshore fisheries and fish population changes in Lake Kariba. In: Jul-Larsen, E., Kolding, J., Overa, R., Raakjær Nielsen, J., van Zwieten, P.A.M. (Eds.), Management, Co-management or no-management? Major dilemmas in southern African freshwater fisheries. Food and Agriculture Organization of the United Nations, Rome, pp. 67–99.

Kolding, J., van Zwieten, P., Mkumbo, O., Silsbe, G., Hecky, R., 2008. Are the Lake Victoria fisheries threatened by exploitation or eutrophication? Towards an ecosystem-based approach to management. In: Bianchi, G., Skjoldal, H.R. (Eds.), The ecosystem approach to fisheries. CAB International, pp. 309–354. https://doi.org/0.1079/9781845934149.0309.

Kolding, J., van Zwieten, P.A.M., 2012. Relative lake level fluctuations and their influence on productivity and resilience in tropical lakes and reservoirs. Fish. Res. 115, 99–109. https://doi.org/10.1016/j.fishres.2011.11.008.

Kraemer, B.M., Pilla, R.M., Woolway, R.I., Anneville, O., Ban, S., Colom-Montero, W., Devlin, S.P., Dokulil, M.T., Gaiser, E.E., Hambright, K.D., Hessen, D.O., Higgins, S.N., Jöhnk, K.D., Keller, W., Knoll, L.B., Leavitt, P.R., Lepori, F., Luger, M.S., Maberly, S.C., Müller-Navarra, D.C., Paterson, A.M., Pierson, D.C., Richardson, D.C., Rogora, M., Rusak, J.A., Sadro, S., Salmaso, N., Schmid, M., Silow, E.A., Sommaruga, R., Stelzer, J.A.A., Straile, D., Thiery, W., Timofeyev, M.A., Verburg P., Weyhenmeyer, G.A., Adrian, R., 2021. Climate change drives widespread shifts in lake thermal habitat. Nat. Clim. Change 11, 521–529. https://doi.org/10.1038/s41558-021-01060-3.

Kranenburg, W., Tiessen, M., Veenstra, J., De Graaff, R., Uittenbogaard, R., Bouffard, D., Sakindi, G., Umutoni, A., Van de Walle, J., Thiery, W., van Lipzig, N., 2020. 3D-modelling of Lake Kivu: horizontal and vertical flow and temperature structure under spatially variable atmospheric forcing. J. Great Lakes Res. 46, 947–960. https://doi.org/10.1016/j.jglr.2020.05.012.

Lam, D.C.L., Leon, L.F., Hecky, R., Bootsma, H.A., McCrimmon, C. 2003. A modelling approach for Lake Malawi/Nyasa/Niassa: integrating hydrological and limnological data. In: Odada, E.O., Olago, D. (Eds.), The East African Great Lakes: limnology, palaeolimnology and biodiversity. Springer, Netherlands, pp. 189–208. https://doi.org/10.1007/0-306-48201-0_6.

Le Moal, M., Pannard, A., Brient, L., Richard, B., Chorin, M., Mineaud, E., Wiegand, C., 2021. Is the cyanobacterial bloom composition shifting due to climate forcing or nutrient changes? Example of a shallow eutrophic reservoir. Toxins 13, 351. https://doi.org/10.3390/toxins13050351.

Langenberg, V.T., Sarvala, J., Roijackers, R., 2003. Effect of wind induced water movements on nutrients, chlorophyll-a, and primary production in Lake Tanganyika. Aquat. Ecosys. Health Manage. 6, 279–288. https://doi.org/10.1080/14634980301488.

Liberati, M.R., Sowa, S.P., May, C.A., Doran, P.J., 2020. Making measures count: Structured indicator selection to improve program success. Environmental and Sustainability Indicators 8, 100077. https://doi.org/10.1016/j.indic.2020.100077.

Lovett, G.M., Burns, D.A., Driscoll, C.T., Jenkins, J.C., Mitchell, M.J., Rustad, L., Shanley, J.B., Likens, G.E., Haeuber, R., 2007. Who needs environmental monitoring? Frontiers in Ecology and the Environment 5, 253–260. https://doi.org/10.1890/1540-9295(2007)5[253:WNEM] 2.0CO;2.

Lung'ayia, H., Sitoki, L., Kenyanya, M., 2001. The nutrient enrichment of Lake Victoria (Kenyan waters). Hydrobiologia 458, 75–82. https://doi.org/10.1023/A:1013128027773.

Lake Victoria Fisheries Organization, 2016. Fisheries Management Plan III for Lake Victoria 2016-2020. Lake Victoria Fisheries Organization, Jinja, Uganda.

Lowe-McConnell, R., 1997. EAFRO and after: a guide to key events affecting fish communities in Lake Victoria (East Africa). S. Afr. J. Sci. 93, 570–574.

Lymer, D., Welcomme, R.,2012. An audit of inland capture fishery statistics-Africa. FAO Fisheries and Aquaculture Circular 1051. Food and Agricultural Organization of the United Nations. http://www.fao.org/3/i2608e/i2608e00.htm.

MacIntyre, S., 2013. Climatic variability, mixing dynamics, and ecological consequences in the African Great Lakes. In: Goldman, C.R., Kumagai, M., Robarts, R.D. (Eds.), Climatic change and global warming of inland waters: Impacts and mitigation for ecosystems and societies. Wiley-Blackwell, Hoboken, New Jersey, United States, pp. 311–336. https://doi.org 10.1002/9781118470596.ch18.

MacIntyre, S., Romero, J.R., Kling, G.W., 2002. Spatial-temporal variability in surface layer deepening and lateral advection in an embayment of Lake Victoria, East Africa. Limnol. Oceanogr. 47, 656–671. https://doi.org/10.4319/lo.2002.47.3.0656.

MacIntyre, S., Romero, J.R., Silsbe, G.M., Emery, B.M., 2014. Stratification and horizontal exchanges in Lake Victoria, East Africa. Limnol. Oceanogr. 59, 1805–1838. https://doi.org/10.4319/lo.2014.59.6.1805

Madadi, V.O., Wandiga, S.O., Jumba, I.O., 2005. The status of persistent organic pollutants in Lake Victoria catchments. International Lake Environment Committee Foundation (ILEC), 107–112.

Martens, K., Coulter, G., Goddeeris, B., 1994. Speciation in ancient lakes-40 years after J.L. Brooks. Adv. Limnol 44, 75–96.

Mchau, G.J., Makule, E., Machunda, R., Gong, Y.Y., Kimanya, M., 2019. Harmful algal bloom and associated health risks among users of Lake Victoria freshwater: Ukerewe Island, Tanzania. J. Water Health 17, 826–836. https://doi.org/10.2166/wh.2019.083.

McGlue, M.M., Ivory, S.J., Stone, J.R., Cohen, A.S., Kamulali, T.M., Latimer, J.C., Brannon, M.A., Kimirei, I.A., Soreghan, M.J., 2020. Solar irradiance and ENSO affect food security in Lake Tanganyika, a major African inland fishery. Sci. Adv. 6, eabb2191. https://doi.org/10.1126/sciadv.abb2191.

Medard, M., Kabati, M., Komba, D;, Mlahagwa, E., Ngussa, D., 2002. An assessment of the nutritional status of fishing and farming communities in Tanzania's Lake Victoria basin. In: Geheb, K. (Ed.), Report of the LVFRP Nutrition Survey. LVFRP Technical Document No. 18. LVFRP/TECH/00/18. The Socio-economic Data Working Group of the Lake Victoria Fisheries Research Project, Jinja, Uganda, pp. 30–48.

Mercier, F., Cazenave, A., Maheu, C., 2002. Interannual lake level fluctuations (1993-1999) in Africa from Topex/Poseidon: connections with ocean-atmosphere interactions over the Indian Ocean. Glob. Planet. Change 32, 141–163. https://doi.org/10.1016/S0921-8181(01)00139-4.

Mgaya, Y.D., Mahongo, S. (Eds.), 2017. Lake Victoria Fisheries Resources: Research and Management in Tanzania. Monographiae Biologicae 93. Springer International Publishing, Cham, Switzerland. https://doi.org/10.1007/978-3-319-69656-0.

Moore, J.E.S., 1899. The molluscs of the Great African Lakes II. The anatomy of *Typhobias*, the with a description of the new genus (Bathanalia). Q. J. Microsc. Sci. 41: 181–204.

Mudakikwa,E.R., Thiery,W, Latli,A., Leporcq,B., Rugema E., Descy, J.-P., 2021. Phytoplankton pigment analysis as a tool for monitoring a tropical great lake, Lake Kivu (East Africa). Inland Waters 11, 223–233. https://doi.org/10.1080/20442041.2021.1888624.

Muro, A.I., Kaatano, G., Medard, M., 2005. Report on Communicable Diseases, health and sanitation along the fishing communities in Lake Victoria, Tanzania. Report to WB/Lake Victoria Environmental Programme Phase 1. LVEMP Secretariat, Dar Es Salaam, Tanzania.

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.: Res. Manag. 16, 273–280. https://doi.org/10.1111/j.1440-1770.2011.00486.x.

Musinguzi, L., Natugonza, V., Ogutu-Ohwayo, R., 2017. Paradigm shifts required to promote ecosystem modeling for ecosystem-based fishery management for African inland lakes. J. Great Lakes Res. 43, 1–8. https://doi.org/10.1016/j.jglr.2016.11.007.

Muyodi, F.J., Hecky, R.E., Kitamirike, J.M., Odong, R., 2009. Trends in health risks from water-related diseases and cyanotoxins in Ugandan portion of Lake Victoria basin. Lakes Reserv.: Res. Manag. 14, 247–257. https://doi.org/10.1111/j.1440-1770.2009.00407.x.

