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Commentary

Advancing Africa's great lakes research and academic potential: Answering the call for harmonized, long-term, collaborative networks and partnerships

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ABSTRACT

The African Great Lakes (AGL) have rich fisheries and are renowned “biodiversity hotspots”. Consequently the AGLand the ecosystem services they provide, underpin the welfare and livelihoods of over 50 million people across 10 countries. Despite the recognized importance of the AGL, these vital ecosystems and their livelihood support systems are threatened by numerous anthropogenic stressors at local, regional, and global scales. Past and continued efforts to address critical challenges on these lakes are often short-term, parochial, disparate, and uncoordinated resulting in a lack of comprehensive and comparable scientific data and inadequate resources to influence evidence-based policy. Over the past two decades, several international workshops, conferences and scientific publications have identified the need for collaboration, knowledge sharing, and harmonization of research and management as key elements to enhance conservation efforts in the AGL. In this commentary, we introduce the African Center for Aquatic Research and Education (ACARE), which aims to strengthen research and provide the scientific evidence needed to make informed decisions related to sustainable fisheries and aquatic resource management in the AGL. To do this, ACARE will administer a highly collaborative network of experts with three long-term goals: (1) strengthen global and regional research partnerships; (2) establish transboundary and inter-jurisdictional lake advisory groups; and (3) build capacity of freshwater scientists through experiential education and public engagement.

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Introduction

The African Great Lakes (AGL) ecosystems have a combined catchment area spanning over 850,000 km² across seven major lake basins, namely: Lakes Albert, Edward, Kivu, Malawi/Nyasa/Niassa, Tanganyika, Turkana, and Victoria in East and Central Africa (Cox and Ogutu-Owhayo, 2019). These lakes host invaluable resources at local, regional, and global scales (Daley, 2003). The lakes include the world's largest permanent desert and alkaline lake (Turkana), and the deepest and second oldest freshwater lake

on the planet (Tanganyika; Table 1). Three of these lakes (Victoria, Tanganyika, and Malawi) together hold one-quarter of the Earth's total surface freshwater supply (Plisnier et al., 2018). The lakes form headwaters to the three longest rivers of Africa—the Nile, the Congo, and the Zambezi—whose basins support over 300 million people with food, water, transport, energy, and secure livelihoods (UNEP, 2010).

The AGL are known for their rich fisheries and as “biodiversity hotspots” with spectacular endemic fish faunas (Lowe-McConnell, 2009). A comparison of the collective diversity of fishes in the five most species-rich AGL (~1800 species, ~95% endemic) with that of the five North American Great Lakes (176 species, 3% endemic) highlights the species-level richness (Hubbs et al., 2004). This takes into consideration the combined surface area of

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Table 1
Summary information of key characteristics of the African Great Lakes and their basins. Source: African Great Lakes Information Platform (<https://www.africangreatlakesinform.org>). Accessed on 20th November 2018. For comprehensive information on the African Great Lakes see Cowx and Ogutu-Ohwayo (2019).

Lake	Area (km ²)	Mean and (maximum) depth (m)	Surface elevation (m.a.s.l)	Catchment area (km ²)	Basin countries	Special features and fish diversity	Human population in basin/ Average population density
Victoria	68,800	40 (84)	1,133	193,000	Burundi, Kenya, Rwanda Tanzania, Uganda,	Largest tropical lake in the world, and the second largest freshwater lake in the world. ~ 700 fish species	~45 million people; average population density of 250 persons per km ²
Tanganyika	32,600	580 (1,470)	773	231,000	Burundi, Rwanda Zambia, Democratic Republic of Congo, Tanzania	Largest and deepest of the Rift Valley lakes and the 2nd oldest lake in the world. About 250 cichlids (98% endemic) and 75 non-cichlids	~10 million people; population density 13–250 persons per km ² .
Malawi/ Niassa/ Nyasa	29,500	264 (7 0 0)	457	100,500	Malawi, Mozambique Tanzania	The third largest lake in Africa, and the 9th largest in the world. Home to 800–1000 fish species (80% endemic cichlids). Most fish species-rich lake in the world.	~10 million people; Average population density of 106 persons per km ² .
Turkana	7,560	30 (1 1 4)	360	130,860	Kenya, Ethiopia, South Sudan	World's largest permanent desert lake and the largest alkaline lake in the world. ~ 60 fish species (11 endemics); 2 species of Nile perch	~500,000 people; population density of approximately 6 persons per km ² .
Albert	5,300	25 (58)	615	17,000	Democratic Republic of Congo, Uganda	Northernmost lake in the Western Rift Valley. 40–55 fish species (36% endemic); 2 species of Nile perch	Population density up to 149 people per km ² (Hoima district, Ugandan side).
Kivu	2,370	240 (4 8 5)	1,460	5,097	Democratic Republic of Congo, Rwanda	Third deepest of the Rift Valley lakes and located at the highest altitude of all other AGLs. ~ 28 species (50% endemic haplochromine cichlids)	~2 million people. Low density in the DRC (89 people/km ²), but high in Rwanda (350 persons per km ²).
Edward	2,325	17 (1 1 7)	912		Democratic Republic of Congo, Uganda	Smallest among the African Great Lakes, but its basin includes the highly productive Lake George, connected by the Kazinga Channel. ~ 81 fish species in Lake Edward-George system)	The average population density of 126 persons per km ² (Kasese district on Ugandan side).

the AGL (~146,000 km²) which is substantially smaller than that of North American Great Lakes (~244,000 km²) (Salzburger et al., 2014). The biodiversity and natural resources of the AGL, together with the ecosystem services they provide, underpin the welfare and livelihoods of over 50 million people in the 10 riparian countries (Doran et al., 2018; Plisnier et al., 2018) which include Burundi, Democratic Republic of Congo, Ethiopia, Kenya, Malawi, Mozambique, Rwanda, Tanzania, Uganda, and Zambia. They also support the largest freshwater lake fisheries in the world, upon which tens of millions of people (50 to 70% in the riparian countries) depend for inexpensive protein (Daley, 2003) and, in the case of the export fishery on Lake Victoria, critical foreign exchange (Njiru et al., 2014). Lake Victoria's capture fisheries produce more fish, >one million metric tonnes annually, than the commercial fisheries on all five North American Great Lakes (Lawrence et al., 2018). Lake Tanganyika's fisheries alone yield 165,000 to 200,000 tons of fish per year (O'Reilly et al., 2003), employ around 100,000 people, and provide 25–40% of the protein needs of around 1 million people (LTA Secretariat, 2012).

