

Building Capacity for Fish Biology in Subsaharan Africa

A Summary of a Roundtable Discussion at the PAFFA 7 conference

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by

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Introduction

At the seventh Pan African Fish and Fisheries Association (PAFFA) conference, held in Brazzaville during September 2023, participants from eleven countries and three continents gathered to discuss the challenges facing the diverse community of ichthyologists and fisheries biologists who strive to understand, manage, and preserve Africa's remarkable diversity of fishes. About a dozen scientists described the obstacles facing African scientists and brainstormed possible solutions (Figs 1, 2), while many others listened and signed up to indicate their interest in receiving a copy of this report.

Inadequate facilities and funding topped the list of challenges. The lack of sufficient infrastructure, equipment and consumables seemed universal. Though a handful of wealthier countries find themselves on surer footing than the remainder, every African country finds its scientific means falling short of its scientific needs. Regional resource disparities widen that gap, accentuate the problem and impede progress. As such, the assembled scientists shared a long-term goal of establishing more natural history collections throughout Africa, with a particular need in Francophone regions, where there is not a single well-supported repository. Until that need is met, many specimens will continue to be deposited overseas. For this to be acceptable, more opportunities must be created for African scientists to access and study these specimens and their associated metadata, and to receive the training needed to conduct such studies effectively. A huge gap separates the demand for training and the opportunities to receive such education. Many participants identified a need for more international collaboration



Figure 1. Kiselwa Tchalondawa standing and speaking at the PAFFA7 roundtable. Seated in foreground: Pascal Masilya Mulungula. Visible in audience: Nestor Ngoua Aba'a, Wilson Mayo, Alain Bolonga, Taylor Mambo Baba and Esperance Musombwa Kubota.

throughout Africa, but cited political, logistical, financial, regulatory, and linguistic obstacles to such cooperation.

Conversations with students outside of the formal roundtable also illustrated examples of progress being halted or slowed because poor or non-existent internet access, limited access to libraries and needed publications, eroding infrastructure, safety concerns, and challenges that can arise because of student identities. For examples of the latter, childcare obligations tend to fall disproportionately on women and can severely limit time spent in the field or laboratory. Some expressed concerns about travelling in certain regions because of their ethnic identities. That so many

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Figure 2. Tobit Liyandja offers his perspective at the PAFFA7 roundtable. Also seated in foreground: Bauchet Katemo Manda, Pascal Masilya Mulungula, and Kisekelwa Tchlaondawa. In audience, front row: Wilson Mayo and Emmanuel Abwe. In audience, second and third rows: Nestor Ngoua Aba'a, Lérège Batiabo and Isabelle Mady-Goma.

students had persevered through these challenges to present outstanding work at the conference provides ample testament to their impressive grit and willpower. However, all would prefer to actualize a future that eliminates or reduces such obstacles.

The assembled scientists proposed many innovative and forward-thinking approaches to help overcome those obstacles and hasten a new era for African ichthyology and fisheries biology. In that respect, the roundtable's greatest success lay in charting potential paths forward, rather than in dwelling on cataloging concerns.

The need to establish more natural history collections in Africa

The workshop participants agreed broadly that Africa needs many more natural history collections to catalyze the science needed to discover, describe, document, archive and protect the continent's exceptional fish diversity. Such collections could provide appropriate storage *in situ* for the voucher specimens and genetic resources upon which biodiversity sciences rely, the facilities needed to unlock the data in those specimens, and intellectual homes for the researchers who perform the science. Of course, such collections must be maintained and supported after establishment. This is in some ways a more difficult proposition than creating them, as it requires long-term commitment to management, training, and financial support. The roundtable participants saw the greatest hope of achieving that goal in the creation of regional centers across the continent, which could play roles like those of the South African Institute of Aquatic Biodiver-

sity (SAIAB) and the National Museums of Kenya (NMK). The largest needs are in central and west Africa, particularly in Francophone regions, where no well-supported collections exist (Fig. 3). For example, the Congo Basin in central Africa is the second most species-rich river basin worldwide and the first in Africa, yet no well-maintained fish collections exist within the countries of this extremely diverse river system.