Mwamburi, J., Basweti, G., Owili, M., Babu, J., Wawiye, P., 2020. Spatio-temporal trends of nutrients and physico-chemical parameters on lake ecosystem and fisheries prior to onset of cage farming and re-opening of the Mbita passage in the Nyanza Gulf of Lake Victoria. Lakes Reserv.: Res. Manag. 25, 292–313. https://doi.org/10.1111/lre.12329.

Naithani, J., Deleersnijder, E., & Plisnier, P. D.,2002. Origin of intraseasonal variability in Lake Tanganyika. Geophysical Research Letters, 29(23). https://doi.org/10.1029/2002GL015843

Naithani, J., Deleersnijder, E., Plisnier, P.-D., 2003. Analysis of wind-induced thermocline oscillations of Lake Tanganyika. Environ. Fluid Mech. 3, 23–39. https://doi.org/10.1023/A:1021116727232.

Naithani, J., Plisnier, P.-D., Deleersnijder, E., 2011. Possible effects of global climate change on the ecosystem of Lake Tanganyika. Hydrobiologia 671, 147–163. https://doi.org/10.1007/s10750-011-0713-5.

Naithani, J., Plisnier, P.-D., Deleersnijder, E., 2012. Tanganyika Lake, modeling the eco-hydrodynamics. In: Bengtsson, L., Herschy, R.W., Fairbridge, R.W. (Eds.), Encyclopedia of Lakes and Reservoirs. Spinger, Dordrecht. https://doi.org/10.1007/978-1-4020-4410-6.

Nakamura, N., Kayanne,H., Iijima,H., McClanahan, T. R. , Behera, S. K. , Yamagata, T., 2009. Mode shift in the Indian Ocean climate under global warming stress. Geophys. Res. Letters 36, L23708, https://doi.org/10.1029/2009GL040590.

Natugonza, V., Ainsworth, C., Sturludóttir, E., Musinguzi, L., Ogutu-Ohwayo, R., Tomasson, T., Nyamweya, C., & Stefansson, G. , 2019. Ecosystem models of Lake Victoria (East Africa): Can Ecopath with Ecosim and Atlantis predict similar policy outcomes? J. Great Lakes Res. 45, 1260–1273. https://doi.org/10.1016/j.jglr.2019.09.018.

NEMA, 2012. The environmental monitoring plan for the Albertine graben 2012 - 2017. The Republic of Uganda National Environmental Management Authority, Uganda.

Nicholson, S.E., 2017: Climate and climatic variability of rainfall over eastern Africa. Reviews of Geophysics 55, 590-635. https://doi.org/10.1002/2016RG000544.

Njiru, M., Sitoki, L., Nyamweya, C., Jembe, T., Aura, C., Waithaka, E., Masese, F., 2012. Habitat degradation and changes in Lake Victoria fisheries. In: Adoyo, W.A., Wangai, C.I. (Eds.), Environmental degradation: Causes, issues and management. Nova Science Publishers, New York, pp. 1–34.

Njiru, J., van der Knaap, M., Kundu, R., Nyamweya, C., 2018. Lake Victoria fisheries: Outlook and management. Lakes & Reserv. 23, 152–162. https://doi.org/10.1111/lre.12220.

Nyamweya, C., Sturludottir, E., Tomasson, T., Fulton, E.A., Taabu-Munyaho, A., Njiru, 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.

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, e105564. https://doi.org/10.1016/j.fishres.2020.105564.

Obiero, K.O., Abila, R.O., Njiru, M.J., Raburu, P.O., Achieng, A.O., Kundu, R., Ogello, E.O., Munguti, J.M., Lawrence, T., 2015. The challenges of management: Recent experiences in implementing fisheries co-management in Lake Victoria, Kenya. Lakes Reserv.: Res. Manag. 20, 139–154. https://doi.org/10.1111/lre.12095.

Obiero, K., Lawrence, T., Ives, J., Smith, S., Njaya, F., Kayanda, R., Waidbacher, H., Olago,D., Miriti, E., Hecky, R.E., 2020. Advancing Africa's great lakes research and academic potential: Answering the call for harmonized, long-term, collaborative networks and partnerships. J. Great Lakes Res. 46: 1240–1250. https://doi.org/10.1016/j.jglr.2020.02.002.

Ochumba, P.B.O., 1987 Periodic massive fish kills in the Kenyan part of Lake Victoria. Wat. Qual. Bull. 12, 119–122.

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.

Ochumba, P. B.O, & Kibaara, D. I., 1989. Observations on blue-green algal blooms in the open waters of Lake Victoria, Kenya. Afr. J. Ecol. 27, 23–34. https://doi.org/10.1111/j.1365-2028.1989.tb00925.x.

Odada, E.O., Olago, D.O., 2006. Challenges of an ecosystem approach to water monitoring and management of the African Great Lakes. Aquat. Ecosyst. Health Manag. 9, 433–446. https://doi.org/10.1080/14634980601013293.

Ofulla, A.V.O., Karanja, D., Omondi, R., Okurut, T., Matano, A., Jembe, T., Abila, R., Boera, P., Gichuki, J., 2010. Relative abundance of mosquitoes and snails associated with water hyacinth and hippo grass in the Nyanza gulf of Lake Victoria. Lakes & Reserv. 15, 255–271. https://doi.org/10.1111/j.1440-1770.2010.00434.x.

Ogello, E.O., Obiero, K., Munguti, J.M., 2013. Lake Victoria and the common property debate: Is the tragedy of the commons a threat to its future? Lakes Reserv. Ponds 7, 101–126.

Ogutu-Ohwayo, R., & Balirwa, J. S., 2006. Management challenges of freshwater fisheries in Africa. Lakes & Reservoirs: Research & Management, 11(4), 215-22 https://doi.org/10.1111/j.1440-1770.2006.00312.x

Ogutu-Ohwayo, R., Natugonza, V., Musinguzi, L., Olokotum, M., Naigaga, S., 2016. Implications of climate variability and change for African lake ecosystems, fisheries productivity, and livelihoods. J. Great Lakes Res. 42, 498–510. https://doi.org/10.1016/j.jglr.2016.03.004.

Ogutu-Ohwayo,R., Hecky, R.E., Cohen, A.S., Kaufman, L., 1997. Human impacts on the African Great Lakes. Environ. Biol. Fishes 50, 117–-131. https://doi.org/ 10.1023/A:1007320932349.

Ogutu-Ohwayo, R., Natugonza, V., Olokotum, M., Rwezawula, P., Lugya, J., Musinguzi, L., 2020. Biogeography: Lakes—African Great Lakes. In: Goldstein, M.I., DellaSAla, D.A. (Eds.), Encyclopedia of the World's Biomes. Elsevier, pp. 243–260. https://doi.org/10.1016/B978-0-12-409548-9.12090-1.

Olaka, L.A., Odada, E.O., Trauth, M.H., Olago, D.O., 2010. The sensitivity of East African rift lakes to climate fluctuations. J. Paleolimnol. 44, 629–644. https://doi.org/10.1007/s10933-010-9442-4.

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, 766–768. https://doi.org/10.1038/nature01833.

Osano, O., Nzyuko, D., Tole, M., Admiraal, W., 2003. The fate of chloroacetanilide herbicides and their degradation products in the Nzoia Basin. Ambio 32, 424–427. https://doi.org/10.1579/0044-7447-32.6.424

Owino, A. O., Ryan, P. G., 2007. Recent papyrus swamp habitat loss and conservation implications in western Kenya. Wetl. Ecol. Manag. 15, 1–12. https://doi.org/10.1007/s11273-006-9001-y.

Patterson, G., Kachinjika, O., 1995. Limnology and phytoplankton ecology. In: Menz, A. (Ed.), The fishery potential and productivity of the pelagic zone of Lake Malawi/Niassa. Scientific report of the UK/SADC pelagic fish resource assessment project. Natural Resources Institute, London, pp. 1–68.

Patterson, G., Hecky, R.E., Fee, E.J., 2000. Effect of hydrological cycles on planktonic primary production in Lake Malawi/Niassa. Adv. Ecol. Res. 31, 421–43. https://doi.org/10.1016/S0065-2504(00)31022-4.

Plisnier, P.-D., 1997. Climate, limnology, and fisheries changes of Lake Tanganyika. FAO/FINNIDA Research for the Management of Fisheries on Lake Tanganyika, report. GCP/RAF/271/FIN-TD/72.

Plisnier, P.-D., 1998. Lake Tanganyika: Recent climate changes and teleconnections with ENSO. In: Demarée, G., Alexandre, J., De Dapper, M. (Eds.), Tropical climatology, meteorology and hydrology. Royal Academy of Overseas Sciences, Brussels, pp. 228–250.

Plisnier, P.-D., Chitamwebwa, D., Mwape, L., Tshibangu, K., Langenberg, V., Coenen, E., 1999. Limnological annual cycle inferred from physical-chemical fluctuations at three stations of Lake Tanganyika. In: Lindqvist, O.V., Mölsä, H., Salonen, K., Sarvala, J. (Eds.), From limnology to fisheries: Lake Tanganyika and other large lakes. Developments in Hydrobiology 141, 48–58. https://doi.org/10.1007/978-94-017-1622-2_4.

Plisnier, P.-D., Coenen, E.J., 2001. Pulsed and dampened annual limnological fluctuations in Lake Tanganyika. In: Munawar, M.,. Hecky, R.E. (Eds), The Great Lakes of the World (GLOW): Food-web, health and integrity. Ecovision World Monograph Series, Leiden, Netherlands, pp. 81–96.

Plisnier, P.-D., Marijnissen, S.A.E, 2010. Lake Tanganyika regional integrated environmental monitoring programme, institutional needs assessment. LTRIEMP/PCU/C1/2010, UNDP/GEF. https://doi.org/10.13140/RG.2.1.1959.3767.

Plisnier, P.-D., Nshombo, M., Mgana, H.F., Ntakimazi, G., 2018. Monitoring climate change and anthropogenic pressure at Lake Tanganyika. J. Great Lakes Res. 44, 1194–1208. https://doi.org/10.1016/j.jglr.2018.05.01.

