Ecology in Africa: historical perspectives, present state and prospects

[1]Margaret Awuor Owuor, Wyss Academy for Nature and Institute of Ecology and Evolution, University of Bern, Switzerland. margaret.owuor@wyssacademy.org orcid: 0000-0002-6734-7055
[2]Ole Seehausen, Institute of Ecology and Evolution, University of Bern, Switzerland and Department of Fish Ecology and Evolution, Centre of Ecology, Evolution and Biogeochemistry, EAWAG Swiss Federal Institute of Aquatic Science and Technology, Kastanienbaum, Switzerland. ole.seehausen@unibe.ch
[3]Israel Borokini, Department of Ecology, Montana State University, Bozeman, Montana 59717, United States; israel.borokini@montana.edu; orcid: 0000-0002-1258-7932
[4]Romulus Abila, Maasai Mara University. Department of Environmental Studies. P.O. Box 861 – 20500, Narok, Kenya. abila@mmarau.ac.ke
[5]Yvonne Wambui Githiora, Wildlife Works and Department of Earth and Climate Sciences, University of Nairobi. Nairobi, Kenya y.githiora@gmail.com orcid: 0000-0001-6274-4791
[6]Chinwe Ifejika Speranza, Institute of Geography, University of Bern, Hallerstr. 12, 3012 Bern, Switzerland. chinwe.ifejika.speranza@giub.unibe.ch
[7]Michael Gabriel Njau, Temeke Municipality, Department of Secondary Education, P.O. Box 46212, Dar es Salaam, Tanzania. mimigabu@gmail.com
[8]Peggy Ngila, Centre for Biodiversity Information Development (BID-C), Strathmore University, P.O. BOX 59857 - 00200, Nairobi, Kenya. pngila@strathmore.edu orcid: 0000-0002-8664-8865
[9]David Chiawo, Centre for Biodiversity Information Development (BID-C), Strathmore University, P.O. BOX 59857, 00200, Nairobi, Kenya. dchiawo@strathmore.edu
[10]Dario Riccardo Valenzano, Leibniz Institute on Aging; Friedrich Schiller University, Jena, Germany. Email: dvalenzano@leibniz-fli.de, orcid: 0000-0002-8761-8289
[11]Grace N. Alawa, Rivers State University, Department of Animal and Environmental Biology, P.M.B. 5080, Nkpolu-Oroworukwo, Port Harcourt. Email: grace.alawa1@ust.edu.ng, orcid: 0000-0003-2499-0726
[12]Perpetra Akite, College of Natural Sciences, Department of Zoology, Entomology & Fisheries Sciences, Makerere University, P.O Box 7062, Kampala, Uganda perpetra.akite@gmail.com orcid: 0000-0002-0302-1822
[13]Rachael B Gross, Fenner School of Environment and Society, Australian National University, Australia; rachael.gross@anu.edu.au , orcid: 0000-0002-9814-7072
[14]David O. Alila, Division of Aquatic Ecology and Evolution, Institute of Ecology & Evolution, University of Bern, 3012 Bern, Switzerland, Department of Fish Ecology and Evolution, Centre of Ecology, Evolution, and Biogeochemistry, EAWAG Swiss Federal Institute of Aquatic Science and Technology, Kastanienbaum, Switzerland, Department of Biological Sciences, Mkwawa College of Education, University of Dar es Salaam, Tanzania; aliladavy@yahoo.co.uk , orcid: 0000-0002-2334-2201
[15]Georges Alex Agonvonon, Institute of Geography, University of Bern, Hallerstrasse 12, 3012 Bern, Switzerland. Email: agonvononga@gmail.com, orcid: 0000-0002-0199-9691
[16]Anna Mahulu, Institute of Ecology and Evolution, University of Bern, Switzerland
Department of Fish Ecology and Evolution, Centre of Ecology, Evolution, and Biogeochemistry, EAWAG Swiss Federal Institute of Aquatic Science and Technology, Center for Ecology, Evolution & Biogeochemistry, Kastanienbaum, Switzerland. anna.mahulu@unibe.ch orcid: 0000-0003-3808-605

Abstract

Ecology research, education and conservation policies in Africa are heavily influenced by western science and philosophy, resulting in the marginalization of African traditional ecological knowledge (TEK) systems. This legacy persists in post-colonial African government structures and academic institutions, influencing teaching methodologies, research approaches, and conservation policy frameworks. These challenges are further exacerbated by funding dynamics that promote parachute science, hindering the intellectual empowerment of African scientists. To address these challenges, a group of researchers from Africa, Diasporan African scientists and collaborators from Australia, Germany, Switzerland, and the United States identified several areas within three domains – ecology education, research, and policy – that need attention. Suggested solutions include decolonizing ecology research, introducing transformative curricula that integrate TEK and modernized pedagogies in ecology teaching, increasing government funding for ecology research and education, promoting regional and transboundary research collaborations, and engagement with the African Diasporan experts. Community-based conservation that generates benefits to Indigenous and local communities, and policy interventions by and with African governments, with stable administrative structures for effective policy implementation are also required. Effective implementation of these recommendations by African governments and other actors is necessary to reverse the brain drain, ensure quality ecology education to boost research and conservation, empower local experts, promote ethical and equitable research collaborations, and prepare ecology students for addressing the challenges of biodiversity loss, ecosystem degradation and climate change.

Keywords: Ecology, Africa, decolonization, education, research, funding, partnerships, policy

Introduction

Africa is renowned for its extraordinary biodiversity, exemplified by the latitudinal diversity gradient, which highlights the greatest species richness near the equator[1,2,3]. The continent boasts iconic ecosystems like the Guineo-Congolian forest, the second-largest tropical forest after the Amazon, serving as a vital carbon sink[4,56,7]. Equally impressive is Africa's savanna, the largest grassland biome on Earth, home to unparalleled diversity and density of ungulates[8,9]. However, this natural wealth is juxtaposed with high human population growth, widespread poverty, and dependence on natural resources, leading to habitat loss, species overexploitation, and elevated extinction risks. Coincidentally, mega biodiverse regions in the world, including Africa, are also home to exceptional cultural and linguistic diversity, but also high population densities and population growth resulting in severe poverty levels[10,11,12,13]. With about 2,000 native languages, it is not surprising that Africa has the highest linguistic diversity in the world[14]. Consequently, dependence on natural resources for livelihoods is widespread in African societies, resulting in unprecedented levels of habitat loss and degradation and species overexploitation, thus, greater extinction risks[15,16]. Notably, eight of the world's biodiversity hotspots are found in Africa[17,18]. Biodiversity patterns in tropical biomes, including those in Africa, are attributed to relatively high net diversification, strongly tied to long-term relative climatic stability[19,20]. Therefore, many African flora and fauna exhibit greater phylogenetic and climatic niche conservatism[21,22,23], which implies that slight climatic changes may have dramatic impacts on African taxa with narrow niches[24,25,26]. Moreover, recent studies indicate that biodiversity surveys across the continent are lacking, leaving many species yet to be discovered[27,28,29]. Due to land use and climate changes, many of the unique biodiversity in the tropics may go extinct before they are discovered and described[30,31,32]. This underscores the importance of more in-depth biodiversity studies in Africa.

Ecology is the scientific study of the interactions among living things and their abiotic environment across time and space[33]. An understanding of the dynamics of these interactions is used to infer the processes underlying patterns in community ecology and macroecology, and how local and regional communities will be impacted by current and emerging environmental changes. Moving beyond its conventional methods of field studies, ecology has metamorphosed and advanced in the last three decades, integrating new tools in answering multidisciplinary and transdisciplinary research questions. Relatively new approaches include the use of geospatial data and remote sensing for ecological modelling[34,35], generating and modelling functional trait data to infer community assembly rules[36,37], integrating genetic, genomic, and phylogenetic information with species and community data to elucidate eco-evolutionary processes and patterns[38,39,40], and combining laboratory, greenhouse, and field experiments to explain physiological processes and ecological phenomena[41,42,43]. Ecological education and research will continue to play important roles in understanding biodiversity patterns and processes, which are urgently needed to evaluate the vulnerability of natural systems to biodiversity crises and how to mitigate them. It is in this light that a team of African ecologists and allies organized a symposium during the 2022 International Association for Ecology (hereafter, INTECOL 2022) conference in Geneva, Switzerland. The goal of the symposium was to evaluate the state of ecological research in Africa, identify the roots of the challenges, and discuss opportunities for building and advancing ecology research and study in Africa.