Any attempt to establish such centers would need to establish clear policies on how to share credit, resources, and responsibility. If a center is to serve many countries, its creators must secure cooperative funding from those governments and coordinate among many academic institutions. Alternatively, some countries might choose to establish national centers focused on biodiversity within their borders, which would ease some of the political challenges, but miss the opportunity to pool resources. Either approach would help, though of course fish distributions do not recognize political boundaries. At a very minimum, reconstructing a continent-wide picture of fish diversity will require substantial data-sharing among institutions throughout Africa and beyond.

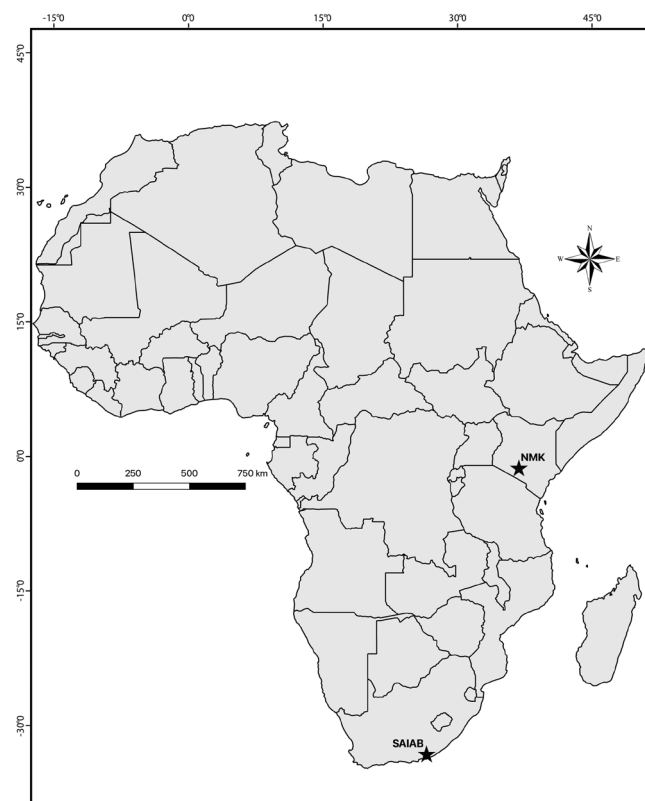


Figure 3. Map of the African continent showing the location of the only two well-maintained biorepositories: the South African Institute of Aquatic Biodiversity (SAIAB) and the National Museums of Kenya (NMK). Background map from https://github.com/qgis/qgis/blob/master/resources/data/world_map.gpkg

The need for better access to specimens and data, particularly for types

The systematic ichthyologists universally lamented that the type specimens for so many African species are held outside of Africa, implying that African scientists must spend disproportionate and unreasonable resources to travel to study the specimens upon which scientific nomenclature rests. A long-term solution to this problem would require the establishment of more institutions in Africa with the capacity to house and care for these valuable specimens, but such a solution is not imminent.

Until that vision becomes a reality, the community advocates much improved digital access to specimens held outside Africa. For example, detailed photos and radiographs can allow meaningful comparisons between fresh and historical samples, and several scientists asked for the creation of a repository for such images. Many such images already exist for types, but the fact that so many people are asking for them suggests that barriers still exist to access. Part of the problem may involve the distributed nature of the material. Currently, each institution manages its own image database, usually using different software and varied means of access. There are also substantial language barriers. While most of the museum websites are available in English or French, few are available in both languages, and few ichthyologists speak both languages fluently. As such, the creation of a portal that aggregates images and metadata from many institutions and that is available in multiple languages would be a huge boon to the African ichthyological community.