Poikane, S., Birk, S., Böhmer, J., Carvalho, L., de Hoyos, C., Gassner, H., Hellsten, S., Kelly, M., Lyche Solheim, A., Olin, M., Pall, K., Phillips, G., Portielje, R., Ritterbusch, D., Sandin, L., Schartau, A.-K., Solimini, A.G., Van Den

Berg, M., Wolfram, G., van de Bund, W., 2015. A hitchhiker's guide to European lake ecological assessment and intercalibration. Ecol. Indic. 52, 533–544. https://doi.org/10.1016/j.ecolind.2015.01.005.

Rastetter, E.B., Ohman, M.D., Elliott, K.J., Rehage, J.S., Rivera-Monroy, V.H., Boucek, R.E.,Castañeda-Moya, E., Danielson, T.M., Gough, L., Groffman, P.M., Jackson, C.R., F. Miniat, C.F., Shaver, G.R., 2021. Time lags: insights from the U.S. Long Term Ecological Research Network. Ecosphere 12, :e03431. https://doi.org/10.1002/ecs2.3431.

Robarts, R.D.,Zohary, T., 2018. Limnology and the future of African inland waters. Inland Waters 8, 399–412. https://doi.org/10.1080/20442041.2018.1481729.

Rugema, E., Darchambeau, F., Sarmento, H., Stoyneva-Gärtner, M., Leitao, M., Thiery, W., Latli, A., Descy, J.-P., 2019. Long-term change of phytoplankton in Lake Kivu: The rise of the greens. Freshw. Biol. 64, 1940–1955. https://doi.org/10.1111/fwb.13383.

Saji, N.H., Goswami, B.N., Vinayachandran, P.N., Yamagata, T. 1999. A dipole mode in the tropical Indian Ocean. Nature 401, 360–363. https://doi.org/10.1038/43854.

Salzburger, W., Van Bocxlaer, B., Cohen, A. S.,2014. Ecology and evolution of the African Great Lakes and their faunas. Ann. Rev. Ecol. Evol. Sys. 45, 519–545. https://doi.org/10.1146/annurev-ecolsys-120213-091804.

Sarmento, H., Darchambeau, F., Descy J-P., 2012. Phytoplankton of Lake Kivu. In: J.-P. Descy, J.-P., Darchambeau, F., Schmid, M. (Eds.), Lake Kivu: Limnology and biogeochemistry of a tropical great lake. Aquatic Ecology Series 5, Springer, Dordrecht, pp. 67–83. https://doi.org/10.1007/978-94-007-4243-7_5.

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

Scheren, P.A.G.M., Mirambo, V., Lemmens, A.M.C., Katima, J.H.Y., Jansse, F.J.J.G., 2001. Assessment of pollution sources and socio-economic circumstances related to the eutrophication of Lake Victoria. In: LVEMP Conference, Kisumu, Kenya.

Schmid M., Halbwachs, M., Wehrli, B., Wüest, A., 2005. Weak mixing in Lake Kivu: New insights indicate increasing risk of uncontrolled gas eruption. Geochem. Geophys. Geosystems 6, Q07009. https://doi.org/10.1029/2004GC000892.

Shiklomanov, L.A., 1993. World Freshwater Resources. In: Gleick, P.H. (Ed.), Water in crisis: A guide to world's freshwater resources. Oxford University Press, New York, pp. 13–24.

Shin, Y.-J., Rochet, M.-J., Jennings, S., Field, J.G., Gislason, H., 2005. Using size-based indicators to evaluate the ecosystem effects of fishing. ICES J. Mar. Sci. 62, 384–396. https://doi.org/10.1016/j.icesjms.2005.01.004.

Silsbe, G.M., Hecky, R.E., Guildford, S.J., Mugidde, R., 2006. Variability of chlorophyll a and photosynthetic parameters in a nutrient saturated tropical great lake. Limnol. Oceanogr. 51, 2052–2063. https://doi.org/10.4319/lo.2006.51.5.2052.

Smith, K.A., Semazzi, F.H., 2014. The role of the dominant modes of precipitation variability over Eastern Africa in modulating the hydrology of Lake Victoria. Adv. Meteorol. 2014, 516762. https://doi.org/10.1155/2014/516762.

Souverijns, N., Thiery, W., Demuzere, M., van Lipzig, N.P.M., 2016. Drivers of future changes in East African precipitation. Environ. Res. Lett. 11, 114011. https://doi.org/10.1088/1748-9326/11/11/114011.

Spigel, R.H., Coulter, G.W., 1996. Comparison of hydrology and physical limnology of the East African Great Lakes: Tanganyika, Malawi, Victoria, Kivu and Turkana (with reference to some North American Great Lakes). In: Johnson, T.C., Odada, E.O., Whittaker, K.T. (Eds.), The limnology, climatology and paleoclimatology of the East African lakes. Gordon and Breach Science Publishers, Amsterdam, pp. 103–139.

Stager, J.C., Ruzmaikin, A., Conway, D., Verburg, P., Mason, P.J., 2007. Sunspots, El Niño, and the levels of Lake Victoria, East Africa. J. Geophys. Res. 112, D15106. https://doi.org/10.1029/2006JD008362.

Sterner, R.W., Keeler, B., Polasky, S., Poudel, R., Rhude, K., Rogers, M.,2020. Ecosystem services of Earth’s largest freshwater lakes. Ecosystem Services 41, 101046. https://doi.org/10.1016/j.ecoser.2019.101046.

Street-Perrott, F.A., Harrison, S.P., 1984. Temporal variations in lake levels since 30,000 yr BP—an index of the global hydrological cycle. In: Hansen, J.E., Takahashi, T. (Eds.), Climate processes and climate sensitivity 29, 118129.

Sturmbauer, C., 2008. The Great Lakes in East Africa: biological conservation considerations for species flocks. Hydrobiologia 615, 95-101. https://doi.org/10.1007/s10750-008-9554-2.

Talling, J.F., 1956. Some observations on seasonal and diurnal changes of stratification in Lake Victoria . East Coast Fishing Research Organisation, Annual Report 1955/1956, 10–11.

Talling, J.F., 1966. The annual cycle of stratification and phytoplankton growth in Lake Victoria (East Africa). Int. Revue ges. Hydrobiol. 51, 545–621. https://doi.org/10.1002/iroh.19660510402.

Ticheler, H.J., Kolding, J., Chanda, B., 1998. Participation of local fishermen in scientific fisheries data collection: a case study from the Bangweulu Swamps, Zambia. Fish. Man. Ecol. 5, 81–92.

Tiercelin, J.J., Lezzar, K.E., 2002. A 300 million years history of rift lakes in Central and East Africa: an updated broad review. In: Odada, E.O., Olago, D.O. (Eds.), The East African Great Lakes: limnology, palaeolimnology and biodiversity. Springer, Dordrecht, pp 3–60. https://doi.org/10.1007/0-306-48201-0_1.

Thenya, T., Wassmann, R., Verchot, L., Mungai, D., 2006. Degradation of the riparian wetlands in the Lake Victoria basin - Yala swamp case study. Proceedings of the 11th World Lakes Conference 2, 483–494.

Thiery, W., Martynov, A., Darchambeau, F., Descy, J.-P., Plisnier, P.-D., Sushama, L., van Lipzig, N.P.M., 2014a. Understanding the performance of the FLake model over two African Great Lakes. Geosci. Model. Devel.7, 317–337. https://doi.org/10.5194/gmd-7-317-2014.

Thiery, W., Stepanenko, V.M., Fang, X., Jöhnk, K.D., Li, Z., Martynov, A., Perroud, M., Subin, Z.M., Darchambeau, F., Mironov, D., van Lipzig, N.P.M., 2014b. LakeMIP Kivu: Evaluating the representation of a large, deep tropical lake by a set of one-dimensional lake models. Tellus A: Dyn. Meteorol. Oceanogr. 66, 21390. https://doi.org/10.3402/tellusa.v66.21390.

Thiery, W., Davin, E.L., Panitz, H.-J., Demuzere, M., Lhermitte, S., van Lipzig, N.P.M., 2015. The impact of the African Great Lakes on the regional climate. J. Clim. 28, 4061–4085. https://doi.org/10.1175/JCLI-D-14-00565.1.

Thiery, W., Davin, E.L., Seneviratne, S.I., Bedka, K., Lhermitte, S., van Lipzig, N.P.M., 2016. Hazardous thunderstorm intensification over Lake Victoria. Nat. Commun. 7, 12786. https://doi.org/10.1038/ncomms12786.

Thiery, W., Gudmundsson, L., Bedka, K., Semazzi, F.H.M., Lhermitte, S., Willems, P., van Lipzig, N.P.M., Seneviratne, S.I., 2017. Early warnings of hazardous thunderstorms over Lake Victoria. Environ. Res. Lett. 12, 074012. .https://doi.org/10.1088/1748-9326/aa7521.

United Nations, 2021. Environment Assembly of the United Nations Environment Programme - Fifth session. Nairobi (online), 22–26 February 2021. Information on implementation of resolution 3/10 on addressing water pollution to protect and restore water-related ecosystems UNEP/EA.5/INF/14.

Vanderkelen, I., van Lipzig, N.P.M., Thiery, W., 2018a. Modelling the water balance of Lake Victoria (East Africa) – Part 1: Observational analysis. Hydrol. Earth Syst. Sci. 22, 5509–5525. https://doi.org/10.5194/hess-22-5509-2018.

Vanderkelen, I., van Lipzig, N.P.M., Thiery, W., 2018b. Modelling the water balance of Lake Victoria (East Africa) – Part 2: Future projections. Hydrol. Earth Syst. Sci. 22, 5527–5549. https://doi.org/10.5194/hess-22-5527-2018

Van der Knaap, M., 2013. Comparative analysis of fisheries restoration and public participation in Lake Victoria and Lake Tanganyika. Aquat. Ecosyst. Health Manag. 16, 279–287. https://doi.org/10.1080/14634988.2013.816618.