Despite the recognized importance of the AGL, these amazing ecosystems are subjected to numerous anthropogenic stressors at global and regional scales, which have already affected their stability and threaten components of their extraordinary biodiversity with extinction (Salzburger et al., 2014). At the global scale, the Living Planet Report (WWF, 2018) documents global freshwater species populations have dropped by 83% since 1970, outpacing comparative declines in marine and terrestrial ecosystems. Reid et al. (2018) documented 12 emerging threats to freshwater biodiversity that are either entirely new or have intensified since the seminal review by Dudgeon et al. (2006) on major pressures on freshwater ecosystems. At the regional scale, freshwater species in the AGL basins are highly threatened by a range of human-induced drivers such as rapid population increase, climate change, habitat destruction, urban and industrial pollution, overfishing, poaching, illegal wildlife and fisheries trade, and non-native invasive species, as well as natural drivers such as diseases, insect

pests, and natural disasters (Hecky et al., 2010; IPBES, 2018; Sayer et al., 2018). For example, a recently launched freshwater biodiversity assessment report from the International Union for Conservation of Nature and Natural Resources (IUCN) in the Lake Victoria basin shows alarming trends of declining biodiversity and ecosystem services (Sayer et al., 2018). The combined threats have resulted in 20% of freshwater species and 76% of the region's endemic freshwater species identified as threatened with extinction (Sayer et al., 2018). Climate change, manifested by a rise in temperature and lake-level fluctuations, and changes in rainfall pattern, distribution and quantity, exacerbates all the other drivers of biodiversity loss (IPBES, 2018; Ogutu-Ohwayo et al., 2016; Sayer et al., 2018). In addition, oil exploration and drilling activities are a serious threat (Verheyen et al., 2016) and are likely to affect the ecosystem health, water supply and food security of local communities (Plisnier et al., 2018). For Lake Tanganyika, whose flushing time is ~7000 years, recovery from an oil spill could take millennia (Verheyen et al., 2016). In Lake Kivu, methane extraction, if not carefully done, may reduce the lake's permanent stratification and lead to eutrophication of the productive layers and the limnic eruption of dissolved gases could lead to unimaginable disaster if their concentrations surpass unacceptable levels (Wüest et al., 2012).

The numerous and exacerbating threats to the AGL, coupled with the extremely high levels of biodiversity loss primarily from global climatic changes and anthropogenic stressors, call for collective stewardship of these important resources for current and future generations (Cohen, 2018; Ogutu-Ohwayo et al., 2016; Robarts and Zohary, 2018). Cowx and Ogutu-Ohwayo (2019) recently highlighted options for addressing the problems facing the aquatic resources and specifically the importance of effective management of the fisheries and ecosystems of the AGL to achieve the UN Sustainable Development Goals to ensure food and nutrition security and sustainable livelihoods. Over the past two decades, there have been ongoing calls by global scholars and institutions advocating for harmonized, multi-lake, collaborative

research networks to enhance successful implementation of sustainable solutions for AGL's challenges, specifically, the need for comprehensive, long-term scientific knowledge and information to better inform water management (Daley, 2003; Plisnier et al., 2018; Robarts and Zohary, 2018). For example, in an editorial for an AGL special issue of the *Journal of Great Lakes Research (JGLR)* in September 2003, Ralph Daley stated that "inadequate supply and quality of freshwater, inadequately managed, is arguably Africa's greatest developmental challenge" (Daley, 2003, p. 1). To tackle this challenge, Daley advocated for a new African water paradigm, one of integrated capacity development, based on country ownership, adaptive home-grown policies, open stakeholder participation, and greater equity in the North-South development relationship. The new 'knowledge imperative' was anchored on four components, focused on the ability to:

- Measure and understand Great Lakes ecosystems and resources, through monitoring, research, and technology development;
- Legislate, regulate, and achieve compliance, through effective institutional and participatory frameworks leading to community acceptance;
- Provide appropriate, affordable water services, infrastructure, and products, through sustained investment and management by both the public and private sectors; and,
- Educate, train, and raise awareness (including community, adult, and formal education) so that competent human resources are available to build the core scientific, governmental, and engineering capacities.

Daley's calls are part of widespread appreciation for collective action to address issues that threaten African freshwater resources. Further calls to action to identify solutions to recurring challenges through sustainable partnerships were made by the U.S. Department of State's Special Envoy for the African Great Lakes and the Democratic Republic of Congo in collaboration with the Lake Tanganyika Authority during the Great Lakes to Great Lakes Initiative (<https://isthmus.com/events/the-great-lakes-to-great-lakes-initiative/>. Accessed 12 December 2018) meeting for Lake Tanganyika held in Kigoma, Tanzania in February 2015. During this meeting, experts from the AGL met their counterparts from the North American Great Lakes to exchange information and share knowledge on issues related to the sustainable management of transboundary lakes.

Within this context, The Nature Conservancy (TNC) in partnership with regional and global funding agencies, academic and research regional organizations organized the African Great Lakes Conference (AGLC) on May 2–5, 2017, in Entebbe, Uganda (Doran et al., 2018; Cowx and Ogutu-Ohwayo, 2019; Olago et al., 2017). The conference organizers documented the major conference outcomes (organized around six major themes) and formally adopted 26 conference resolutions agreed by over 300 participants to guide present and future actions related to the conservation and sustainable development of the lakes and their basins (Doran et al., 2018; Cowx and Ogutu-Ohwayo, 2019). To promote networking between researchers and other stakeholders, the conference resolved to: "Establish a 'Network of African Great Lakes Basin Stakeholders' to coordinate action and exchange on priority issues defined by the African Great Lakes Conference and subsequent gatherings supported by the experience of the African Network of Basin Organizations and the International Network of Basin Organizations, as it develops its structure and functions" (Resolution #21).