Several also pointed out that type specimens are often in terrible shape and provide only a piece of the needed information to conduct systematic revisions. Data from non-type specimens also has considerable value and should be shared similarly. Topotypes (new specimens collected from the same localities as historical types) are perhaps the most valuable specimens after holotypes and should be prioritized, but all specimens with associated images, tissues and accurate metadata hold considerable value. Fresh specimens typically provide the only reliable source of genetic information, given the age of most type specimens and the degradation of any DNA that might remain therein. Fresh specimens also often yield higher quality images than do historical types and provide the only means to record and visualize live coloration. For all specimens, newer technologies such as microCT scanning and photogrammetry can provide 3D representations and newer technologies can automate the extraction of measurements from 2D and 3D images. If widely available, such images and tools could further reduce the need for costly travel, and these too should be integrated into a comprehensive portal. One way or another, digitization of non-type material has lagged behind that for types. The need for access to both categories of specimens should be filled if

African ichthyology is to move forward. This implies a concerted effort to digitize and aggregate additional material, and the need to fund such an effort.

Naturally, available data are only valuable when they are reliable, and when the capacity exists to interpret them. In terms of reliability, the greatest problem lies in taxonomic misidentification. To address this problem, the community advocated the creation of a collection of expertly identified specimens with high quality photographs. Access to that resource could greatly improve the ability of non-specialists to sort new specimens reliably into established species. For example, ecologists conducting regional biodiversity assessments or studying community structure could compare their specimens to the photographic catalog to improve their accuracy. A comprehensive database of expertly identified material would also help curators recognize and correct misidentified materials already in collections. While the workshop participants envisioned an eventual database spanning all the continent's fishes, initial efforts could focus on producing well-curated photographic guides to regional faunas. These could be later synthesized into an ambitious and transformative product.

The need for enhanced genetic capacity

While all manner of improved facilities will aid African scientists in researching the biology, evolution, conservation, and management of fishes, the need for improved genetic capacity may be most acute. While some laboratories have access to basic equipment, like microscopes or calipers, very few have molecular capacity. Since most modern research in systematics or population structure blends genetic data with geography and morphology, this gap substantially impedes the ability of African scientists to conduct research using methods that have become universal elsewhere.

Several investigators from countries with a narrower gap between needs and means mentioned exciting new directions for African ichthyology that rely on molecular information. For example, a project in South Africa aims to produce whole genomes for every native fish species in the country by 2030. Others mentioned plans to return to historical type localities across the continent to collect new specimens from sites examined by ichthyologists long ago. Old specimens from those localities have great taxonomic importance, but no longer contain usable DNA. By returning to those sites, collecting new specimens, sequencing their DNA, and sharing the resulting information broadly, we can greatly accelerate taxonomic revisions. Even simple barcoding approaches can help to reveal cryptic species, resolve species complexes, or quantify biodiversity, particularly when results and data are shared broadly to catalyze comparisons among watersheds. Crucially, until more molecular capacity exists

on the continent, most such projects will require international collaboration.

Many participants expressed the desire to establish regional sequencing centers within Africa that could handle the demand for DNA barcoding without the need to send samples overseas. This would still incur substantial logistic challenges (Where would the centers be located? Where would the technicians receive training? Who would fund the maintenance of the equipment? Who will pay technicians that can perform lab analyses?) but could be preferable to needing to send samples off the continent, particularly given how expensive international shipping from Africa can be. If there were regional sequencing centers, then individual labs could focus on establishing the capacity to collect and store tissue samples and to extract DNA. While this would still require some equipment, such as freezers, heat blocks, centrifuges, it would eliminate the need for labs to maintain their own sequencers and possibly reduce the need for thermal cyclers. It would also minimize the consumables that would be needed to be delivered regularly. Several participants mentioned how difficult it is to get molecular reagents delivered to African addresses. The materials needed for DNA extraction (cryovials, proteinase K, ethanol, etc.) are stable at room temperatures, and would not require refrigerated shipping. These may be more feasible to obtain than reagents requiring cold or ultracold storage.