Van der Knaap M., 2019. Are climate change impacts the cause of reduced fisheries production in the African Great Lakes region? The Lake Tanganyika case study. In: Johnson, J., De Young, C., Bahri, T., Soto, D., Virapat, C. (Eds.), 2019. Proceedings of FishAdapt: the global conference on climate change adaptation for fisheries and aquaculture, Bangkok, Thailand, 8–10 August, 2016. FAO Fisheries and Aquaculture Proceedings 61, 49–51.

van Zwieten, P.A.M., Kolding, J., Plank, M.J., Hecky, R.E., Bridgeman, T.B., MacIntyre, S., Seehausen, O., Silsbe, G.M., 2015. The Nile perch invasion in Lake Victoria: cause or consequence of the haplochromine decline? Can. J. Fish. Aquat.. Sci. 73, 622–643. https://doi.org/10.1139/cjfas-2015-0130.

Verburg ,P., Hecky, R.E., Kling, H., 2003. Ecological consequences of a century of warming in Lake Tanganyika. Science 301, 505–507. https://doi.org/10.1126/science.1084846.

Verheyen, E., Abila, R., Akoll, P., Albertson, C., Antunes, D., Banda, T., Bills, R., Bulirani, A., Chocha Manda, A., 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., Genner, M.J., Härer, A., Hata, H., Irvine, K., Isumbisho Mwapu, P., Janssens de Bisthoven, L., Jungwirth, A., Kaleme, P., Katongo, C., Kéver, L., Koblmüller, S., Konings, A., Lamboj, A., Lemmel-Schaedelin, F., Machado Schiaffino, G., Martens, K., Masilya Mulungula, P., Meyer, A., More, H.L., Musilova, Z., Muterezi Bukinga, F., Muzumani, R., Ntakimazi, G., Okello W., Phiri, H., Pialek, L., Plisnier, P.-D., Raeymaekers, J.A.M., Rajkov, J., Rican, O., Roberts, R., Salzburger, W., Schoen, I., Sefc, K.M., Singh, P., Skelton, P., Snoeks, J., Schneider, K., Sturmbauer, C., Svardal, H., Svensson, O., Torres Dowdall, J., Turner, G.F., Tyers, A., van Rijssel, J.C., Van Steenberge, M., Vanhove, M.P.M., Weber, A.-T., Weyl, O., Ziegelbecker, A., Zimmermann, H., 2016. Oil extraction imperils Africa's Great Lakes. Science 354(6312), 561–562. https://doi.org/10.1126/science.aal1722.

Virts, K.S., Goodman, S.J., 2020. Prolific lightning and thunderstorm initiation over the Lake Victoria basin in East Africa. Mon. Weather Rev. 148, 1971–1985. https://doi.org/10.1175/MWR-D-19-0260.1.

West, K., 2001. Lake Tanganyika: Results and experiences of the UNDP/GEF conservation initiative (RAF/92/G32) in Burundi, D.R. Congo, Tanzania, and Zambia. UNDP-GEF UNOPS.

Witte, F., Silsbe, G.M., Hecky, R.E., Goudswaard, P.C., Guildford, S.J., Kishe-Machumu, M.A., Wanink, J.H., 2012. Did the loss of phytoplanktivorous fish contribute to algal blooms in the Mwanza Gulf of Lake Victoria?. Hydrobiologia 679, 283–296. https://doi.org/10.1007/s10750-011-0893-z.

Wolff, C., Haug, G.H., Timmermann, A., Sinninghe Damsté, J.S., Brauer, A., Sigman, D.M., Cane, M.A., Verschuren, D., 2011. Reduced interannual rainfall variability in East Africa during the last ice age. Science 333, 743–747. https://doi.org/10.1126/science.1203724.

World Water Quality Alliance, 2021. World Water Quality Assessment: First global display of a water quality baseline. A consortium effort by the World Water Quality Alliance - towards a full global assessment. Information Document Annex for display at the 5th Session of the United Nations Environment Assembly, Nairobi 2021.

Worthington, E.B., 1930. Observations on the temperature, hydrogen-ion concentration, and other physical conditions of the Victoria and Albert Nyanzas. Int. Revue ges. Hydrobiol. Hydrogr. 24, 328–357. https://doi.org/10.1002/iroh.19300240306.

Xu, L., Zhao, S., Chen, S.S., Yu, C., Lei, B., 2020. Analysis of arable land distribution around human settlements in the riparian area of Lake Tanganyika in Africa. Appl. Geogr. 125, 102344. https://doi.org/10.1016/j.apgeog.2020.102344.

Yongo, E.O., Abila, R.O., Lwenya, C., 2010. Emerging resource use conflicts between Kenyan fishermen, pastoralists and tribesmen of Lake Turkana. Aquatic Ecosystem Health & Management 13, 28–34. https://doi.org/10.1080/14634980903578308.

Table 1: Environmental and anthropogenic threats at the AGL

THREATS	References
climate variability and change	O'Reilly et al, 2003; Verburg et al., 2003; Katsev et al., 2014; Kraemer et al., 2021; Naithani et al.,2011; Ogutu-Ohwayo et al, 2016;Rugema et al., 2019; Souverijns et al., 2016; Vanderkelen et al., 2018a,b; Van der Knaap, 2019
hazardous thunderstorm	Thiery et al., 2016,2017; Virts and Goodman,2020.
shoreline flooding	Bakibinga-Ibembe et al., 2011
massive algal blooms	Mchau et al., 2019; Witte et al., 2012
fish kills	Ochumba 1987, 1990
parasite infestation	Gabagambi and Skorping, 2018, Gabagambi et al., 2020
limnic gas eruption risk	Balagizi et al., 2018b; Schmid et al., 2005; Bärenbold et al., 2020.
heavy exploitation	Haambiya et al., 2015 ; Kolding, 1995; Van der Knaap, 2013; Nyamweya et al., 2020; Obiero et al., 2015
excessive sedimentation from intensive agriculture/deforestation	Bootsma and Hecky, 2003; West, 2001; Bakibinga-Ibembe et al., 2011
eutrophication	Deirmendjian et al., 2021; Hecky et al., 2010; Lung'ayia et al., 2001
oxygen depletion	Hecky et al., 1994; Jane et al., 2021; Njiru et al., 2012
loss of fish biodiversity	Sayer et al., 2018; Mgaya and Mahongo, 2017
invasive fish species	Obiero et al.,2020; Ogello et al., 2013; Ogutu-Ohwayo et al., 1997; van Zwieten et al., 2016
invasive water weeds	Mgaya and Mahongo, 2017; Ofulla et al., 2010
habitat loss due to shoreline development	Thenia et al., 2001; Owino and Ryan, 2007

pollution (mining, chemicals, plastics etc.)	Kanangire et al., 2018; Odada and Olago, 2006; Scheren et al., 2001
cage fish farming	Kashindye et al., 2015; Mwamburi et al., 2020
hydrocarbon extraction	Heather-Clark and de Jong, 2007; NEMA, 2012; Verheyen et al., 2016
public health issues	Medard et al., 2002; Muro et al., 2005; Karanja, 2006; Muyodi et al., 2009; Bompangue et al., 2011
internal and inter-state conflicts	Yongo et al., 2010; Glaser et al., 2019

Table 2: The six themes of the proposed multi-lake long-term monitoring of AGL

Themes	Description
Climate	The main meteorological parameters (as detailed below) are included in the monitoring. This component is an essential input to all themes. Meteorological data from some dedicated networks are missing or difficult to access and often costly or not available.
Limnology	The water quality topic includes physical-chemical characteristics, hydrodynamics, planktonic abundance and pollution. Water key parameters related to the lake's ecology mainly are targeted. Polluted water will be sampled and analysed by specialized laboratories not part of the present monitoring proposal.
Fisheries	Concerning the fisheries topic, it focalizes particularly on catches and efforts although other topics such as fish stock, biology and ecology of main fish species are also important if there are enough capacities to conduct a continuous monitoring.
Land use	Land use addresses the impact of e.g. deforestation and agriculture practices on erosion with impact on sedimentation and eutrophication.
Biodiversity	The monitoring of biodiversity is meant to document distribution and abundance as well as assess population trends and impacts of factors that impact biodiversity, with specific attention to the risks of invasive species and possible loss of endemic species
Socio-economy / human environment	The socio-economic monitoring includes collection of information on fishers, fish products and aquaculture as indicators of anthropogenic pressure and surveys linked to the human environment related to AGL.

Table 3: Facilities and critical equipment required for a basic multi-lake monitoring program; Opt. means "optional", DO = Dissolved oxygen.

Facilities and equipment	Country institution	Multi-lake program
Research station on lake shore (+ electricity, water)	x	
Staff	x	
Boats/vehicles	x	
Functionning (LT monitoring)	x	x
Computer - printer - internet connection	x	x
Hand held probe - temperature		x
- conductivity, pH, DO		Opt.
CTD (conductivity, temperature and depth probe)		Opt.
Mooring and thermistors/possibly other sensors		Opt.
Underwater light sensor (automatic)		x
Underwater light sensor manual		x
Thermistors for coastal temperature measurement		x
Sampling bottle and messenger		x
Secchi disk		x
Level gage		x
Weighing balances		x
Fish measuring board		x
Equipment for biodiversity monitoring (gears etc.)		x
Automatic weather station		x

Table 4 : Main parameters for long-term multi-lake monitoring related to limnology and water quality, fisheries, meteorology, biodiversity, land use/erosion and socio-economy and frequency at different locations (x = mandatory, (x) = optional, S= station, C = coast, P = pelagic, L = lake, B = basin, SD = Secchi disk, Chl a = chlorophyll-*a*, RS = remote sensing, AWS = automatic weather station, CAS = catch assessment survey, T = near surface temperature ,prec. = precipitations, WS = winds speed, WD = wind direction, Atm. P = atmospheric pressure, ISR = incoming shortwave radiation, ILR = incoming long wave radiation, RH = relative humidity, cloud. = cloudiness, agric = agriculture).