Since mid-2017, several international workshops, conferences including the 8th Speciation in Ancient Lakes (SIAL 8) Conference among others and publications have advocated and prioritized regional collaboration, knowledge sharing, and harmonization of research and management as key elements to enhance AGL conser-

vation efforts (Doran et al., 2018; Ives and Lawrence, 2018; Plisnier et al., 2018; Robarts and Zohary, 2018). Corresponding calls have been made for advancing education and training of the next generation of freshwater scientists, practitioners and decision makers to influence policies, strategies, and legal frameworks that support the sustainable use of water-related ecosystem services. Specifically, the AGLC resolved to: "Ensure that future generations of scientists, managers, politicians, and stakeholders have the capacity, knowledge, and ability to address current and future issues of the African Great Lakes and their basins" (Resolution #26). These resolutions have resulted in the formation and registration of the African Center for Aquatic Research and Education (ACARE) under section 402 of the Not-For-Profit Corporation Law of the United States in July 2017. Here we introduce ACARE and its goals.

Research and capacity building challenges in the AGL region

Since the early 1990s, the AGL have been the focus of numerous reports and publications in various journals, using research involving over a hundred scientists, and financed by many international bodies (Lowe-McConnell, 2003, 2009). For decades, parochial scientific inquiry and data acquisition on the AGL was mainly conducted in the frame of short-term funded projects leading to discontinuous time series data (Plisnier et al., 2018). Plisnier et al. (2018) reported that environmental and limnological monitoring of the AGL has often not been continuous or standardized among bordering countries. In a special issue of *Limnology and Oceanography* entitled, "Long-term perspectives in aquatic research", Hampton et al. (2019) demonstrated many key ecological relationships can be obscured in short term studies by common features such as time lags, natural variability, nonlinear relationships, interactive drivers and relatively slow processes. Furthermore, research is often conducted by entities external to the riparian countries, and results are rarely used to inform good policy and management (Paul Mafabi, *Pers. Comm.*, Ministry of Water and Environment, Uganda). Cohen (2018) also noted that to date, paleolimnological studies in the AGL are primarily conducted by researchers from outside the region, often as one-off investigations with limited involvement of local research scientists. As argued by Kariuki (2016), researchers in Africa often work in 'silos', which wastes limited human resources and infrastructure. This also implies that researchers are competing for a small pool of grants and decreasing their chances of success (Kariuki, 2016). The disparate, parochial, short-term research often results in temporarily inconsistent and incomparable scientific data due to lack of standardized approaches, and disjointed country-and-regional specific datasets that hinder evidence-based formulation and implementation of regulations, policies and conservation actions. Therefore, to address these shortcomings, long-term research partnerships and funding mechanisms are vital to coordinate action on priority research, policy, and management issues at the regional and global level.

Scientific and professional development opportunities for early-to mid-career scientists in low-and-middle-income countries are limited and inconsistent. Significant human and institutional capacity gaps still limit the technical readiness of freshwater professionals in AGL riparian countries. Despite inevitable differences, African universities have several shared challenges. These include limited government funding, rapid growth in undergraduate enrollments, low postgraduate enrollment and graduation rates, a general shortage of academic staff (particularly those holding PhDs), and relatively limited research production (Breier, 2015; Kariuki, 2016), the latter primarily because of low institutional and national funding for state-of-the-art equipment and research facilities. Although Africa comprises 16.6% of the world's popula-

tion, the continent still accounts for less than 1% of global research output (Duermeijer et al., 2018; Ngongalah et al., 2018). This challenge is exacerbated by a disproportionately low number of freshwater post-graduate students compared to academic institutions in the global North, an inadequate number of skilled practitioners in the workforce to rapidly assimilate new knowledge from the water sciences into practical solutions (Vörösmarty et al., 2018), and “brain drain” occasioned by emigration of scientists from their countries of birth for employment and education elsewhere (Breier, 2015; Duermeijer et al., 2018).

The African Center for aquatic research and education

To address the calls for action and historical challenges, we introduce ACARE, a highly collaborative organization dedicated to harmonizing research on the AGL and increasing the local capacity of Africa’s next generation of freshwater experts through partnerships, collaboration, and innovative learning experiences. We propose three major goals to be facilitated and supported by ACARE:

- 1) Strengthen global and regional partnership and collaborative networks to bring together the vast, existing knowledge on freshwater resources;
- 2) Establish long-term inter-jurisdictional lake advisory groups to harmonize and promote joint multi-lakes research monitoring projects; and,
- 3) Expand and develop comprehensive education and training programs to produce the next generation of freshwater researchers, policymakers and practitioners.

Strengthening global and regional research partnerships

Long term international research partnerships and equitable research collaborations are imperative for sharing of ideas, data, infrastructure, and costs. Specifically, long-term, multi-site research has been rated as the most highly valued approach for generating, understanding and for developing general theory in ecology and evolutionary research (Kuebbing et al., 2018). Research partnerships and collaborative networks of stakeholders at all levels—from those involved in defining data to be collected and formulation of knowledge gaps through to decision-making, policy development, and implementation of both the research and the governance and management of the AGL are essential for sustainable resource management (Dörner et al., 2015). As researchers come together, they can close in on ever more important pieces of the puzzle needed to answer key questions about the global freshwater resources. For instance, Hampton et al. (2019) recently proposed that “more collaboration among aquatic scientists and remote sensing experts, and availability of remote sensing products at finer spatial scales together will revolutionize the tractability of multi-decadal global lake studies”. Currently, there are academic partnerships among international universities that drive innovative research and education, and thus could enable African institutions to become a larger part of global resource management and freshwater science.