Nanopore sequencers such as the MinION (Oxford Nanopore Technologies) offer another promising avenue that may alleviate some of the obstacles to *in situ* sequencing within Africa. These relatively inexpensive sequencers can be purchased for approximately \$1,000 USD. Coupled with adaptors that support smaller “Flongle” flow cells, these sequencers allow for sequencing costs to approach \$1 per sample. Recent protocols have outlined how this technology can produce COI barcodes for hundreds to thousands of specimens in a way that allows one to match the resulting sequence to individual specimens. Laboratory set-ups costs would likely not exceed \$15,000 USD, which would include the MinION sequencer, flongle adaptor, computer, thermocycler, basic molecular equipment, and reagents. The training needed to produce these sequences is also minimal; during a recent workshop in Kenya, users with no molecular biology experience were able to produce sequences on their first try. However, this approach does not solve the obstacles to receiving flow cells and reagents in most of Africa or the burdens of cold storage and refrigerated transportation. Though not a complete remedy, these low-cost and relatively simple nanopore sequencers should allow more *in-situ* sequencing in the future.

Even so, many participants outlined major challenges with finding funds for durable supplies as simple as specimen jars, let alone molecular reagents. Some said that it was much easier to fund major (one-time) equipment purchases

than to locate reliable sources of modest funds to handle recurring charges. Funds to support the service contracts that maintain equipment are often non-existent, and such costs can be substantial. In that light, some participants expressed that it might be better to invest in human capital than in durable supplies or expensive service contracts. In other words, it might be more effective to invest in training students to interpret and analyze molecular data, rather than focusing on generating data *in situ*. After all, an increasing number of labs in the global north send all their samples out for sequencing and basic analysis, letting faculty and students focus on interpretation, grant writing and publication rather than routine procedures that can be easily automated. These labs no longer maintain extensive molecular facilities, and this might be a more viable model for Africa. However, any plan to adopt such a model currently would need to solve the logistical difficulties and high costs of shipping samples internationally.

An alternative solution would be to establish collaboration and cooperation with the medically focused molecular facilities that exist in some countries. For example, the National Institute for Biomedical Research (INRB) in Kinshasa (D.R. Congo), has significantly improved their sequencing capacity in recent years. However, such governmental facilities are generally reserved for medical research and rarely have a biodiversity (much less an ichthyological) department. Expanding the capacities of such institutions and incorporating biodiversity research in their programs could provide an interim solution while the ichthyological community works towards the eventual establishment of regional collections and biodiversity-focused sequencing centers.

Human capital and the need for improved training

Outside of improved facilities and access to specimens and their metadata, participants most frequently cited the need for improved training and expressed concern that a major knowledge gap may arise when the current generation of professors retire. If regional centers or repositories are to become realities, proper training and compensation of their staff is imperative. Many expressed deep gratitude for the training workshops offered in Belgium at the Royal Museum for Central Africa and for the funding from the JRS Biodiversity Institute that made participation possible for some. Unfortunately, the number of interested students far outstrips the available slots in those programs. To come even close to meeting the demand, training needs to happen in Africa, and funds must be allocated to make such opportunities a reality.

In the meantime, a lot can be learned remotely. Some training materials and protocols have already been developed and made freely available online. A clear list of recom-

mended materials, and perhaps even a curriculum of study could help students know where to start and where to focus. Such a list needs to be made available minimally in French and in English, and materials available only in one of these languages should be translated into the other. And, no matter how widely spoken, it must be acknowledged that these are both colonial languages imposed upon Africa during a particularly troubling period of history. As some participants mentioned, truly forward thinking would involve spending the time and resources to translate training courses and materials into languages native to Africa, such as Swahili.