	PARAMETERS	SITES	FREQUENCY								
			30 min	Daily	Weekly	15 days	Monthly	6 months	1/2 years	3/4 years	5 years
Water	Temperature	S-C		x							
		S-P				(x)	x				
	Conductivity	S-C		x							
		S-P				(x)	x				
	SD transparency	S-C		(x)	x						
		S-P				(x)	x				
	Underwater light measurement	S-P				(x)	x				
	Lake level	S-C		x							
	Chl a	S-C				(x)	(x)				
		S-P				(x)	(x)				
	Chl a, cyanobacteria, temperature (RS)	L		x							
Fisheries	Catch assessment survey CAS	S/L			(x)	(x)	x	(x)			
	Sizes of fish	S			(x)	(x)	x				
	Frame survey	L							(x)	x	(x)
	Biomass/stock assessments	L								(x)	(x)
Meteorology	T,prec.,WS,WD, Atm. P., ISR ,ILW, RH (AWS)	S	x								
	WS,WD, prec., sol. R., cloud. (RS)	L + B		x							
Biodiv.	Changes from baseline (fish)	S							x		
	Changes from baseline (plants)	S									x
Land use /erosion	Surface types (agric/forest/…)	S							x		
	Exposed soil by slope categories	S							x		
	Erosion hazard risk assessment	S							x		
	Population distribution	S								x	

	Land use maps (RS)	B				x
Socio-economy	Fishermen statistics	S		x		
	Fish prices at the market	S	x			
	Aquaculture statistics	S	x			
	Specific surveys	S		(x)	x	

Table 5 (a): National institutions/organizations related to lakes in Kenya, Uganda and Tanzania (V= Lake Victoria, Tu = Lake Turkana, A = Lake Albert, E = Lake Edward, Ta = Lake Tanganyika, MN = Lake Malawi/Nyasa/Niassa; M= mandated, LTM = long-term monitoring currently, TBD = to be determined, NBP = No monitoring but possible; L=lake, B=basin).

Lakes	Mandate	Monitoring	INSTITUTIONS /Organizations	Water	Fisheries	Biodiversity	Land use	Socio-eco	Climate
			KENYA						
V,Tu	M	LTM	Kenya Marine and Fisheries Research Institute (KMFRI) www.kmfri.co.ke	L+B	L+B	L+B		L+B	L+B
V,Tu	M	LTM	Kenya Fisheries Service www.kenyafisheriesservice.go.ke		L				L+B
V,Tu	M		Kenya Coast Guard kcgs.go.ke		L				L+B
V,Tu	M		Kenya Wildlife Service (KWS) www.kws.go.ke	L	L	L+B		L+B	
V,Tu	M		Local County Councils	L	L				
V,Tu	M		National Environment Management Authority (NEMA) www.nema.go.ke	L+B		L+B		L+B	
V,Tu	M		National Land Commission www.landcommission.go.ke				B		
V,Tu	M		State Dept for Fisheries, Aquaculture & The Blue Economy kilimo.go.ke		L				L+B
V,Tu	M		Water Resources Management Authority (WARMA) wra.go.ke	L+B					L+B
V	M		Lake Basin Development Authority (LBDA) lbda.go.ke						
Tu	M		Kerio Valley Development Authority (KVDA) kvda.go.ke	L+B	L		B	B	
V,Tu			Universities (e.g. Maseno, Eldoret, Nairobi etc.)	L+B	L+B	L+B		L+B	L+B
V,Tu			Osienala, Friends of lake Victoria osienala.net		L+B			L+B	L
Tu			Friends of Lake Turkana www.friendsoflaketurkana.org	L+B	L+B	L+B	L+B	L+B	
Tu			Turkana Basin Institute (TBI) www.turkanabasin.org/	L+B	L+B	L+B	B	L+B	L+B
Tu			Turkana University College (TUC) www.tuc.ac.ke	L+B	L+B	L+B	L+B	L+B	L+B
V,Tu			Inter-University Council of East Africa (IUCEA) iucea.org	L+B	L+B	L+B	L+B	L+B	L+B
V,Tu			Institute for Climate Change and Adaptation (ICCA) www.icca.uonbi.ac.ke	L+B	L+B	L+B	L+B		L+B
			UGANDA						
V,E,A	M	LTM	National Fisheries Ressources Research Institute www.firi.go.ug	L+B	L+B	L+B		L+B	

V,E,A	M	LTM	Min. of Water & Environ. (Dir. Water Res. Manag.) www.mwe.go.ug	L+B		L+B		L+B	
V,E,A	M	LTM	Min. of Agr. Animal Industr. & Fish. (Dir. Fish. Res.) www.agriculture.go.ug	L+B	L+B	L+B		L+B	
V,E,A	M		Min. of Agr. Animal Industr. & Fish(Dir. Crop Res.) www.agriculture.go.ug				B		
V,E,A	M	LTM	Uganda National Meteorological Authority www.unma.go.ug						L+B
V,E,A	M		National Water and Sewerage Corporation www.nwsc.co.ug	L+B					
V,E,A			Fisheries Training Institute		L+B				
V,E,A			Water Resource Institute, Entebbe	L+B					
V,E,A			Makerere University www.mak.ac.ug/	L+B	L+B	L+B	L+B	L+B	L+B
V,E,A			Mbarara University Science &Technology www.must.ac.ug	L+B	L+B	L+B	L+B	L+B	L+B
V,E,A			Busitema University busitema.ac.ug/	L+B	L+B	L+B	L+B	L+B	L+B
V,E,A			Gulu University	L+B	L+B	L+B	L+B	L+B	L+B
V,E,A			Various fisheries organization (*)		L+B				
			TANZANIA						
V,Ta,MN	M	LTM	Tanzania Fisheries Research Institute (TAFIRI) www.tafiri.go.tz	L+B	L+B	L+B		L+B	
Ta	M	TBD	Lake Tanganyika Basin Water Board (LTBWB) www.lvbwb.go.tz	L+B					
MN	M	TBD	Lake Nyasa Basin Water Board (LNBWB) lakenyasabasin.blogspot.com	L+B					
V,Ta,MN	M		Fisheries Development Division www.mifugouvuvi.go.tz		L+B	L+B		L+B	
V,Ta,MN	M		Aquaculture Division www.mifugouvuvi.go.tz		L+B			L+B	
V,Ta,MN	M		Ministry of Agriculture www.kilimo.go.tz				B	B	
V,Ta,MN	M		Ministry of Natural Resources/forestry www.maliasili.go.tz			B	B	B	
V,Ta,MN	M		Ministry of Natural Resources/wildlife www.maliasili.go.tz		L+B	L+B		L+B	
V,Ta	M		Beach Management Units (BMUs) Community organisation		L+B				
V,Ta,MN	M		Ministry of Water www.maji.go.tz	L+B	L+B			L+B	
V,Ta,MN	M		Ministry of Land www.lands.go.tz				B	B	
V,Ta,MN	M		Ministry of Environment	L+B	L+B		L+B		
V,Ta,MN	M	LTM	Tanzania Meteorological Authority www.meteo.go.tz						L+B
V,Ta,MN	M		National Environnent Manag. Council (NEMC) www.nemc.or.tz	L+B	L+B		L+B		
V,Ta,MN	M		Local government Authorities (LGAs)		L + B	L+B			
V,Ta,MN			Universities	L+B	L+B	L+B	L+B	L+B	L+B

(*) Fisheries Protection Force, Association of Fishers and Lake Users, Uganda National Women Fisher Organisation, Bugiri UN Women Group, Katosi women Group, Katosi Development Trust, Uganda Fish conservation Association, Uganda Fish Processors and Exporters Association, Walimi Fishers Organisation, Federation of Fishers Association.

Table 5 (b) National institutions/organizations related to main environmental topics in Rwanda, Burundi, DR Congo and Zambia (V= lake Victoria, Tu = lake Turkana, A = lake Albert, E = lake Edward, K = lake Kivu, Ta = lake Tanganyika, MN= lake Malawi-Nyasa-Niassa; M= mandated, LTM =Long term monitoring, TBD = To be determined, NBP = No monitoring presently but possible; L=lake, B=basin).

Lakes	Mandate	Monitoring	INSTITUTIONS /Organizations	Water	Fisheries	Biodiversity	Land use	Socio-eco	Climate
			RWANDA						
K	M	LTM	Rwanda Environment Management Authority www.rema.gov.rw	L+B	L+B	L+B	L+B	L+B	
K	M	LTM	Rwanda Agriculture & Animal Resources Development Board www.rab.gov.rw		L+B	L+B		L+B	
K	M		Rwanda Water and Resource Board www.rwb.rw	L+B				L+B	
K	M		Ministry of Agriculture and Animal Resources www.minagri.gov.rw		L+B	L+B	L+B	L+B	
K	M	LTM	Rwanda Meteo Agency www.meteorwanda.gov.rw						L+B
K		NBP	University of Rwanda ur.ac.rw	L+B	L+B	L+B	L+B	L+B	
K			Institut d'Enseignement Supérieur (INES) Ruhengeri ines.ac.rw	L+B			L+B	L+B	
			BURUNDI						
Ta	M	LTM	Direction de la Promotion des Filières halieutiques	L+B	L+B			L+B	
Ta	M	LTM	REGIDESO www.regideso.bi	L+B					
Ta	M		Office burundais pour la Protection de l'Environnement (OBPE) www.obpe.bi	L+B	L+B	L+B	L+B	L+B	
Ta	M		Office burundais de l'urbanisme, de l'habitat et de la construction (OBUHA)				B		
Ta	M		Institut Géographique du Burundi (IGEBU)	L+B					L+B
Ta	M		Programme National de Lutte Anti-Erosive (PNLAE)				B		
Ta	M		Autorité de régulation des secteurs eau potable et énergie www.areen.bi	L+B					
Ta	M		Direction Générale de l'Aménagement du Territoire				B	B	
Ta	M		Dir. Générale Envir., Res. en Eau & Assainissement	L+B			B		
Ta		NBP	Université du Burundi www.ub.edu.bi	L+B	L+B	L+B	L+B	L+B	L+B
Ta			International Rice Research Institute (IRRI) www.irri.org/where-we-work/countries/burundi				L+B	L+B	