The symposium, "Ecology in Africa: present and future prospects"

This paper distils a synthesis from the discourse during a symposium titled, "Ecology in Africa: present and future prospects". The session had oral presentations by scientists from Benin Republic, Central African Republic, Nigeria, South Africa, Tanzania, Uganda, and Kenya, as well as Diasporan African scientists and collaborators from Australia, Germany, Switzerland, and the United States, who have research experience and intellectual investment in Africa. The presentations included topics on teaching ecology in institutions of higher learning, challenges and opportunities for African early-career ecology researchers, biodiversity and human health, citizen science and participatory/collaborative approaches, and the challenges associated with decolonizing ecology research in Africa. To have an inclusive and engaging democratic discussion, we adopted the Open Forum method as a facilitation tool[44]. The Open Forum method uses *Doors* as entry points into a discussion; doors in this context refer to education, research and policy which are the main entry points into and out of Africa to the world (Fig. 1). Doors were selected by the presenters at the conference based on key themes emerging from the presentations at the session and also based on the challenges faced by the presenters coming from Africa during the preparation and participation to the conference in 2022. In the Open Forum, participants are encouraged to contribute by selecting the *Door* they want to contribute to or present on.

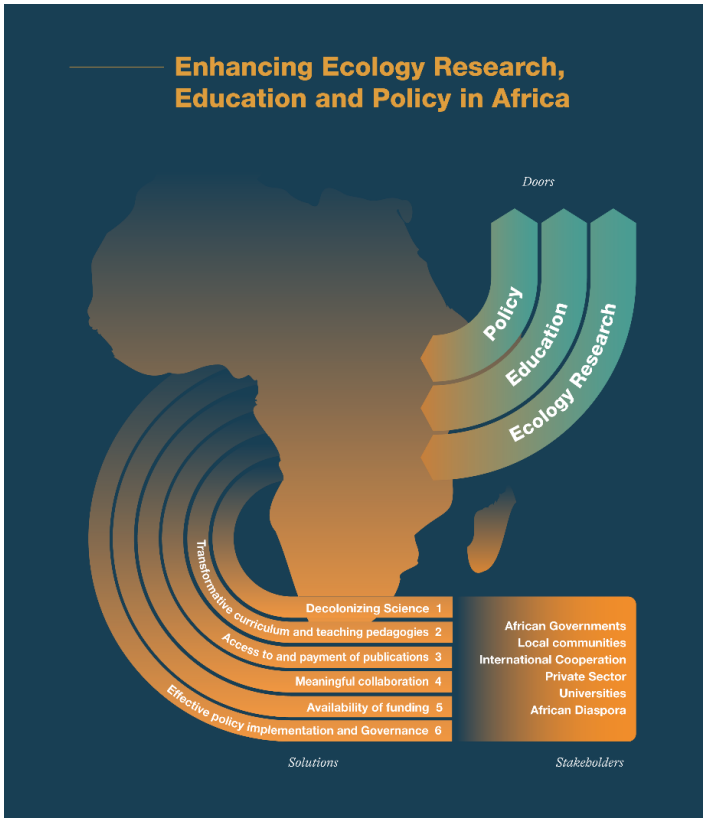

Figure 1: The Open Forum method and its conceptual framework of Doors as entry points for discussion

The state of ecological science in Africa, challenges and solution options

Drawing from the symposium, this paper provides historical context, describes the current state, and offers solution options to identified issues on ecology education, research, and policy in Africa (Table 1).

Education

Formal education in Western science, including modern ecology was introduced to Africa by tertiary institutions in the Global North when European colonial governments ruled most African countries in the 19th and 20th centuries[45,46,47]. Many prominent universities in Africa today were originally established as satellite campuses of European universities. Therefore, academic programs followed a Western approach, leaving no room for African traditional ecological knowledge (TEK) systems[48,49,50]. Additionally, many Africans were sponsored to study at European universities in the 1950s and 1960s, bringing back the colonial/neocolonial education philosophy with them. At independence, African countries largely adopted the languages and educational systems of their former colonizers, such as French, British, Spanish or Portuguese systems. This colonial footprint has persisted and continues to influence African academic institutions. However, despite adopting Western education and philosophy, many African universities face challenges in achieving the resources and infrastructure available to their counterparts in the Global North. For example, many ecology-related courses such as conservation biology, biogeography, macroecology, evolutionary biology, conservation genetics, population biology, and population and/or landscape genomics, among others, offered in Global North universities are either lacking or offered in a few African universities. In addition to classroom teaching, formal learning in ecology and life sciences require hands-on laboratory and field-based studies and student-centered projects, which promote experiential learning, critical thinking, and application of knowledge to real world problems. However, ecology education in African institutions is characterized by instructor-dominated classroom teaching, and learning assessments based on memorizations[51]. With rapid advances in ecological research techniques, instructor-dominated teaching is inadequate in imparting the knowledge required to make African ecology graduates globally competitive. Furthermore, student enrolment in biology courses is declining in favor of IT and business-related careers[52]. Because of limited undergraduate ecology education, most African ecologists today have only entered the field as graduate students[53]. The problems described here underscore the chronic lack of qualified teaching, research faculty and laboratories due to the lack of funding for African universities[54,55]. Funding allocations for research and development in African countries is still insufficient[56]. This minimal expenditure is reflected in the continent's minimal contributions (ca. 1-2%) to global research and innovation[58]. Although it is unclear how much of this minimal funding goes to ecology, through this deficiency, many African countries limit the potential of researchers in Africa and their contributions as well as the thematic focus of research.

The high lecturer-to-student ratio, heavy teaching workload, and assigning lecturers to teach courses beyond their academic expertise impact the quality of education and research[59]. Furthermore, lack of continuing education programmes to train educators on cutting-edge research tools, lack of current research infrastructure, poor remuneration, decreasing quality of education,

non-conducive socioeconomic conditions, political conflicts, political interference in education, and poor post-graduation career trajectory have driven brain drain in Africa[60,61,62].

To address these shortcomings in African ecology education, we advocate for transformed curriculum and pedagogies, offering more fundamental ecology courses that prepare ecology students for the current real-world and Africa-related needs, teaching and research infrastructure, and increased funding for education in Africa. Core ecology courses such as population biology, community ecology, multivariate statistics and ecological modelling, network ecology, metapopulation and metacommunity dynamics, macroecology, evolutionary ecology, and biogeography must be introduced at both undergraduate and graduate levels. Along with these, transformed pedagogical approaches that emphasize student-centered learning and diversified delivery of classroom instruction, project-based learning, educational field trips, and directed internships, as well as effective use of educational technology and open-source resources should be encouraged[63,65,66,51,67]. Different degree tracks may be established so that undergraduate students with career interests in research will be offered courses that advance their knowledge of ecological theories and concepts, ecological modelling and statistical tools, while students interested in conservation careers can be directed towards applied biology, conservation social sciences and other courses that prepare them for community engagement and participatory approach to habitat and species management. However, expertise, funding and material resources to teach many of these foundational ecology courses may be lacking in many African universities, which is why we strongly encourage engagement and involvement of the African Diaspora.