Building on these existing partnerships, ACARE seeks partnerships that leverage the combined skills, assets, technologies, and resources of public, private, and nonprofit entities to enhance sustainable research. A community of institutions and actors contributing to sustainable aquatic ecosystem services and capacity building already exists in the African Great Lakes region. This community is well-placed to mobilize with ACARE to address these challenges. Many of these organizations are formally and informally already a part of the growing, collaborative community, including the Nile Basin Initiative (NBI), Lake Victoria Basin

Commission (LVBC), Lake Victoria Fisheries Organization (LVFO), Lake Tanganyika Authority (LTA), Autorité du Bassin du Kivu et de la Ruzizi (ABAKIR) and the Lake Kivu Monitoring Program initiatives as well as the ministries and research centres/stations spread across the aforementioned AGL countries. At the global scale, ACARE is seeking partnerships and collaborations with global organizations, universities, and initiatives to unite freshwater specialists and efforts engaged in freshwater research, data synthesis, conservation, education and outreach, and policymaking, e.g., the Alliance for Freshwater Life (Darwall et al., 2018).

Establishing long-term, inter-jurisdictional lake advisory groups

Sustainability over a multi-generational timeframe requires a meaningful, global commitment to address degraded transboundary drainage basins and their affiliated freshwater ecosystems, as well as a long-term commitment to adequate collective stewardship of natural resources (Garrick et al., 2017). The engagement of relevant actors from academia, government, the private sector and civil society is needed to ensure that stakeholders in the AGL will be able to meet their prioritized Sustainable Development Goals (SDGs) and commitments, including those expressed in the 2030 Agenda for Sustainable Development (UN General Assembly, 2015) (Table 2). Ultimately, ACARE aims to create a perpetual network among key stakeholders that enables entities on the AGL to have a mechanism of regular communication and collaboration. To achieve this, ACARE is on a path to become the connecting link for people to get research and projects done collaboratively to advance the big picture for ecosystem and community health.

Due to the shared nature of Africa’s multi-jurisdictional lakes, coordinated, cooperative, inter-jurisdictional and transboundary management mechanisms are necessary to moderate unilateral, parochial actions on shared resources (Gaden et al., 2012). The approach being proposed by ACARE comes from the current Great Lakes Fishery Commission’s collaboration arrangement on the North American Great Lakes where lake committees have been created and are successful mechanisms for inter-jurisdictional cooperation. In the lake committee system of the North American Great Lakes “high-ranking officials of each of the five Great Lakes to meet as a group to coordinate their management responsibilities” (Gaden et al., 2012). Similarly, around Lake Victoria, the LVFO Secretariat and Executive structure facilitate the processes for policies and decisions created at the highest levels of the LVFO—Council of Ministers (LVFO, 2001; Lawrence et al., 2018). Plisnier et al. (2018) proposed a regionally administered and standardized long-term monitoring programme based on experiences from the Lake Tanganyika Regional Integrated Monitoring Programme.

Mirroring the North American Great Lakes’ lake committee process (see www.glf.org/joint-strategic-plan-committees.php), and the successful structure of the LVFO (Daley, 2003; Lawrence et al., 2018), ACARE is developing a network of stakeholders, and a process of collaboration, to guide future research through creation of lake-specific advisory groups. Building on this momentum, ACARE will facilitate lake advisory groups to enhance scientific inquiry in a systematic and consistent manner; foster a community of shared knowledge and practice, across sectors and geography; and positively influence policymaking using science, communication, education, community engagement and other strategies. Specifically, advisory group members will meet at least annually to: (a) prioritize research needs on each lake; (b) determine and undertake specific projects to address prioritized research; (c) exchange knowledge regarding relevant research, monitoring trends, and practices; (d) foster partnerships to inform and

Table 2
United Nations Sustainable Development Goals and how they are addressed by ACARE's collaborative network.

SDG Number	SDG Name	How it is being addressed	Focus
17	Partnerships for the Goals	<ul style="list-style-type: none"> Using the highly collaborative networks described in this paper, SDG 17 is the mechanism that ACARE is using to address the below SDGs 	Major driver
4	Quality Education	<ul style="list-style-type: none"> One of ACARE's major efforts is to enhance education and training of freshwater experts in the region, and globally, to address the challenges herein 	Direct Impact
5	Gender Equality	<ul style="list-style-type: none"> ACARE is creating opportunities for women to engage in the processes of networking and partnerships at the core of its mission, and developing shorter term opportunities for students and those in early career to engage with the larger global freshwater community 	Direct Impact
6	Clean Water and Sanitation	<ul style="list-style-type: none"> In addressing some of the largest freshwater resources on the planet, experts will be addressing water quality issues directly. Sanitation is important and will likely be addressed along with SDG 11 and 15 as land-based activities (industrial activity) and farming (run-off) both heavily impact these lakes 	Direct Impact
14	Life Below Water	<ul style="list-style-type: none"> Protecting the biodiversity and ensuring sustainable use of the resources for the people who depend on them are the drivers for ACARE's existence 	Direct Impact
1	No Poverty	<ul style="list-style-type: none"> The intent of ACARE's activities are to enhance the health and quality of these vast natural resources. Such resources as fisheries and clean water both contribute to reducing poverty through economic gain and human health 	Indirect Impact
2	Zero Hunger	<ul style="list-style-type: none"> Similar to SDG 1, enhancing the health and quality of these vast natural resources, upon which millions of people depend on for their livelihoods, could reduce hunger through healthy fisheries and clean water 	Indirect Impact
3	Good Health and Well Being	<ul style="list-style-type: none"> Cleaner lakes and sustainable resources within them will reduce poverty and hunger resulting in better nutrition and less sickness 	Indirect Impact
8	Decent Work and Economic Growth	<ul style="list-style-type: none"> The health of the AGL has, in the past, demonstrated that these resources increase economic growth through a variety of activities such as fisheries, transportation, and other water-related, land-based activities. Ensuring the health of the lakes increases the chances of these activities to continue. 	Indirect Impact
9	Industry Innovation and Infrastructure	<ul style="list-style-type: none"> Some of the biggest advances in Africa include activities surrounding aquaculture. Many of the freshwater experts already engaged with ACARE's network are leading the way in aquaculture studies and innovations and will continue to do so and a more effective pace when working together 	Indirect Impact
11	Sustainable Cities and Communities	<ul style="list-style-type: none"> Communities who depend on these lakes for their livelihoods need clean, sustainable resources. With stronger collaborations and science, cleaner lakes will ensure communities can depend on these resources into the future 	Indirect Impact
12	Responsible Consumption and Production	<ul style="list-style-type: none"> Freshwater experts, with the right resources and information, can assist in the responsible use of these critical waterbodies 	Indirect Impact
13	Climate Action	<ul style="list-style-type: none"> Climate change is affecting our natural resources in a variety of ways. One is the negative impacts on the ability to produce crops in arid areas of the world like Africa. This often causes a general human migration towards large, freshwater resources such as the AGL which have shown high rates of growth around the lakes' edges. Attention to climatic impacts on riparian and freshwater resources will be critical in addressing the issues affecting these lakes. 	Indirect Impact
15	Life on Land	<ul style="list-style-type: none"> The health of all water bodies on the planet depend on what flows into them. Life on land and the activities that take place in the riparian communities around them will be critical 	Indirect Impact
16	Peace, Justice, and Strong Institutions	<ul style="list-style-type: none"> The culmination of ACARE and its partner's activities are that long-term efforts become engrained in how we care for, use, and address these important natural resources. That we care for them so that the lakes continually to allow the citizens in these regions to be self-reliant societies, realizing their own visions of livelihoods, justice, equity, democracy, and peace. 	Overall Impact