			DR CONGO						
Ta	M	NBP	Centre de Recherche en Hydrobiologie (CRH)-Uvira	L+B	L+B	L	B	L+B	L
K	M	LTM	Observatoire Volcanologique de Goma	L+B					B
K	M		Centre de Recherche en Sc. Naturelles africanbirds.fieldmuseum.org	L+B			L+B		
Ta,K,E,A	M		Ministère de l'Agriculture/ Direction Nationale des Pêches www.agriculture.gouv.cg	L+B	L+B				
Ta,K,E,A	M		Ministère de l'Environnement/ Direction des Ressources en Eau medd.gouv.cd	L+B					
Ta,K,E,A	M		Ministère de l'Agriculture pêche et élevage/Bureau de pédologie				B		
Ta,K	M		REGIDESO www.regidesordc.com	L+B					
Ta,K,E,A	M		METTELSAT						L+B
Ta,K,E,A	M		Institut Congolais pour la Conservation de la Nature (ICCN) www.iccnrdc.org			L+B			
K	M	NBP	Institut Supérieur Pédagogique de Bukavu www.uerhaispbkv.org	L+B	L+B	L+B	L+B	L+B	L+B
K	M	NBP	Université Officielle de Bukavu (UOB) www.univofbukavu.org	L+B	L+B	L+B	L+B	L+B	L+B
K		NBP	Université Catholique de Bukavu Bukavu ucbukavu.ac.cd	L+B	L+B	L+B	L+B	L+B	L+B
K		NBP	Centre de Recherche en Biodiversité, Ecologie, Evolution et Conservation	L+B		L+B			
E		NBP	Université Officielle de Ruwenzori www.uor-rdc.net	L+B	L+B	L+B	L+B	L+B	L+B
E		NBP	Institut Supérieur du Bassin du Nil - Beni (ISBN)	L+B	L+B	L+B	L+B	L+B	L+B
A		NBP	Université Shalom de Bunia www.unishabunia.org/	L+B	L+B	L+B	L+B	L+B	L+B
			ZAMBIA						
Ta	M	LTM	Department of Fisheries (DOF)/ Ministry of Fisheries and Livestock www.mfl.gov.zm	L	L+B	L+B		L+B	L
Ta	M	LTM	Dept of Water affairs (DWA)/Ministry of Water Development Sanitation and Environmental Protection www.mwdsep.gov.zm	L+B	L+B	L+B	L+B	L+B	L+B
Ta	M		Zambia Environmental Management Agency (ZEMA) www.zema.org.zm	L+B	L+B	L+B	L+B		L+B
Ta	M		Dept of Public Health /Ministry of Health www.moh.gov.zm					L+B	
Ta	M		Zambia Meteorological Department (ZMD) www.zmd.gov.zm						L+B

Ta	M	Land Husbandry/ Ministry of Agriculture www.agriculture.gov.zm			L+B	L+B	L+B
Ta	M	Forestry Dept/Ministry of Lands and Natural Resources www.mlnr.gov.zm		L+B	L+B	L+B	L+B
Ta	M	Department of National Parks and Wildlife/ Ministry of Tourism and Arts www.mota.gov.zm	L+B	L+B			
Ta		University of Zambia (UNZA) www.unza.zm	L	L			
Ta		Copperbelt University (CBU) www.cbu.ac.zm	L	L			

Table 5 (c): National institutions/organizations related to lakes in Ethiopia, Malawi and Mozambique, Uganda and Tanzania (Tu = Lake Turkana, MN= Lake Malawi/Nyasa/Niassa; M= mandated, LTM = long-term monitoring currently, TBD = to be determined, NBP = No monitoring but possible; L=lake, B=basin).

Lakes	Mandate	Monitoring	INSTITUTIONS /Organizations	Water	Fisheries	Biodiversity	Land use	Socio-eco	Climate
			ETHIOPIA						
Tu	M		Ministry of Agriculture www.moa.gov.et		L+B		L+B	L+B	L+B
Tu	M		Ministry of Water, Irrigation and Electricity www.mowie.gov.et	L+B			L+B	L+B	L+B
Tu	M		Ethiopian Biodiversity Institute www.ebi.gov.et			L+B			
Tu	M		Ethiopian Environ., Forest & Climate Change Commission www.efccc.gov.et www.efccc.gov.et/	L+B	L+B	L+B	L+B		L+B
Tu	M		Ethiopian Energy Authority eea.gov.et	L+B			L+B	L+B	
Tu	M		Ethiopian Electric Power www.eep.com.et/en/	L+B			L+B	L+B	
Tu	M		Ethiopian National Meteorology Agency www.ethiomet.gov.et						L+B
Tu	M		The Central Statistics Agency of Ethiopia www.statsethiopia.gov		L+B		L+B	L+B	
Tu		NBP	Addis Ababa University www.aau.edu.et	L+B	L+B	L+B	L+B	L+B	L+B
Tu		NBP	Jimma University ju.edu.et	L+B	L+B	L+B	L+B	L+B	L+B
Tu			Jinka University www.jku.edu.et	L+B	L+B	L+B	L+B	L+B	L+B
Tu			Ethiopian Institute of Agriculture Research (EIAR) www.eiar.gov.et	L+B	L+B	L+B	L+B	L+B	L+B
			MALAWI						
MN	M	LTM	Department of Fisheries		L	L			
MN	M	LTM	Department of Water Resources agriculture.gov.mw	L					
MN	M		Ministry of Natural Resources, Energy, and Environment				L+B		
MN	M		National Statistical Office www.nsomalawi.mw					L+B	
MN	M		Department of Climate Change and Meteorological Services (DCCMS) www.metmalawi.gov.mw						L+B
MN	M		LFMA Local Fisheries Management Authority		L				
MN			Lilongwe University of Agriculture and Natural Resources (LUANAR) www.bunda.luanar.mw	L+B	L+B	L+B	L+B	L+B	L+B
MN			Mzuzu University (MZUNI) www.mzuni.ac.mw	L+B	L+B	L+B	L+B	L+B	L+B
MN			University of Malawi - Chancellor College www.unima.mw	L+B	L+B	L+B	L+B	L+B	L+B
MN			University of Malawi - The Polytechnic www.mubas.ac.mw				B		

MN	M	LTM	Ministry of Health www.msh.org › partner › malawi-ministry-of-he…					L+B	
MN	M	LTM	Marine Department - Ministry of transport and Public Works					L+B	
MN			Malawi College of Fisheries (MCF) www.facebook.com › ... › B		L				
MN			Malawi Fisheries Research Institution (MAFRI)		L				
			MOZAMBIQUE						
MN	M	LTM	Fisheries Research Institute (IIP)		L+B	L+B			
MN	M		National Directorate for Fisheries Policies (DIPOL)	L	L	L			
MN	M		National Directorate for Fisheries Operations (DNOP)		L				
MN	M	LTM	National Fisheries Administration (ADNAP)		L				
MN	M	LTM	National Institute of Fisheries and Aquaculture Development (IDEPA)		L			L+B	
MN	M	NBP	National Directorate of Environment			L+B	L+B		L+B
MN	M		National Directorate of Land				B		
MN	M		National Administration for Conservation Areas			L+B			
MN	M		ARA Zambeze - Water resources administration	L+B					
MN	M	LTM	Provincial Directorate of Agriculture and Fisheries, Niassa		L			L+B	
MN		NBP	Universidade Eduardo Mondlane www.uem.mz	L+B	L+B	L+B	L+B	L+B	L+B
MN		NBP	Universidade Lurio	L+B	L+B	L+B	L+B	L+B	L+B
MN		NBP	Universidade Rovuma	L+B	L+B	L+B	L+B	L+B	L+B
MN		NBP	CBO - Community Based Organizations		L				

Table 6 : Regional institutions related to AGL (L=lake, B=basin, M= mandated, V= Lake Victoria, Tu = Lake Turkana, A = Lake Albert, E = Lake Edward, K = Lake Kivu, Ta = Lake Tanganyika, MN= Lake Malawi/Nyasa/Niassa).

Country	Mandated	Lakes	REGIONAL INSTITUTIONS	Water	Fisheries	Biodiversity	Land use	Socio-eco	Climate
Burundi									
Kenya	M	V,A,E, K	Lake Victoria Fisheries Organization (LVFO) - EAC	L	L+B	L+B		L+B	L+B
Rwanda		Tu,Ta, MN	www.lvfo.org	L+B	L+B	L+B	B	L+B	L+B
Tanzania			Lake Victoria Basin Commission (LVBC) - EAC						
Uganda			www.lvbcom.org						
Burundi									
DR Congo	M	Ta		L+B	L+B	L+B		L+B	
Tanzania			Lake Tanganyika Authority (LTA)						
Zambia			lta-alt.org						
Burundi									
DR Congo	M	K	Autorité de Bassin du lac Kivu et de la Ruzizi (ABAKIR)	L+B	B	L+B	L+B	L+B	B
Rwanda			www.anbo-raob.org						

FIGURE CAPTIONS

Figure 1: Schematic presentation of (A) discontinuous information based on irregular data collection during short-term projects/studies and (B) continuous long-term monitoring including key parameters needed for science-based management. This long-term monitoring is independent from possible short-term projects that may take place as previously and may reinforce the long-term monitoring (adapted from Plisnier et al., 2018).