Infrastructural development and investment in education technology are pivotal for effective pedagogies[68,69]. An inclusive ecology education in Africa must integrate traditional ecological knowledge systems. We also call for continuing education and diversified programmes that make education accessible to all[70,71]. Books and research publications by African ecologists should be used among reference materials in schools and colleges, allowing students to have African role models in the field. Exposing students to the achievements and contributions of both past and current African ecologists will help students build a sense of identity and motivation. We also advocate for increased collaborations and knowledge sharing between universities and private sector actors, and among African universities within the Association of African Universities framework, other platforms such as the African Research Universities Alliance, the Africa-Europe Clusters of Research Excellence and other networks, to enhance regional and continental development of human capacity to address societal challenges[72,73].

Research

Africa has been explored by European voyagers since the 15th century, collecting plant and animal specimens without depositing type specimens in the countries where they were found[74,75,76]. As a result, European museums and herbaria hold more African biological collections than those in Africa[77]. These explorations resulted in the ‘discovery’ of new taxa, some of which were named after the discoverers, other scientists, and European government officials, even though many of these native taxa were already known to Indigenous communities[48,78]. The historical and contemporary explorations, biological phenomena observed and learned, and long-term research conducted in tropical biomes of the Global South contributed significantly to the development of

ecological and evolutionary theories. For example, the theory of evolution was developed by Charles Darwin and Alfred Russell Wallace following their explorations in Africa, Asia, and South America, while the theory of island biogeography[79] was inspired when Wilson and MacArthur worked in Southeast Asia. The unified neutral theory of biodiversity and biogeography[80,81] was developed after long-term biodiversity monitoring in a neotropical rainforest. Likewise, the theory of coevolution was developed by Daniel Janzen following his groundbreaking work on the biotic interactions between *Acacia cornigera* and the ant, *Pseudomyrmex ferruginea* in Central America[82]. Like education, ecological research in Africa follows Western science principles but has neglected Indigenous and Local Knowledge (ILK) systems that have been nurtured and passed through generations[83,48,50]. The lack of TEK inclusion in modern ecology research in Africa could not have been accidental because medieval medical training and practices in Europe were strongly tied with ethnobotany, which is like the African TEK system[84,85].

Ecology research in Africa is still heavily influenced by Global North scientists who have financial advantages over local African experts[86,87]. These vertical funding relationships prevent intra-continental research collaborations among African ecologists in favor of working with better-funded Global North scientists. Yet, this also perpetuates helicopter science (aka parachute science), wherein some well-funded researchers and some NGOs from the Global North conduct research in economically disadvantaged but biologically diverse countries, primarily in the Global South, with little to no intellectual investment in the visited regions, minimal acknowledgement of local knowledge, or equitable collaborations with local experts[88,89]. Moreover, open-access data repositories like the Global Biodiversity Information Facility (https://www.gbif.org/) have made it possible for any researcher in the Global North to access African biodiversity data for research without the need to collaborate with local experts from the region. Similarly, a vast majority of the listing of African species on the IUCN Red List of Threatened Species is carried out by Global North scientists with little consultation and collaboration with local experts[90]. While attention has been paid to helicopter science, an emerging trend is the practice of tucking one or two African experts among tens of Global North coauthors on a research article focusing on tropical biodiversity[91].

Despite Africa harboring the second-largest human population, its contribution to global research and development (R&D) remains one of the lowest[92,93]. Several continental declarations such as the Monrovia Declaration of 1979, the 1980 Lagos Plan of Action, and the 2006 Khartoum endorsement by African Union leaders, and more recently, the African Union (AU)'s Science, Technology and Innovation Strategy for Africa 2024 (STISA-2024) released in 2015 encouraged African countries to allocate at least 1% of gross domestic product (GDP) to research and development (R&D; African Union 2015; UNECA 2018). However, to date, most African countries allocate less than 0.5% of their GDP to funding science; this ranges from less than 0.25% in Western Africa to 1% in Eastern and Southern Africa[94,95]. Lack of funding results in acute limitations in technology infrastructure for research in Africa. For example, most African research institutions lack internet bandwidth and cloud or cluster computing resources to store, download, process, or analyze large biological data. A vast majority of research conducted in African universities is self-funded by upper-undergraduate and graduate students; thus, limited funding restricts robust sampling and in-depth experimentation. Research papers from studies with limited

sampling or lacking robust statistical analyses have limited generalizations, making them less appealing to a broader journal readership[96,97]. Though most high-impact factor journals have relatively high rejection rates, studies indicate that rejection rates are higher for African authors, researchers who speak English as a second language (ESL), researchers with non-English reading last names, or those with African institutional affiliations[98,99,100,101]. The cost of publishing in international journals ranges from $2,000 to over $35,000 as of 2023, which is prohibitive for Africa-based researchers[102]. Equitable and fair access to scientific publications sometimes places financial burdens on Global North scientists who inevitably pay hefty open-access publication fees, or their institutions, through expensive agreements with publishing companies. Journals published by African professional societies and institutions are not indexed in globally recognized literature databases and have little online visibility due to print-only issues, thus, African ecologists are robbed of international readership and visibility, while Global North scientists perceive those journals as "local" or "predatory".

We do not call for an eradication of Western science driven ecology research in Africa or hostility towards Global North scientists willing to do research in Africa. Rather, we advocate for a radical transformation of ecological research through bridging with TEKs, increased government funding for research and development (R&D) in the respective countries, transboundary research collaborations, technological advancement, and investment in public and private sector research laboratories, among others (Table 1). African scientists need to be trained on participatory research design approaches that involve learning from and with local communities about their challenges to develop relevant research studies rather than overburdening local communities with questionnaire administrations[103,104]. Climate adaptation in the farming system of local communities is an important example where ecological knowledge can be applied to improve Africa's farming systems that have been dominated by shifting cultivation and its associated habitat destruction. Research in soil ecology, plant physiological tolerance, genetic and epigenetic expressions, and trait ecology can guide effective agricultural production under climate stress and reduce habitat loss.

Funding is pivotal for R&D in Africa; it is needed for research infrastructure such as broader internet bandwidth, cloud computing, and research laboratories, and better compensation for local experts. We urge African countries to honor the continental declarations and AU's strategies for advancing science and technology by contributing at least 1% of their GDP to science. African governments as well as regional and continental associations need to promote trans-boundary and intra-African research collaborations. Many large mammals forage across several African countries, therefore, only transboundary research covering the entire ranges of these megafaunal species can produce more reliable results. Likewise, transboundary research is vital for the management of watersheds of large lakes and rivers. Regional research centers such as the African Institute for Mathematical Sciences (AIMS; https://nexteinstein.org/), East African Community based Inter University Council of East Africa (https://www.iucea.org/), the West Africa based African Higher Education Centres of Excellence (https://ace.aau.org/), Regional Center for Remote Sensing for North African countries (https://crtean.org.tn/) and the South African Department of Science and Innovation–National Research Foundation Centers of Excellence (https://www.nrf.ac.za) must be leveraged for regional and continental collaborations. Regional

and continental scientific conferences should be organized and supported by African governments to promote meeting avenues for African researchers that will nurture collaborations. Quality education boosts research, therefore, transformation in the tertiary education system, as we described above, will have profound impacts on research in Africa. We encourage the numerous efforts of the Global North universities and African experts for continuous professional development; however, organizing such training programmes in Africa will reach more people for less cost rather than inviting a few Africans to the Global North for professional development courses at expensive rates.