accelerate positive change for the lakes; (e) develop policy briefs and communication tools, based on science and community needs; (f) activate collaborative, cross-basin projects between lakes and across sectors; and (g) direct resources towards priority collaborative needs and projects. Membership of each lake-specific advisory group will consist of researchers, managers, and policymakers from each riparian country, and all will be represented in a larger regional body (Fig. 1). Lead members from each of the individual lake-specific advisory groups will constitute the Council of Advisory Groups to harmonization research across basins.

Building the capacity of the next generation of freshwater experts

The availability of qualified professionals coupled with the application of advanced research knowledge can greatly assist developing countries to achieve the SDGs and build the institutional capacity essential to reduce poverty. Higher education institutions play a critical role in training the professionals, high-level specialists, scientists, and researchers needed by the economy and in generating new knowledge in support of the national development (Altbach and Salmi, 2011). In this context, an evaluation report by NORAD (2014) developed a general theory of change for increasing the supply and quality of graduates and improving the production and quality of research by strengthening the

capacity that affects these two outcomes. Specifically, the factors expected to promote the achievement of the desired outcomes are: i) academic recruitment and staff development; ii) enrollment system and procedures; iii) institutional capacity building through activities that improve physical capacity, research capacity and support, and managerial and leadership capacity; and iv) translational research and outreach via activities such as research conferences and workshops, research publication and dissemination, knowledge communities, translation of research findings into policy recommendations (NORAD, 2014).

Significant human and institutional capacity gaps limit the technical readiness of freshwater professionals in addressing the emerging challenges, particularly in Africa where the gap between need and reality is highest (Vörösmarty et al., 2018). The Commission for Africa's report, *Our Common Interest*, launched in March 2005, acknowledged the science gap between Africa and the rest of the world and recommended the establishment of centers of scientific excellence to act as springboards for developing scientific capacity (Commission for Africa, 2005). These centers could either be physical or virtual networks of research that are internationally competitive and regional in scope, as the necessary research is beyond the resources of many single African countries (Commission for Africa, 2005).

Recent attempts have been made to promote human resource capacity building, regional research, and increased teaching capacity in Africa through academic networking and mobility between