Figure 2: The six multi-lake monitoring themes (*) address main aspects of ecosystem functioning of the AGL from climate impacts on the limnological cycles to ecosystems services impacted by direct anthropogenic pressures. Upwelling and internal waves are important drivers which supply nutrient-rich water from the hypolimnion (H) into the epilimnion (E.). A. Trade winds cause upwelling upwind and a resulting nutrient flux that may enable an increase in primary production and algal biomass. B.C.D: On cessation of the trade winds, the thermocline oscillates suppling nutrients at different ends of the lake. Higher nutrient supply and growth (magenta); lower supply and growth (blue). Differences in hydrodynamics between lakes are expected according to their depth, stratification, and the magnitude and duration of the trade winds.

Figure 3: Developing a multi-lake monitoring programme provides a way to better evaluate climatic and anthropogenic impacts on ecosystem services. Research stations with some long-term monitoring are indicated while some sites do not have yet a research station enabling a monitoring.

Figure 4: Steps toward a long-term monitoring network of the African Great Lakes (AGL)

SUPPLEMENTARY INFORMATION

Appendix S1. Biodiversity

Two other types of surveys are indicated below. National and International specialists (experts in taxonomy) are required for those surveys which could take place during short-term projects. Those are not part of the long-term monitoring program but complementary.

(1) The baseline survey targets littoral fish, crustaceans, mollusks, phytoplankton, zooplankton, vegetation and other possible taxonomic groups. It should be organized in case historical data are not sufficient. For fish and plants, it is necessary to identify key species to monitor the "changes from the baseline" results. A reference collection needs to be kept at each station to support the monitoring teams in addition to a DNA barcode database and/or a tissue collection, linked to this collection of specimens. Various other taxonomical groups are targeted: phytoplankton, zooplankton, etc.

(2) The intermittent surveys are done when opportunities arise (e.g. funding) but a suggested frequency is here after indicated: submerged macrophytes (two years), phytoplankton and zooplankton (five years), arthropods (five years), mollusks (five years) etc. The objective is to provide an update of the biodiversity of those groups.

Appendix S2. Survey on people and institution related to AGL environment

Questions asked by the survey organized by IISD-ACARE in February-March 2021:

PERSON

1.Last name ?.
2.First name ?
3.Email?
4.Citizenship ?
5.City in which you work ?
6.Country in which you work ?
7.Your title/position in your institution ?
8.What is your field of work at this institution?
9.What year did you begin working at this institution?
10.What field of expertise have you been involved with at this institution?
11.You may indicate here any other comments you might think is appropriate in relation with lakes and monitoring

INSTITUTION

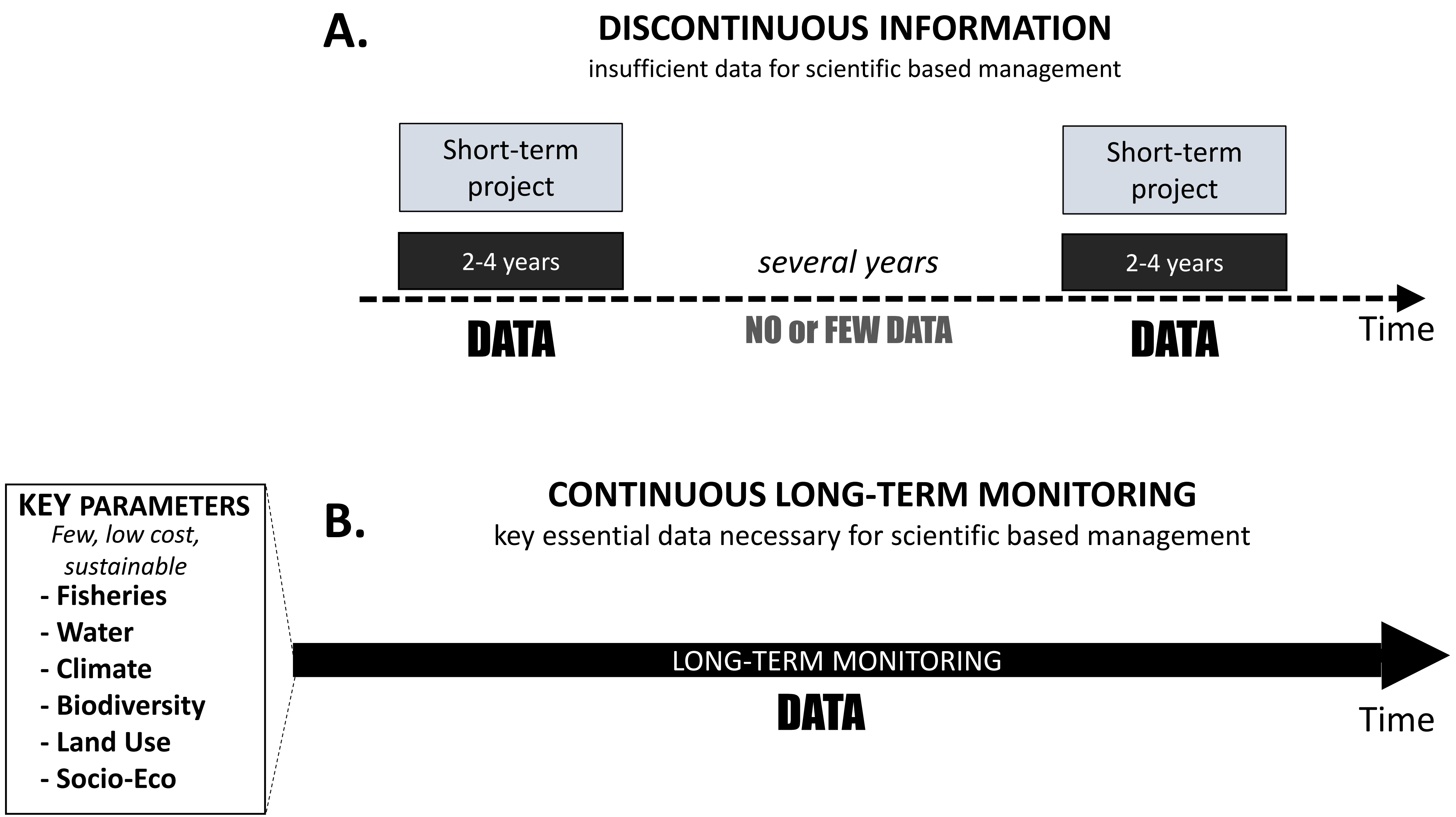
12.Name of your institution?
13.Address of your institution (address, city, code, country) ?
14.General telephone number of your institution ?
15.Website of your institution ?
16.Name of the director or head of your institution (optional) ?
17.Email of the director or head of your institution (optional) ?
18.What are your institution's objectives ?
19.Which African Great Lakes(s) or lake basin(s) does your institution work on or near ?
20.Is your institution governmental, non-governmental, other (please specify) ?
21.Does your institution have an official mandate to implement monitoring activities relevant to AGL or their catchment(s)?
22.What is the type of activity of your institution? (e.g., service to the public, research, education, project-oriented, etc.) ?
23.Does your institution have any field stations located on the African Great Lakes? (at which location?)
24.What are the main parameters that your institution monitor (e.g., catch assessment survey, water/air temperature, land-use/erosion etc...)?

Appendix S3 : How to cite this paper ?

In regard to the high number of authors, it is suggested to add here (or elsewhere) the full reference of this paper since this could facilitate referencing.