Research publications, conference presentations, and other science communication platforms are vital for a scientist's career growth, visibility in the scientific community, collaborations, and for enhancing the likelihood of securing research grants and academic positions. Therefore, we celebrate the expansion of research publication waiver programs of many publication companies for Global South researchers. We commend recent efforts by many Global North researchers and their institutions to pay open-access fees for their accepted papers so that African experts can access them. We also acknowledge efforts by publication companies to create journals focusing on papers from the Global South even if they cover small study areas with limited generalizations. Likewise, we applaud efforts to diversify the reviewer pool and editorial boards of many research journals, however, we worry that this will result in a greater workload for the few selected African experts. Research4Life [https://www.research4life.org/] and other similar programs that allow African researchers to access published papers, need to be advertised widely and integrated into academic programs for students and early career scientists to be exposed to these opportunities. Other Open Science avenues such as accessible pre-prints should be encouraged. We strongly urge the leadership and Editors-in-Chief of journals published by African professional societies and institutions to transform their journals into online editions hosted on stable servers and platforms and strive for indexing their journals in global literature databases. This will help increase the visibility of these journals and the local experts who publish with them.

Apart from research publications, we encourage local experts, especially early career scientists, to attend in-person scientific conferences as a means of building their professional network, gaining visibility in the scientific community, and meeting potential collaborators. While travel costs may be prohibitive, we acknowledge registration waivers and travel support provided by conference organizers to Global South participants and we advocate for sustained efforts and expansion of such initiatives. Professional societies that claim to have global membership should also explore hosting their conferences in the Global South more frequently than current trends. Global North scientists, their academic institutions, and funding agencies must promote research ethics that fund and ensure equitable collaborations with local African experts throughout all stages of research[76,89]. On the other hand, African experts should be empowered with resources and tools to foster equitable research collaborations and set clear authorship guidelines with their foreign collaborators before committing to an international collaborative research team.

Policy and Governance

Many conservation and environmental policies were introduced by colonial and settler governments based on Western scientific knowledge, aiming to 'save' African biodiversity. However, these policies were implemented without local consultation and often blamed local communities for deforestation and land degradation[105]. The rapid deforestation and land degradation, often attributed to both local communities and climate change, led to the establishment of Departments of Forestry across colonial Africa in the late 19th century[106,105]. However, colonial institutions lacked a deep understanding of the local ethnographic relationships and natural history, which led to tensions between colonial governments and African communities[105]. Furthermore, colonial governments extracted numerous resources from Africa for their own benefit[107]. The history of establishing protected areas in Africa includes the forced removal of local and Indigenous communities from their ancestral lands, the strict enforcement of conservation laws that restricted access to biocultural resources and sacred sites[108,109], and the exclusion of these communities from participating in the management of these areas[110]. This created an atmosphere of mistrust between African government scientists, and traditional institutions, thus hindering effective community-based biodiversity conservation. However, European voyagers, Christian missionary groups, and colonial institutions brought several food crops which significantly improved food security in the region[111].

After gaining independence, the 1968 Algiers Convention became the first continental agreement to emphasize the importance of African conservation and wildlife protection[112]. Subsequent meetings of African leaders have continued to emphasize the importance of biodiversity conservation, culminating in the development of the 2003 African Convention on Nature and Natural Resources[113]. Additionally, many African governments have promulgated new environmental and conservation laws, continued to create protected areas, and ratified various international conservation treaties, including commitments to produce national biodiversity action plans (NBSAPs) submitted to the Secretariat of the Convention on Biological Diversity every five years. Studies show that the implementation of NBSAPs is poor and ineffective in many African countries[114], despite the relatively high public awareness and engagement in its development[115]. To make laws is easy, but implementation is costly; environmental policies are challenging to implement when institutional structures are weak, funding is limited, political willpower is low, local stakeholders are largely ignored and excluded from protected area management, and corruption is prevalent[116,117,118,119]. Policy development and implementation are also plagued by research gaps[15,117], partly due to limited funding resources for research. In many parts of Eastern and Southern Africa, protected area management has transformed from a state-rule, top-down system to a wider governance system that acknowledges the Indigenous communities, community-based conservation practices, enforcement of environmental laws and with assistance from mostly international conservation NGOs, and a diversified funding scheme, based mainly on proceeds from ecotourism and international support[120,112]. In West and Central Africa, however, government unilateral rule of protected areas is prevalent, with a small but growing trend of private sector and local stakeholder engagements. Ecotourism is relatively underdeveloped in West Africa, thus, funding for protected areas is limited to meager government support. Thus, it is not uncommon for large protected areas to be managed by a small number of park rangers[121,122,123,124,125]. A study showed that the annual estimated cost of managing protected areas inhabited by African lions ranges between U.S. $1.2-2.4 billion, compared to an annual expenditure of U.S. $381 million collectively spent in 23 African protected areas[126].

Although there are arguments in favor of creating protected areas, this process is often linked to the mistreatment and forced removal of Indigenous communities from their ancestral lands[110]. In such cases, the forced removal of Indigenous people from their land leads to a lack of trust and cooperation with the government in managing protected areas[110]. In other cases, Indigenous communities were allowed to stay within the protected areas as enclave communities, but as time went by, their populations grew, resulting in increased harvesting pressure and demand for land for subsistence farming[127]. Thus, African governments struggle to balance biodiversity conservation and protecting the rights of the Indigenous people. Moreover, many local communities are losing their ethnic identities, native languages, and cultural ties to their homelands due to relocations, modernization, and mobility. In other cases, however, a divide exists between African and Western conservation philosophies. For example, while trophy hunting is increasingly seen as morally inappropriate with strong public opposition in Western countries[128], many local communities in Africa view trophy hunting positively due to the significant challenges posed by human-wildlife conflicts[129,130,131]. High rates of human-wildlife conflicts exacerbated by ecotourism that contribute to the GDP of many East African countries also resulted in reduced enthusiasm by local communities for wildlife conservation[132,133,134]. While Indigenous-supported protected areas have sought to balance socio-cultural, livelihood, and biodiversity protection, further efforts are needed in this direction[135].

A major challenge for most African governments is species overexploitation, which is among the highest in the world, driven by dependence on natural resources for livelihoods[136,137,138]. This is illustrated through selective logging, poaching for bushmeat, illegal ivory and tusk hunting, and overharvesting of commercially viable medicinal plants[139]. While structures such as CITES (CITES[140]), regulate the international trade of threatened species, regional, national, and local sales of endangered species continue largely unchecked[141,142]. Moreover, many African governments face economic challenges resulting in unrest within their respective countries, terrorism, and weak or unstable governments, therefore, conservation research and education are not their priority[143].

In response to these challenges, a forward-looking policy framework should foster inclusive ecology education and research tailored to the African context. Transformative ecology education and research, as well as effective governance on biodiversity conservation, are all hinged on national, regional, and continental policy frameworks and implementation. Transformative curricula and pedagogies that bridge TEK with Western science require a revised education policy across various academic levels[144]. A funding policy that facilitates scholarships and grants to merit and underprivileged students and researchers is warranted to improve access to quality research opportunities across Africa[145]. Ecology research in Africa can benefit from policies that enhance collaboration and research partnerships among Africa-based research institutions, decolonize the scientific process, and motivate diaspora engagement[11]. African governments, especially those in West Africa must develop sustainable funding schemes that will back research and development in their respective countries. Increased government funding will have profound impacts on ecology research and education across African universities. Studies have shown that funding for R&D results in economic development and enhancement[146]. Knowledge sharing among tertiary institutions, conservation NGOs, and government-funded research institutes must be promoted. Funding from the private sector and alumni groups should be encouraged to diversify the

university financial base and ensure their long-term viability. While many non-governmental institutions are working towards better science in Africa, government support is critical for the sustenance of such initiatives. Strong policies should decolonize science processes by creating an environment that challenges colonial legacies in science, empowering researchers to adopt inclusive, diverse, and ethical practices[50]. African governments need to adequately finance research by researchers in Africa, and more funding provisions are needed to fund the participation of African researchers in internationally funded research programmes and projects to reduce inequitable and unethical research practices. Decolonization of research and education in Africa requires the empowerment of local experts by both African governments and international funders, relearning the science of ecology and conservation, and an appreciation of cultural values and indigenous knowledge.