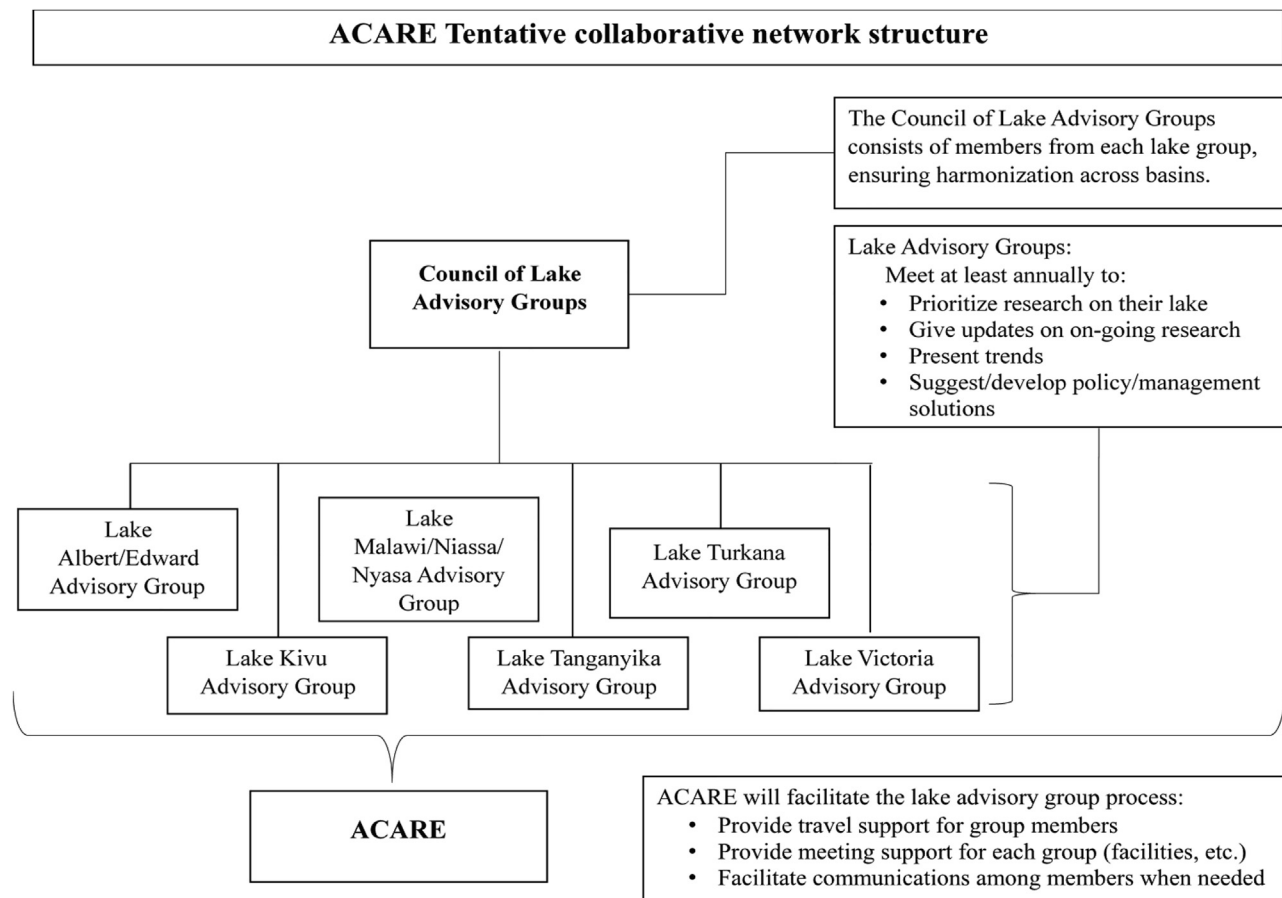


Fig. 1. Proposed collaborative structure for advisory groups on the AGL. As of November 2019, six groups have been formed, with Lakes Albert and Edward forming one under the rationale that experts on each lake overlap. Note that each “advisory group” may identify differently depending on their purposes. Lake Tanganyika, for example, is called the Lake Tanganyika – Scientific Advisory Group (LT-SAG); and the Lake Malawi/Niassa/Nyasa Basin Fisheries and Aquaculture Network.

institutions. The African Union’s (AU) Agenda 2063 *The Africa We Want* recognizes the need to “Catalyse an education and skills revolution and actively promote science, technology, research and innovation, to build knowledge, human resources, capabilities and skills for the African century”. To achieve this goal, the Agenda proposes a “faster movement on the harmonization of continental admissions, curricula, standards, programmes and qualifications and raising the standards of higher education to enhance the mobility of African youth and talent across the continent by 2025” (African Union Commission, 2015). Another laudable attempt that can facilitate intra-Africa mobility and academic integration is AU’s recent announced plans to introduce a single passport to create a ‘continent without borders’ by abolishing visa requirements for all African citizens in all Africa countries by 2018 (<https://theculturetrip.com/africa/articles/a-new-passport-is-creating-an-africa-without-borders/>. Accessed 15 December 2018). All these efforts can “unlock the gates of higher education” and promote the skills revolution that is required for Africa to harness its youth demographic dividend (Obiero et al., 2016).

To achieve these noble goals, the World Bank financed the Africa Higher Education Centres of Excellence Project (ACE) to build and nurture specialized world-class higher education institutions on the continent (World Bank, 2014). This project was realized in multiple phases: ACE I with 19 Centres of Excellence in West and Central Africa and ACE II with 24 Centres of Excellence in Eastern and Southern Africa. Recently, ACE III was introduced as a successor to ACE I, and is focusing on increasing post-graduate education quality in selected universities through regional specialization, applied research, improved linkages with

industry, and growing regional and international coordination (World Bank, 2014). These ACE project goals are to build and sustain excellence in higher education in African countries because few African economies have the sustained means to fund internationally competitive centers of excellence in the broad range of areas required for their economic growth and development. In addition, where there are suitable academic and training efforts, they are often not comprehensive, leading to specialists who may lack a thorough knowledge or skill set (World Bank, 2014).

Working with the region’s established academic institutes, research facilities and institutes, Centres of Excellence and other academic and research exchange programs, ACARE aims to help facilitate a comprehensive and innovative learning experience for young freshwater experts in the African Great Lakes riparian countries, coupled with exposure to innovative research and global partnerships. The education and resulting skill sets will contribute to stability, food security, and environmental security on a much larger scale, and to better livelihoods and peaceful outcomes. To avoid duplicative effort, ACARE will facilitate collaboration within ongoing academic initiatives and mobility programs among universities, public, private sectors, laboratories, and institutions (Table 3). The intent is to create a system by which students interested in freshwater sciences can attend any institution that will allow them to attain world-class educational standards. To achieve this goal, ACARE will facilitate:

- African universities to supplement new and existing courses with hands-on experience, partnering with national, regional and global networks of academic and research institutions;

Table 3

Selected examples of key initiatives to promote capacity building of freshwater scientists in Africa.