Figure1

Click here to access/download;Figure;Fig. 1.pptx



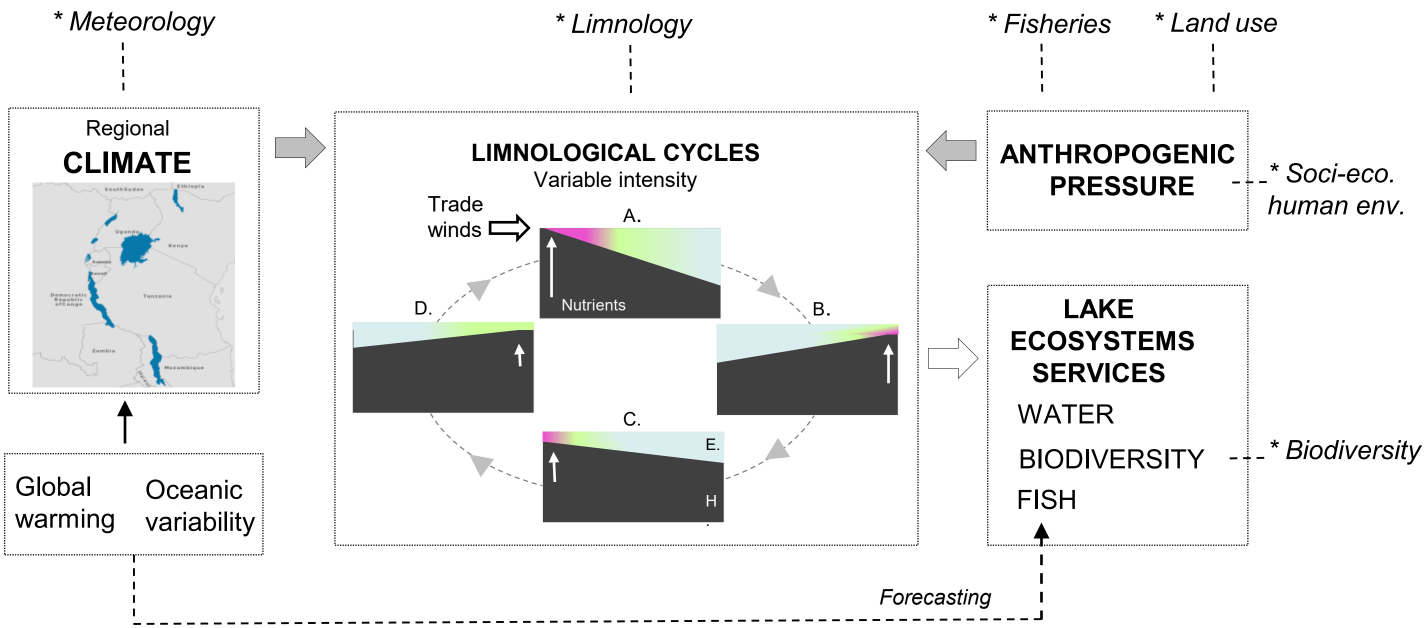
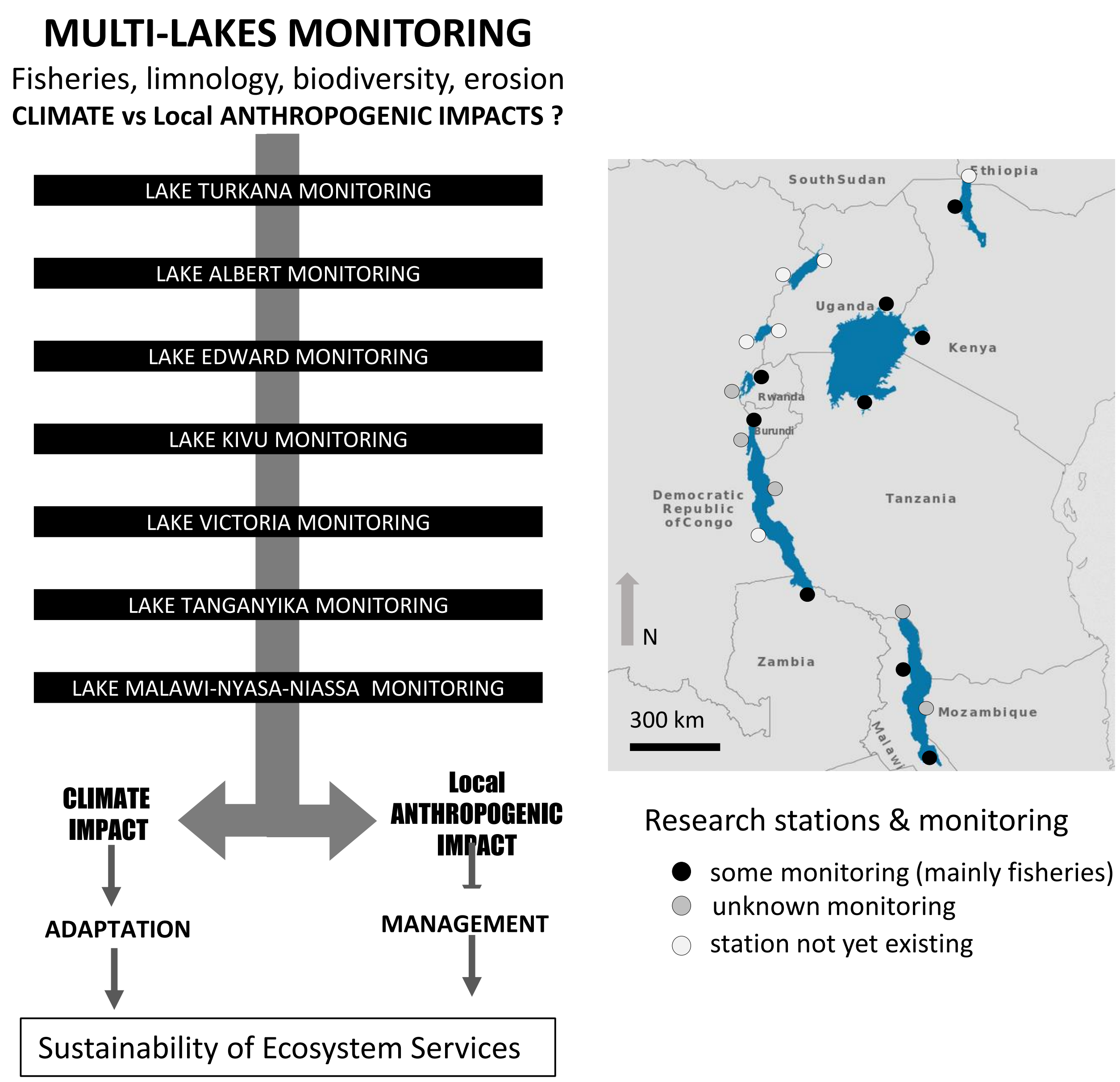
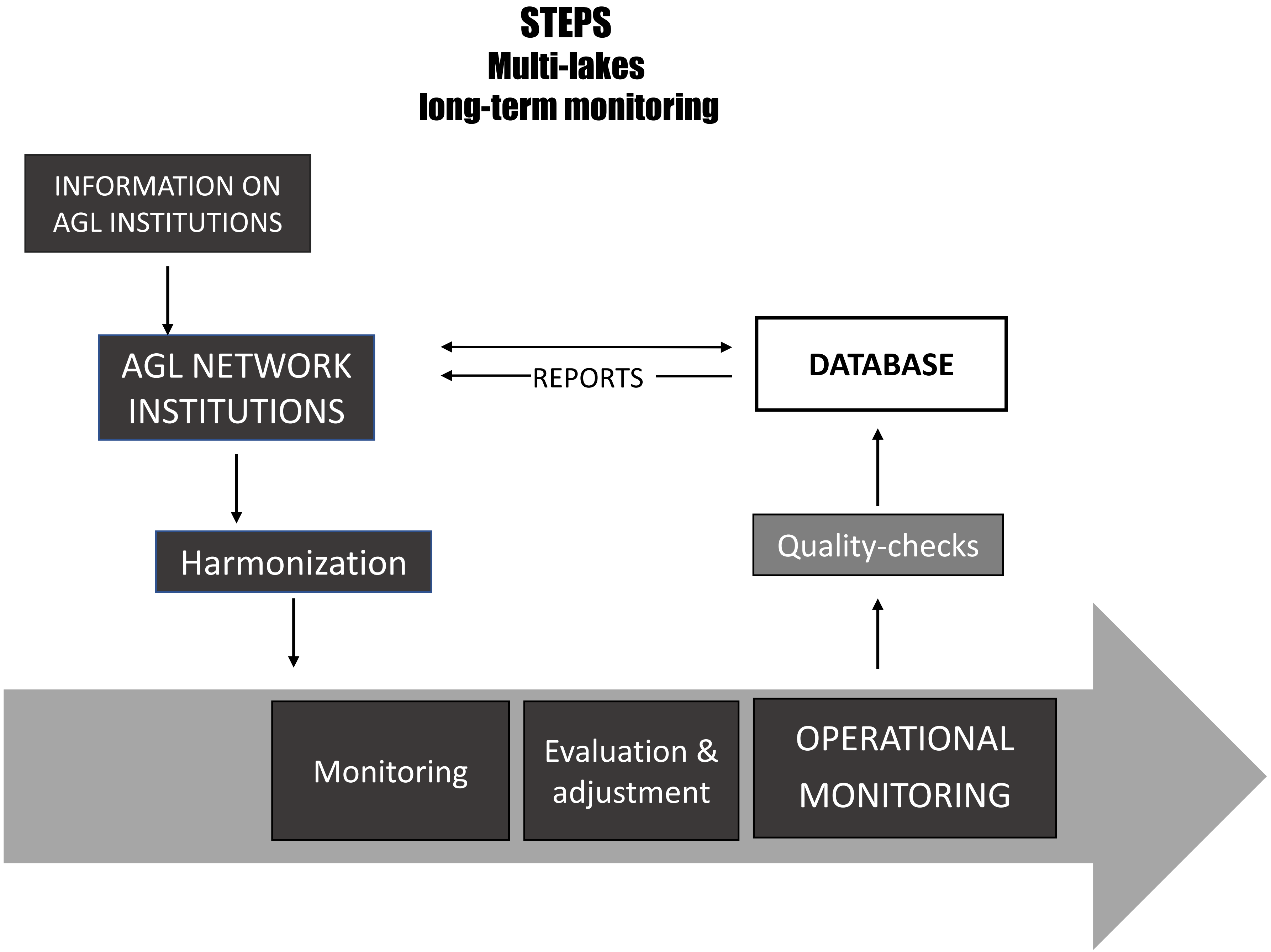

* Meteorology
* Limnology
* Fisheries
* Land use
Regional
CLIMATE
LIMNOLOGICAL CYCLES
Variable intensity
Trade winds
A.
B.
C.
D.
E.
H
Nutrients
ANTHROPOGENIC PRESSURE
* Soci-eco. human env.
LAKE ECOSYSTEMS SERVICES
WATER
BIODIVERSITY
FISH
* Biodiversity
Global warming
Oceanic variability
Forecasting

Figure3


MULTI-LAKES MONITORING
Fisheries, limnology, biodiversity, erosion
CLIMATE vs Local ANTHROPOGENIC IMPACTS ?
LAKE TURKANA MONITORING
LAKE ALBERT MONITORING
LAKE EDWARD MONITORING
LAKE KIVU MONITORING
LAKE VICTORIA MONITORING
LAKE TANGANYIKA MONITORING
LAKE MALAWI-NYASA-NIASSA MONITORING
CLIMATE IMPACT
Local ANTHROPOGENIC IMPACT
ADAPTATION
MANAGEMENT
Sustainability of Ecosystem Services
SouthSudan
Ethiopia
Uganda
Kenya
Rwanda
Burundi
Democratic Republic ofCongo
Tanzania
Zambia
Mozambique
Malawi
N
300 km
Research stations & monitoring
some monitoring (mainly fisheries)
unknown monitoring
station not yet existing


STEPS
Multi-lakes
long-term monitoring
INFORMATION ON AGL INSTITUTIONS
AGL NETWORK INSTITUTIONS
REPORTS
DATABASE
Harmonization
Quality-checks
Monitoring
Evaluation & adjustment
OPERATIONAL MONITORING

Declaration of interests

☒ 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.

☒The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Pierre-Denis Plisnier
(signing for all authors)