A balance of power in protected area management with Indigenous People and Local communities (IPLC) is beneficial for biodiversity, the people, and local economies. Policies that vest absolute land ownership powers to the government, at the detriment of IPLCs and their traditional institutions, need to be revised. Strategic implementation of policies that enhance the engagement of IPLCs and other stakeholders in policy formulation and community-based conservation is advocated[147,148]. Community engagement requires years of trust building as opposed to strict enforcement of laws and forced land grabbing. African governments and other policies should recognize and respect indigenous knowledge systems by supporting research initiatives, allowing for a more equitable distribution of resources and recognition[149,150]. Inclusive socioeconomic development of local communities, coupled with institutional strengthening and awareness creation must be prioritized to reduce the dependence on natural resources for livelihoods[151,152,153,154].

Conclusions

Species overexploitation and habitat loss are the greatest threats to Africa biodiversity and these drivers are expected to increase due to high population growth and continued dependence on natural resources in Africa. Moreover, economic development in Africa continues to grow, supported by a relatively young population, which potentially increases the demand for land for industrialization and urbanization. Therefore, maintaining the delicate balance among economic development, human growth, and biodiversity conservation and attaining the transformative change requires training ecologists in advanced research methods and technologies, as well as the development of real world problem solving skills, integration of TEK in the scientific process, productive collaborations among African ecologists, technological advancement that will support cutting edge research, engagement with the African Diaspora, open science and knowledge sharing, and sustainable funding base for these and many more initiatives. These new directions require policy intervention that will codify them into law to ensure government support and funding. We hope for a healthy African biodiversity where populations of native fauna and flora are resilient to environmental stresses and disturbances, and a balanced interaction between human and nature, which are guided by relevant and problem-solving ecology education and research.

Table 1. Doors for enhancing ecology research, education and policy in Africa

Doors	Challenges	Opportunities and solutions
Education	1. Colonial foundation of ecology education, excluding African traditional ecological knowledge (TEK) 2. Limited foundation courses in ecology and skills development in community-based conservation 3. Classroom-focused teaching with poor education field trips and project-based learning 4. Heavy teaching workload, high lecturer-student ratio, and inadequate teaching facilities	1. Transform curricula to integrate TEK and project-based learning 2. Offer of foundational ecology courses that increase global competitive ability of African graduates 3. Increase funding for education and teaching technology 4. Engage Diaspora as adjunct faculty to teach core courses (brain circulation) 5. Break bureaucratic barriers to transformative changes
Research	1. Colonial structure characterized by Western science philosophy, excluding TEK 2. Parachute science by Global North scientists and institutions driven by higher funding leverage and power dynamics 3. Insufficient research funding, leading to limited capacity for scientific production and publication	1. Boost funding for research from African governments, institutions and the private sector 2. Promote brain circulation through Diaspora engagement 3. Index African journals in global databases 4. Foster collaborations and resource sharing among African research institutions
Policy and governance	1. Weak governance and poor policy implementation 2. Inadequate policies for education and research investment 3. Colonial governance creating local tensions	1. Strengthen regional cooperation for transboundary research 2. Develop inclusive policies involving Indigenous communities in research designs and science-based protected area management 3. Establish sustainable funding and partnerships 4. Facilitate Africa Diaspora engagement 5. Policy interventions to support equitable research partnerships 6. Implement 1% GDP funding policy for research and development

REFERENCES

1. Willig, M. R., Kaufman, D. M. & Stevens, R. D. Latitudinal Gradients of Biodiversity: Pattern, Process, Scale, and Synthesis. *Annu. Rev. Ecol. Evol. Syst.* **34**, 273–309 (2003).
2. Hillebrand, H. On the Generality of the Latitudinal Diversity Gradient. *The American Naturalist* **163**, 192–211 (2004).
3. Mittelbach, G. G. *et al.* Evolution and the latitudinal diversity gradient: speciation, extinction and biogeography. *Ecology Letters* **10**, 315–331 (2007).
4. Malhi, Y., Adu-Bredu, S., Asare, R. A., Lewis, S. L. & Mayaux, P. African rainforests: past, present and future. *Phil. Trans. R. Soc. B* **368**, 20120312 (2013).
5. De La Estrella, M. *et al.* The impact of rainforest area reduction in the Guineo-Congolian region on the tempo of diversification and habitat shifts in the Berlinia clade (Leguminosae). *Journal of Biogeography* **47**, 2728–2740 (2020).
6. Harris, N. L. *et al.* Global maps of twenty-first century forest carbon fluxes. *Nature Climate Change* **11**, 234–240 (2021).
7. Gatti, L. V. *et al.* Amazonia as a carbon source linked to deforestation and climate change. *Nature* **595**, 388–393 (2021).
8. Du Toit, J. T. & Cumming, D. H. Functional significance of ungulate diversity in African savannas and the ecological implications of the spread of pastoralism. *Biodiversity & Conservation* **8**, 1643–1661 (1999).
9. Bond, W. & Zaloumis, N. P. The deforestation story: testing for anthropogenic origins of Africa's flammable grassy biomes. *Phil. Trans. R. Soc. B* **371**, 20150170 (2016).
10. Luck, G. W. A review of the relationships between human population density and biodiversity. *Biological Reviews* **82**, 607–645 (2007).
11. Barrett, A. M., Crossley, M. & Dachi, H. A. International collaboration and research capacity building: learning from the EdQual experience. *Comparative Education* **47**, 25–43 (2011).
12. Gorenflo, L. J., Romaine, S., Mittermeier, R. A. & Walker-Painemilla, K. Co-occurrence of linguistic and biological diversity in biodiversity hotspots and high biodiversity wilderness areas. *Proc. Natl. Acad. Sci. U.S.A.* **109**, 8032–8037 (2012).
13. Hua, X., Greenhill, S. J., Cardillo, M., Schneemann, H. & Bromham, L. The ecological drivers of variation in global language diversity. *Nature communications* **10**, 2047 (2019).
14. Sands, B. Africa's Linguistic Diversity. *Language and Linguistics Compass* **3**, 559–580 (2009).
15. Archer, E. *et al.* The regional assessment report on biodiversity and ecosystem services for Africa: summary for policymakers. (2018).
16. Chapman, C. A. *et al.* The future of sub-Saharan Africa's biodiversity in the face of climate and societal change. *Frontiers in Ecology and Evolution* **10**, 790552 (2022).
17. Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A. & Kent, J. Biodiversity hotspots for conservation priorities. *Nature* **403**, 853–858 (2000).
18. Noss, R. F. *et al.* How global biodiversity hotspots may go unrecognized: lessons from the North American Coastal Plain. *Diversity and Distributions* **21**, 236–244 (2015).
19. Hill, J. L. & Hill, R. A. Why are tropical rain forests so species rich? Classifying, reviewing and evaluating theories. *Progress in Physical Geography: Earth and Environment* **25**, 326–354 (2001).