Name of Initiative	Objectives	How?	Actors/Partners
Africa Centre of Excellence in Aquaculture and Fisheries (AQUAFISH)	To foster innovation and entrepreneurship in the production of highly skilled fit-for-purpose critical mass of agricultural scientists for improved aquaculture and fisheries management to enhance food, nutrition and economic security in Eastern and Southern Africa	<ul style="list-style-type: none"> • train a critical mass of MSc and PhD graduates who are competent to create innovations that will revolutionize the aquaculture and fisheries sector in Africa; • enhance the capacity of Lilongwe University of Agriculture and Natural Resources (LUANAR) as a Center of Excellence to attract national and regional students and train world class scientists that are relevant to industrial and development needs in the aquaculture and fisheries sector in Africa; • Improve innovations/technologies for increasing fish production, value addition and marketing, through partnerships with the private sector, academic and research institutions, and civil society organizations. 	WorldFish Centre; Soya Bean Innovation Lab (SIL), Regional Universities Forum for Agricultural Development (RUFORUM), MALDECO, University of Eldoret; Catholic University of Mozambique; University of Malawi (UNIMA); Freshwater Fisheries Research Centre (China); Malawi Department of Fisheries; Malawi University of Science and Technology (MUST); National Aquaculture and Research Development (Zambia); Mzuzu University (Malawi)
Education and Research Hub for the Sustainable Management of Aquatic Ecosystems in Eastern Africa (AQUAHUB)	To foster the sustainable management of aquatic ecosystems and their resources to improve livelihoods in Eastern Africa and to contribute towards the achievement of the SDG's 2, 4, 6, 12, 14 and 15.	<ul style="list-style-type: none"> • Support education and research hubs to intensify south-south collaborations, provide highly qualified graduates to the job market and develop/implement projects/research in Eastern Africa; • Implement an international joint degree Master's program "Limnology and Wetland Management-LWM" by BOKU, EGU and IHE Delft and the regional "Aquatic Ecosystems and Environmental Management (AEEM)" by AAU, BDU, EGU and EIAR-NFALRC. • Establish a web-based network of southern and northern institutions with common interests towards the sustainable management of aquatic ecosystems; • Assess impact of 40 years of collaboration in limnology between Austria and Eastern Africa (IPGL), including recommendations for future development. 	University of Natural Resources and Life Sciences, Vienna (BOKU), Egerton University (EGU), Addis Ababa University (AAU), Bahir Dar University (BDU), The Ethiopian Institute of Agricultural Research (EIAR).The project is within the scope of the International Training Programmes in Limnology (IPGL) that has been running for close to 40 years.
Collaborative Training in Fisheries and Aquaculture in East, Central and Southern Africa (COTRA)	To build the capacity of African HEIs to produce skilled and competent professionals required to achieve and maintain the sustainability of fisheries and bolster adoption and up-scaling of aquaculture technologies	<ul style="list-style-type: none"> • Improve the skills and competencies of academic staff in research, training and supervision; • Enhance the quality of graduate training to build innovative and fit-for-purpose professionals; and, • Improve the skills and competencies of administrative staff in implementing international mobility. 	African partner institutions (University of Eldoret (Kenya), Makerere University (Uganda), Rhodes University (Republic of South Africa), Mzuzu University (Malawi), and the Official University of Bukavu (DR Congo), and BOKU Technical partner
Strengthening Regional Capacity in Research and Training in Fisheries and Aquaculture for Improved Food Security and Livelihoods in Eastern Africa (STRECAFISH)	To build capacity in Higher Educational Institutions (HEIs) towards improved response of education to the fast-moving aquaculture and fisheries industry	<ul style="list-style-type: none"> • Establish educational and research networking responsive to the aquaculture and fisheries industry in Eastern Africa; • Analyse and realign curricula and support capacity building activities that are fit-for-the demands of the stakeholders; and • Foster aquaculture development through tailor-made training of fishery officers, development agents and farmers and develop model aquaculture villages. 	Makerere University; University of Natural Resources and Life Sciences, Vienna; University of Eldoret; Ethiopian Institute of Agricultural Research
International Lake Environment Committee Foundation (ILEC)	To advance international cooperation for conserving lake environments and promoting environmentally-sound management of world lakes through investigations and research on rational methods for achieving harmony	<ul style="list-style-type: none"> • Collaborate to identify and assess the range of lake and other lentic water basin governance and socio-economic challenges for effective implementation of integrated lake basin management (ILBM) 	International Lake Environment Committee Foundation; University of Nairobi; Ministry of Water and Sanitation (Kenya), Ministry of Environment and Forestry (Kenya); County Governments in Kenya with

(continued on next page)

Table 3 (continued)

Name of Initiative	Objectives	How?	Actors/Partners
	between environmental management and sustainable development, and scientific knowledge on lake environments internationally.	<ul style="list-style-type: none"> Collaborate to identify, compile, analyze, update and disseminate knowledge, data and management experiences related to ILBM Jointly develop, promote and disseminate assessment protocols, methods and indicators to identify, assess, refine and address lake and other lentic water basin environmental and governance issues Collaborate to undertake relevant water-related programmes, activities and workshops Share already existing resource materials 	jurisdictions over lake basins; Lake Victoria Basin Commission; Kenya Marine and Fisheries Research Institute; Water Resources Authority (Kenya); Flamingo Net; Osienala; Université de Cheikh Anta Diop (Senegal, and other partners in the West Africa region)

- Flexible opportunities for visiting scientists, professors, decision-makers, and managers to transfer expertise from institutions globally; and,
- Extensive exchange potential among African, Asian, North American, and European partners.

Collaboration between institutions, regionally and globally, will help achieve the critical number of participants necessary to run more training programs or courses than otherwise possible. The collaborative educational programs will enhance graduate students' ability to think critically and creatively, enabling them to make cross-disciplinary connections and allow them to gain competency in a global environment and strengthen their professional network (Fig. 2). Professional development training will occur through webinars, web resources, and conference workshops.

Looking forward: Creating a platform to enhance information exchange

To support information sharing, collaboration, and dissemination of data and best practices, TNC and its partners developed the web-based African Great Lakes Information Platform (AGLI; www.africangreatlakesinform.org) in 2017 (Doran et al., 2018). The AGLC resolved to enhance AGLI to promote research and collaboration and support decision-making through sharing of information. In 2018, TNC began transitioning AGLI to be co-administered by ACARE and the University of Nairobi. The intention is that AGLI will become one of the major mechanisms for communications and coordination in the region. The long-term goal of AGLI is to support decisions that ensure the African Great Lakes continue to provide the region with economic, social