Some of the student participants also mentioned that many of the workshops that have been developed occur at the graduate level and focus narrowly on specific skills or protocols, such as fish identification, DNA extraction or amplification via PCR. These skills are crucial and important and can help to meet a need for skilled technicians. However, a substantial need also exists for much more basic training. For example, some mentioned that their undergraduate institutions did not offer effective courses in ichthyology, population biology, genetics, physiology, or other foundational areas of study needed to make the most of graduate-level training opportunities. Others mentioned that they completed such courses in their undergraduate institutions but lacked opportunities to gain laboratory experience. While it is beyond the scope of this community to re-envision the undergraduate curriculum across Africa (which is in any respect a highly heterogeneous educational landscape), it does seem that there is ample room and need to develop one or more freely available undergraduate courses or curricula in ichthyology and fisheries biology. And of course, none of this will happen without adequate funding.

Collaboration and leadership

Lastly, and perhaps most importantly, the roundtable outlined a substantial need for Africans to take the lead in deciding on research and training priorities. The research that moves forward must align with the development needs in each country. Thoughtful selection of research projects that align with national priorities can help to demonstrate the importance of the work to government officials and help justify funding. Only people on the ground in Africa truly have the expertise and experience to set these priorities and to communicate effectively among stakeholders, governments, NGOs, and academic institutions. Only by working with all these communities and integrating their needs can we bridge the gap between research and the needs for economic growth, biodiversity conservation and sustainable fisheries management.

Africa's 54 countries cannot solve the huge challenges facing African ichthyology and fisheries biology by acting in

isolation. The assembled scientists called loudly and clearly for a network of natural history collections across the continent that can promote visits, the exchange of ideas, specimens and information, and collaboration among scientists located throughout Africa. Similarly, many cited the need for much more intergovernmental cooperation. A coordinated system that standardizes and eases the process of obtaining research permits to collect and transport voucher specimens and tissues internationally would be a huge help, but the Nagoya Protocol can inhibit the ability of scientists to collaborate across political boundaries. Intergovernmental agreements within Africa could help considerably, but such agreements will not create themselves. The community of scientists must organize and engage with law and policymakers in their various countries to lobby for this need and to make it a reality, ideally by 2030. This too is an area in which African scientists must lead.

The ichthyological community outside Africa has an important role to play in hastening a future of improved capacity, such as by providing advice, training students, seeking funding, facilitating specimen access and hosting visiting scholars. However, scientists outside of Africa must acknowledge their supporting role. Leadership and priority setting must come from within Africa, not without. Similarly, scientists on other continents need to understand the urgency of the research and conservation to those on the ground in Africa. Progress cannot take forever, and much is at stake for the fishes of the continent and for the people whose careers and lives depend upon them.

In summary, the workshop participants recommended that the community work towards these specific goals.

In the near future:

- Create a bilingual portal to aggregate and share expertly identified images and metadata from African fishes.
- Prioritize the collection and sequencing of topotypes and share such specimens and their metadata freely.
- Digitize, image and share much more of the non-type material held outside of Africa.
- Improve the molecular capacity of existing laboratories within Africa, such as by purchasing relatively inexpensive nanopore sequencers and training technicians to operate that technology.
- Offer more training in Africa on the interpretation and analysis of molecular data.
- Establish collaborations with the medically-focused sequencing centers that exist in some African countries.
- Develop a bilingual curriculum of free online training materials focused on ichthyology and fisheries biology.
- Work with law and policymakers across Africa to establish a standardized system of obtaining permits to research biodiversity and transport specimens and tissues internationally.

In the longer term:

- Establish, fund and support more natural history collections throughout Africa, particularly in Francophone regions.
- Establish clear policies on how to share credit, resources, and responsibility for maintaining such facilities.
- Establish regional sequencing centers within Africa.
- Translate curricula and training materials into African languages, such as Swahili.
- Collaborate and communicate among stakeholders, governments, NGOs, and academic institutions to chart a future that balances economic growth, biodiversity conservation and sustainable fisheries management.

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