20. Brown, J. H. Why are there so many species in the tropics? *Journal of Biogeography* **41**, 8–22 (2014).
21. Schnitzler, J. *et al.* Causes of plant diversification in the Cape biodiversity hotspot of South Africa. *Systematic biology* **60**, 343–357 (2011).
22. Hardy, O. J., Couteron, P., Munoz, F., Ramesh, B. R. & Pélissier, R. Phylogenetic turnover in tropical tree communities: impact of environmental filtering, biogeography and mesoclimatic niche conservatism. *Global Ecology and Biogeography* **21**, 1007–1016 (2012).
23. Crisp, M. D. & Cook, L. G. Phylogenetic niche conservatism: what are the underlying evolutionary and ecological causes? *New Phytologist* **196**, 681–694 (2012).
24. Belle, E. M. S. *et al.* Climate change impacts on biodiversity and protected areas in West Africa, Summary of the main outputs of the PARCC project, Protected Areas Resilient to Climate Change in West Africa. *UNEP-WCMC, Cambridge, UK* (2016).
25. Amarasekare, P. & Johnson, C. Evolution of Thermal Reaction Norms in Seasonally Varying Environments. *The American Naturalist* **189**, E31–E45 (2017).
26. Sintayehu, D. W. Impact of climate change on biodiversity and associated key ecosystem services in Africa: a systematic review. *Ecosyst Health Sustain* **4**, 225–239 (2018).
27. Küper, W., Sommer, J. H., Lovett, J. C. & Barthlott, W. Deficiency in African plant distribution data–missing pieces of the puzzle. *Botanical Journal of the Linnean Society* **150**, 355–368 (2006).
28. Stropp, J. *et al.* Mapping ignorance: 300 years of collecting flowering plants in Africa. *Global Ecol. Biogeogr.* **25**, 1085–1096 (2016).
29. Farooq, H., Azevedo, J. A., Soares, A., Antonelli, A. & Faurby, S. Mapping Africa's biodiversity: More of the same is just not good enough. *Systematic Biology* **70**, 623–633 (2021).
30. Lees, A. C. & Pimm, S. L. Species, extinct before we know them? *Current Biology* **25**, R177–R180 (2015).
31. Liu, J., Slik, F., Zheng, S. & Lindenmayer, D. B. Undescribed species have higher extinction risk than known species. *CONSERVATION LETTERS* **15**, e12876 (2022).
32. Caldwell, I. R. *et al.* Global trends and biases in biodiversity conservation research. *Cell Reports Sustainability* **1**, (2024).
33. Gurevitch, J., Scheiner, S. M. & Fox, G. A. *The Ecology of Plants*. (Sinauer Associates Sunderland, 2002).
34. Cohen, W. B. & Goward, S. N. Landsat's role in ecological applications of remote sensing. *Bioscience* **54**, 535–545 (2004).
35. Pasetto, D. *et al.* Integration of satellite remote sensing data in ecosystem modelling at local scales: Practices and trends. *Methods Ecol Evol* **9**, 1810–1821 (2018).
36. Liu, X. *et al.* Using functional trait diversity to infer community assembly mechanisms: an exclosure experiment as an example. *Journal of plant ecology* **12**, 448–459 (2019).
37. Rosbakh, S., Chalmandrier, L., Phartyal, S. & Poschlod, P. Inferring community assembly processes from functional seed trait variation along elevation gradient. *Journal of Ecology* **110**, 2374–2387 (2022).
38. Webb, C. O., Ackerly, D. D., McPeek, M. A. & Donoghue, M. J. Phylogenies and Community Ecology. *Annu. Rev. Ecol. Syst.* **33**, 475–505 (2002).
39. Hersch-Green, E. I., Turley, N. E. & Johnson, M. T. J. Community genetics: what have we accomplished and where should we be going? *Phil. Trans. R. Soc. B* **366**, 1453–1460 (2011).
40. Clare, E. L. *et al.* Approaches to integrating genetic data into ecological networks. *Molecular Ecology* **28**, 503–519 (2019).

41. Sagarin, R. & Pauchard, A. Observational approaches in ecology open new ground in a changing world. *Frontiers in Ecol & Environ* **8**, 379–386 (2010).
42. Cooke, S. J. *et al.* How experimental biology and ecology can support evidence-based decision-making in conservation: avoiding pitfalls and enabling application. *Conservation Physiology* **5**, cox043 (2017).
43. Goff, K. A., Martinez Del Rio, C. & Kay, K. M. A greenhouse experiment partially supports inferences of ecogeographic isolation from niche models of *Clarkia* sister species. *American J of Botany* **108**, 2002–2014 (2021).
44. Mindell, A. *The Deep Democracy of Open Forums: Practical Steps to Conflict Prevention and Resolution for the Family, Workplace, and World*. (Hampton Roads Publishing, 2002).
45. Ochwa-Echel, J. R. Neoliberalism and University Education in Sub-Saharan Africa. *Sage Open* **3**, 2158244013504933 (2013).
46. Ezeanya-Esiobu, C. *Indigenous Knowledge and Education in Africa*. (Springer Nature, 2019).
47. Assié-Lumumba, N. T. African University Traditions, Historical Perspective. in *The International Encyclopedia of Higher Education Systems and Institutions* (eds. Teixeira, P. N. & Shin, J. C.) 106–111 (Springer Netherlands, Dordrecht, 2020). doi:10.1007/978-94-017-8905-9_10.
48. Das, S. & Lowe, M. Nature read in black and white: decolonial approaches to interpreting natural history collections. *Journal of Natural Science Collections* **6**, 4–14 (2018).
49. Baker, K., Eichhorn, M. P. & Griffiths, M. Decolonizing field ecology. *Biotropica* **51**, 288–292 (2019).
50. Trisos, C. H., Auerbach, J. & Katti, M. Decoloniality and anti-oppressive practices for a more ethical ecology. *Nat Ecol Evol* **5**, 1205–1212 (2021).
51. McCowan, T., Omingo, M., Schendel, R., Adu-Yeboah, C. & Tabulawa, R. Enablers of pedagogical change within universities: Evidence from Kenya, Ghana and Botswana. *International Journal of Educational Development* **90**, 102558 (2022).
52. Kaziboni, A. & Uys, T. The Selection of Academic Role Models by First Year University Students. *Journal of Sociology and Social Anthropology* **6**, 77–86 (2015).
53. Adams, S. & Savahl, S. Nature as children's space: A systematic review. *The Journal of Environmental Education* **48**, 291–321 (2017).
54. Materu, P. N. Higher education quality assurance in Sub-Saharan Africa: status, challenges, opportunities and promising practices. (2007).
55. Mushemeza, E. D. Opportunities and Challenges of Academic Staff in Higher Education in Africa. *International Journal of Higher Education* **5**, 236–246 (2016).
56. Uwizeye, D. *et al.* Factors associated with research productivity in higher education institutions in Africa: a systematic review. *AAS Open Res* **4**, 26 (2022).
58. Caelers, D. & Okoth, D. Research funding in Africa: navigating sustainability and shifting perspectives. *Nature Africa* (2023) doi:10.1038/d44148-023-00360-4.
59. Zickafoose, A. *et al.* Barriers and Challenges Affecting Quality Education (Sustainable Development Goal #4) in Sub-Saharan Africa by 2030. *Sustainability* **16**, 2657 (2024).
60. Ondari-Okemwa, E. Scholarly publishing in sub-Saharan Africa in the twenty-first century: Challenges and opportunities. *First Monday* (2007).
61. Capuano, S. & Marfouk, A. African Brain Drain and Its Impact on Source Countries: What Do We Know and What Do We Need to Know? *Journal of Comparative Policy Analysis: Research and Practice* **15**, 297–314 (2013).