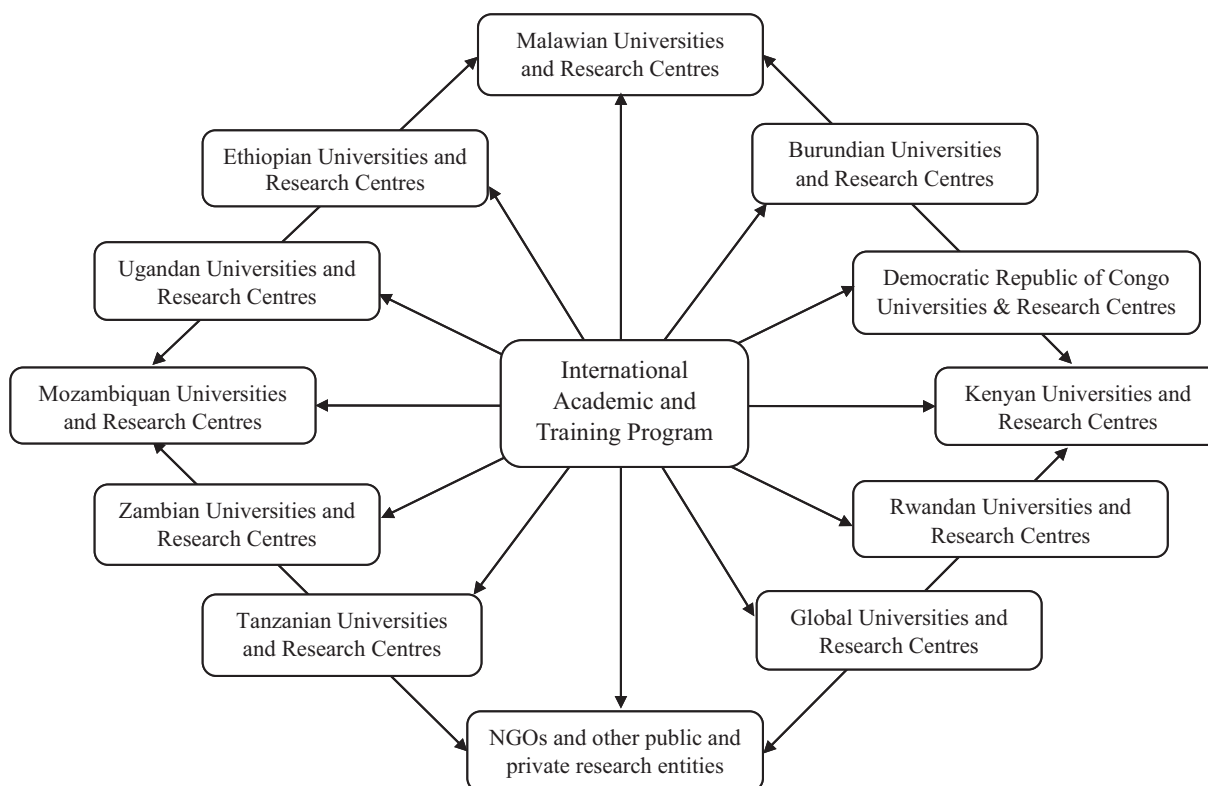


Fig. 2. An example of the desired network of academic and research institutions to be used to facilitate experiential education and training. Arrows demonstrate that students, educators and trainers, information, and credit would be able to seamlessly transfer to appropriate institutions to enhance education. More importantly, while the focus here is on the AGL region, this model is applicable to other regions of Africa which have smaller but still important lakes.

and environmental benefits. The AGLI comprises different modules to communicate various datasets, knowledge, maps, tools, projects and opportunities across the AGL region. The platform has organized information on the seven AGL around six themes: (1) Sustainable Fisheries and Aquaculture Management; (2) Climate Change Impacts, Mitigation and Adaptation; (3) Ecosystem Services and Biodiversity Benefits; (4) Balancing Conservation and Development; (5) Population Dynamics, Health and the Environment, and; (6) Governance and Financing (Olago et al., 2017; Cowx and Ogotu-Ohwayo, 2019). Beginning with the six key themes of the AGLC, the AGLI intends to allow the management community a platform to identify and track progress towards shared goals and provide contextual information about that progress to inform adaptive management and decision making (Doran et al., 2018).

A major challenge to replication and scaling of successful models of natural resource management and sustainable development planning in the AGL region is the lack of access to good information (Doran et al., 2018). More often, the accumulated data and information on the AGL does not reach the scope of potential users in the widest sense (e.g., scientists, planners, managers, practitioners, communities, decision-makers, learners). The AGLI aims to address this by acting as a searchable catalogue of existing information and ongoing and completed work. Problems associated with issues such as climate change and natural resource and biodiversity degradation are becoming increasingly complex and require some means of compiling and utilizing holistically-and practically-synthesized information from different thematic and disciplinary subjects. To this end, links to other databases under the AGLI thematic areas are extremely important so that duplication is avoided (such as with the World Lakes Database).

The long-term sustainability of the platform is envisaged through being embedded in the University of Nairobi's information and community technologies infrastructure and support system. Content development and updates will be submitted by community members (e.g., researchers, managers, and students) working in the AGL, and will be overseen by personnel from the University of Nairobi and ACARE. The University of Nairobi and ACARE will draw upon expert advice to drive the incorporation of the AGLI as a key communications tool for the lake advisory group approach that ACARE is developing on the AGL. This will reduce duplication of efforts on each lake, provide useful information among lake stakeholders to ensure stronger and harmonized data-sets to properly inform freshwater policy and management, and amass resources of like-minded, compatible research efforts, resulting in more vigorous and robust research and results.

Conclusion

The African Great Lakes are in dire need of a long-term, collaborative effort to address myriad threats to these valuable natural resources upon which millions of people depend on for food, water, and livelihoods. To address these issues, the African Center for Aquatic Research and Education (ACARE) is developing a long-term, highly collaborative African Great Lakes (AGL) network of freshwater experts, to protect these important resources. Because no one organization or institution can address the challenges that freshwater resources face, ACARE will leverage on the combined skills, assets, and resources of public, private and nonprofit entities to deliver sustainable research projects, capacity building initiatives and information exchange platform.

The global partnerships and collaborative networks will enhance opportunities for securing core funding to create consistent, credible, and comparable long-term datasets as well as increase the capacity of African freshwater scientists, managers and decision-makers. The enhanced partnerships and mechanisms

for collaboration will cultivate more robust, holistic, and efficient approaches to conducting research on large freshwater systems, and lead to stronger science to inform sound policy and management decisions towards sustainable fisheries and aquatic resources management in the AGL. Moreover, ACARE will enhance the learning of the next generation of freshwater scientists to positively influence policies, strategies, and legal frameworks that support the sustainable use of water-related ecosystem services.

To transition to a more sustainable path in the AGL region, ACARE aims to promote wider engagement through increased institutional collaborations on long-term research programs supported by sustainable funding mechanisms. ACARE shall establish and cement partnerships and collaborative networks at local, national, regional and international levels to unite freshwater specialists, from individuals, the private sector, donor and public agencies engaged in freshwater research, water conservation, education and policymaking. Crucially, these collaborative efforts will help scientists reduce research barriers and avoid duplicating research projects. Ultimately, the multi-disciplinary approach will increase opportunities for global research partnerships, enhance the accumulation of research facilities and financial resources, and create consistent, credible, comparable long-term datasets and increase the certainty of aquatic research impact on the sustainability of lakes, their biodiversity and ecosystems, and their critical livelihood support functions.

Declaration of competing 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.

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