62. Adeniji, A. *et al.* Japa model: A mathematical framework for analyzing brain drain in Africa. *Scientific African* **25**, e02329 (2024).
63. Skop, E. Creating Field Trip-Based Learning Communities. *Journal of Geography* **107**, 230–235 (2009).
65. Nyinkeu, N. D., Katiba, C. T. & Henry, N. Project-Based Teaching for Information Technology Students in Africa: A Case Report. *International Journal of Technology in Teaching and Learning* **11**, 130–139 (2015).
66. Nepeina, K., Istomina, N. & Bykova, O. The role of field training in STEM education: Theoretical and practical limitations of scalability. *European journal of investigation in health, psychology and education* **10**, 511–529 (2020).
67. Fateye, B., Osuolale, O. & Omotoriogun, T. C. Culturally and contextually adapted co-teaching: a case study of collaboration with the diaspora in undergraduate STEM education. *Diaspora, Indigenous, and Minority Education* **18**, 23–36 (2024).
68. Hennessy, S. *et al.* Technology use for teacher professional development in low-and middle-income countries: A systematic review. *Computers and Education Open* **3**, 100080 (2022).
69. Mhlongo, S., Mbatha, K., Ramatsetse, B. & Dlamini, R. Challenges, opportunities, and prospects of adopting and using smart digital technologies in learning environments: An iterative review. *Heliyon* **9**, (2023).
70. Pregowska, A., Masztalerz, K., Garlińska, M. & Osial, M. A worldwide journey through distance education—from the post office to virtual, augmented and mixed realities, and education during the COVID-19 pandemic. *Education Sciences* **11**, 118 (2021).
71. Kumi-Yeboah, A., Young, W. H. & Boadu, K. 21st century distance learning in sub-Saharan Africa: Distance and blended learning in Ghana. in *Advancing technology and educational development through blended learning in emerging economies* 142–158 (IGI Global, 2014).
72. Nsanzumuhire, S. U. & Groot, W. Context perspective on University-Industry Collaboration processes: A systematic review of literature. *Journal of cleaner production* **258**, 120861 (2020).
73. Haghighi Talab, A., Scholten, V. & Van Beers, C. The Role of Universities in Inter-organizational Knowledge Collaborations. *J Knowl Econ* **11**, 458–478 (2020).
74. Figueiredo, E. & Smith, G. F. The colonial legacy in African plant taxonomy: biological types and why we need them. *South African Journal of Science* **106**, 1–4 (2010).
75. Cowell, C. R., Anderson, P. M. L. & Annecke, W. A. Historic herbarium specimens as biocultural assets: An examination of herbarium specimens and their in situ plant communities of the Agulhas National Park, South Africa. *People and Nature* **2**, 483–494 (2020).
76. McAlvay, A. C. *et al.* Ethnobiology Phase VI: Decolonizing Institutions, Projects, and Scholarship. *Journal of Ethnobiology* **41**, 170–191 (2021).
77. Park, D. S. *et al.* The colonial legacy of herbaria. *Nature Human Behaviour* **7**, 1059–1068 (2023).
78. Gillman, L. N. & Wright, S. D. Restoring indigenous names in taxonomy. *Communications Biology* **3**, 609 (2020).
79. MacArthur, R. H. & Wilson, E. O. *The Theory of Island Biogeography*. vol. 1 (Princeton university press, 2001).
80. Bell, G. Neutral Macroecology. *Science* **293**, 2413–2418 (2001).

81. Hubbell, S. P. The unified neutral theory of biodiversity and biogeography: reply. *Ecology* **85**, 3175–3178 (2004).
82. Janzen, D. H. Coevolution of mutualism between ants and acacias in Central America. *Evolution* 249–275 (1966).
83. Borokini, T. I. & Lawal, I. O. Traditional medicine practices among the Yoruba people of Nigeria: A historical perspective. *Journal of Medicinal Plants Studies* **2**, 20–33 (2014).
84. De Divitiis, E., Cappabianca, P. & De Divitiis, O. The "schola medica salernitana": the forerunner of the modern university medical schools. *Neurosurgery* **55**, 722–745 (2004).
85. Pardo-de-Santayana, M., Quave, C. L., Sõukand, R. & Pieroni, A. Medical Ethnobotany and Ethnopharmacology of Europe. in *Ethnopharmacology* (eds. Heinrich, M. & Jäger, A. K.) 343–356 (Wiley, 2015). doi:10.1002/9781118930717.ch29.
86. Reidpath, D., Allotey, P., & 166 signatories. Preserve Global South's research capacity. *Science* **368**, 725–725 (2020).
87. Haelewaters, D., Blackwell, M. & Pfister, D. H. Laboulbeniomycetes: Intimate Fungal Associates of Arthropods. *Annu. Rev. Entomol.* **66**, 257–276 (2021).
88. Odeny, B. & Bosurgi, R. Time to end parachute science. *PLoS medicine* vol. 19 e1004099 (2022).
89. de Vos, A. & Schwartz, M. W. Confronting parachute science in conservation. *Conservation Science and Practice* **4**, e12681 (2022).
90. Hayward, M. W. *et al.* Ambiguity in guideline definitions introduces assessor bias and influences consistency in IUCN Red List status assessments. *Front. Ecol. Evol.* **3**, (2015).
91. Nguah, S. B. & Lartey, M. Helicopter research: A persistent drawback to equitable collaborative research. *Ghana Medical Journal* **58**, 115–116 (2024).
92. North, M. A., Hastie, W. W. & Hoyer, L. Out of Africa: The underrepresentation of African authors in high-impact geoscience literature. *Earth-Science Reviews* **208**, 103262 (2020).
93. UNESCO. *UNESCO Science Report: The Race against Time for Smarter Development*. (UNESCO Publishing, 2021).
94. Olufadewa, I. I., Adesina, M. A. & Ayorinde, T. From Africa to the World: Reimagining Africa's research capacity and culture in the global knowledge economy. *Journal of Global Health* **10**, (2020).
95. Overland, I. *et al.* Funding flows for climate change research on Africa: where do they come from and where do they go? *Climate and Development* **14**, 705–724 (2022).
96. Singh, D. Publication bias-a reason for the decreased research output in developing countries. *African Journal of Psychiatry* **9**, 153–155 (2006).
97. Tuyisenge, M. F. *et al.* Status of African authorship among conservation research output from SUB-SAHARAN Africa: An African perspective. *Conservat Sci and Prac* **5**, e13013 (2023).
98. Hedding, D. W. & Breetzke, G. "Here be dragons!" The gross under-representation of the Global South on editorial boards in Geography. *Geographical Journal* **187**, 331–345 (2021).
99. Liu, F., Rahwan, T. & AlShebli, B. Non-White scientists appear on fewer editorial boards, spend more time under review, and receive fewer citations. *Proc. Natl. Acad. Sci. U.S.A.* **120**, e2215324120 (2023).
100. Amano, T. *et al.* The manifold costs of being a non-native English speaker in science. *PLOS Biology* **21**, e3002184 (2023).
101. Lor, P. Scholarly publishing and peer review in the Global South: the role of the reviewer. *JLIS.it* **14**, 10–29 (2023).

102. Tarkang, E. E. & Bain, L. E. The bane of publishing a research article in international journals by African researchers, the peer-review process and the contentious issue of predatory journals: a commentary. *Pan Afr Med J* **32**, (2019).
103. Yaffee, S. L. & Wondolleck, J. M. Making Collaboration Work: Lessons from a comprehensive assessment of over 200 wideranging cases of collaboration in environmental management. *Conservation in Practice* **1**, 17–24 (2000).
104. Githiora-Murimi, Y. W., Owuor, M. A., Abila, R., Olago, D. & Oriaso, S. Integrating stakeholder preferences into ecosystem services mapping in Yala wetland, Kenya. *Ecosystems and People* **18**, 146–163 (2022).
105. Brown, K. 'Trees, forests and communities': some historiographical approaches to environmental history on Africa. *Area* **35**, 343–356 (2003).
106. Cline-Cole, R. A. African and Africanist biodiversity research in a neo-liberal context. *Africa* **66**, 145–158 (1996).
107. Njoh, A. J. Fairness, Equity, and Justice Implications of FRENCH-INFLUENCED Environmental Policy in Africa. *American J Econ Sociol* **81**, 927–955 (2022).
108. Shultis, J. & Heffner, S. Hegemonic and emerging concepts of conservation: a critical examination of barriers to incorporating Indigenous perspectives in protected area conservation policies and practice. *Journal of Sustainable Tourism* **24**, 1227–1242 (2016).
109. Murdock, E. G. Conserving Dispossession? A Genealogical Account of the Colonial Roots of Western Conservation. *Ethics, Policy & Environment* **24**, 235–249 (2021).
110. Domínguez, L. & Luoma, C. Decolonising conservation policy: How colonial land and conservation ideologies persist and perpetuate indigenous injustices at the expense of the environment. *Land* **9**, 65 (2020).
111. Borokini, I. T. *et al.* Alien flora of Nigeria: taxonomy, biogeography, habitats, and ecological impacts. *Biol Invasions* **25**, 3677–3696 (2023).
112. Abernethy, K., Maisels, F. & White, L. J. T. Environmental Issues in Central Africa. *Annual Review of Environment and Resources* **41**, 1–33 (2016).
113. *An Introduction to the African Convention on the Conservation of Nature and Natural Resources*. (IUCN, Gland, Switzerland and Cambridge, UK, 2004).
114. Santos, E. C. *et al.* Mainstreaming revisited: Experiences from eight countries on the role of National Biodiversity Strategies in practice. *Earth System Governance* **16**, 100177 (2023).
115. Whitehorn, P. R. *et al.* Mainstreaming biodiversity: A review of national strategies. *Biological Conservation* **235**, 157–163 (2019).
116. Barnhizer, D. What causes laws to succeed or fail? *Cleveland-Marshall Legal Studies Paper* (2016).
117. Sorgho, R. *et al.* Climate Change Policies in 16 West African Countries: A Systematic Review of Adaptation with a Focus on Agriculture, Food Security, and Nutrition. *International Journal of Environmental Research and Public Health* **17**, 8897 (2020).
118. Croese, S., Oloko, M., Simon, D. & Valencia, S. C. Bringing the Global to the Local: the challenges of multi-level governance for global policy implementation in Africa. *International Journal of Urban Sustainable Development* **13**, 435–447 (2021).
119. Zulu, E. *et al.* Challenges and advocated solutions for environmental protection legislation for building infrastructure projects in developing countries: Evidence from Zambia. *Project Leadership and Society* **3**, 100056 (2022).
120. Muchapondwa, E. & Stage, J. Whereto with institutions and governance challenges in African wildlife conservation? *Environmental Research Letters* **10**, 095013 (2015).

121. Hilborn, R. *et al.* Effective Enforcement in a Conservation Area. *Science* **314**, 1266–1266 (2006).
122. Laurance, W. F. *et al.* Averting biodiversity collapse in tropical forest protected areas. *Nature* **489**, 290–294 (2012).
123. Lindsey, P. A. *et al.* Underperformance of African Protected Area Networks and the Case for New Conservation Models: Insights from Zambia. *PLOS ONE* **9**, e94109 (2014).
124. Coad, L. *et al.* Widespread shortfalls in protected area resourcing undermine efforts to conserve biodiversity. *Frontiers in Ecol & Environ* **17**, 259–264 (2019).
125. Appleton, M. R. *et al.* Protected area personnel and ranger numbers are insufficient to deliver global expectations. *Nature Sustainability* **5**, 1100–1110 (2022).
126. Lindsey, P. A. *et al.* More than $1 billion needed annually to secure Africa's protected areas with lions. *Proc. Natl. Acad. Sci. U.S.A.* **115**, (2018).
127. Redford, K. H. & Fearn, E. *Protected Areas and Human Displacement: A Conservation Perspective*. vol. 29 (Wildlife Conservation Society New York, 2007).
128. Batavia, C. *et al.* The elephant (head) in the room: A critical look at trophy hunting. *Conservation Letters* **12**, e12565 (2019).
129. Braczkowski, A. *et al.* Evidence for increasing human-wildlife conflict despite a financial compensation scheme on the edge of a Ugandan National Park. *Conservation Science and Practice* **2**, e309 (2020).
130. Hare, D. *et al.* Public perceptions of trophy hunting are pragmatic, not dogmatic. *Proceedings of the Royal Society B: Biological Sciences* **291**, 20231638 (2024).
131. Traill, L. W., Wanger, T. C., Twine, W., van Houdt, S. & Brown, R. P. A global survey of the societal benefits of trophy hunting in Africa. *Biological Conservation* **296**, 110689 (2024).
132. Mekonen, S. Coexistence between human and wildlife: the nature, causes and mitigations of human wildlife conflict around Bale Mountains National Park, Southeast Ethiopia. *BMC Ecol* **20**, 51 (2020).
133. Cui, Q., Ren, Y. & Xu, H. The escalating effects of wildlife tourism on human–wildlife conflict. *Animals* **11**, 1378 (2021).
134. Braczkowski, A. R. *et al.* The unequal burden of human-wildlife conflict. *Communications Biology* **6**, 182 (2023).
135. Tran, T. C., Ban, N. C. & Bhattacharyya, J. A review of successes, challenges, and lessons from Indigenous protected and conserved areas. *Biological Conservation* **241**, 108271 (2020).
136. DeGeorges, P. A. & Reilly, B. K. The realities of community based natural resource management and biodiversity conservation in Sub-Saharan Africa. *Sustainability* **1**, 734–788 (2009).
137. Egoh, B. N. *et al.* Setting the scene for achievable post-2020 convention on biological diversity targets: A review of the impacts of invasive alien species on ecosystem services in Africa. *Journal of Environmental Management* **261**, 110171 (2020).
138. *Building a Nature-Positive Society*. (CBS Library, Frederiksberg, 2022).
139. IPBES, W. Intergovernmental science-policy platform on biodiversity and ecosystem services. *Summary for Policy Makers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES Secretariat, Bonn, Germany* (2019).
140. Andersson, A. A. *et al.* CITES and beyond: Illuminating 20 years of global, legal wildlife trade. *Global Ecology and Conservation* **26**, e01455 (2021).

141. Tranquilli, S. *et al.* Protected Areas in Tropical Africa: Assessing Threats and Conservation Activities. *PLOS ONE* **9**, e114154 (2014).
142. Challender, D. W., Harrop, S. R. & MacMillan, D. C. Understanding markets to conserve trade-threatened species in CITES. *Biological Conservation* **187**, 249–259 (2015).
143. Clay, J. W., Alcorn, J. B. & Butler, J. R. Indigenous peoples, forestry management and biodiversity conservation. *Report to the World Bank. Washington DC, USA: World Bank* (2000).
144. Alexiades, A. V. *et al.* Traditional Ecological Knowledge and Inclusive Pedagogy Increase Retention and Success Outcomes of STEM Students. *The Bulletin of the Ecological Society of America* **102**, e01924 (2021).
145. Masino, S. & Niño-Zarazúa, M. What works to improve the quality of student learning in developing countries? *International Journal of Educational Development* **48**, 53–65 (2016).
146. Coccia, M. Science, funding and economic growth: analysis and science policy implications. *World Review of Science, Technology and Sustainable Development* **5**, 1–27 (2008).
147. West, P., Igoe, J. & Brockington, D. Parks and Peoples: The Social Impact of Protected Areas. *Annu. Rev. Anthropol.* **35**, 251–277 (2006).
148. Garnett, S. T. *et al.* A spatial overview of the global importance of Indigenous lands for conservation. *Nature Sustainability* **1**, 369–374 (2018).
149. Grenier, L. *Working with Indigenous Knowledge: A Guide for Researchers*. (idrc, 1998).
150. Davis, A. & Wagner, J. R. Who knows? On the importance of identifying "experts" when researching local ecological knowledge. *Human ecology* **31**, 463–489 (2003).
151. Thondhlana, G., Vedeld, P. & Shackleton, S. Natural resource use, income and dependence among San and Mier communities bordering Kgalagadi Transfrontier Park, southern Kalahari, South Africa. *International Journal of Sustainable Development & World Ecology* **19**, 460–470 (2012).
152. Soman, D. & Anitha, V. Community dependence on the natural resources of Parambikulam Tiger Reserve, Kerala, India. *Trees, Forests and People* **2**, 100014 (2020).
153. Fedele, G., Locatelli, B., Djoudi, H. & Colloff, M. J. Reducing risks by transforming landscapes: Cross-scale effects of land-use changes on ecosystem services. *PLoS One* **13**, e0195895 (2018).
154. Muhamad, G. M., Heshmati, A. & Khayyat, N. T. How to reduce the degree of dependency on natural resources? *Resources Policy* **72**, 102047 (2021).