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Stories from the front lines

Investing in people, infrastructure, and meaningful collaboration is key for deep-sea biodiversity research and management in South Africa

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Abstract

After over a century of global research in the deep ocean, many nations continue to face barriers to developing and sustaining deep-sea research and management in their own waters. This prevents sound environmental management and limits nations' potential to derive benefits from the deep sea. In this perspective paper, we draw on the experiences of established and early career researchers and managers in South Africa, to reflect on key obstacles limiting deep-sea biodiversity research and management in the country and propose potential solutions to strengthen the field. Challenges range from a lack of equal opportunity, cultural barriers, and poor retention of expertise, to limited financial support, low exposure to and perceived irrelevance of the deep sea, limited access to vessels and technology, and inequitable international standards and partnerships. Key enablers to support capacity development and increase equal opportunities in South African deep-sea biodiversity research and management include increased early exposure to the ocean and deep sea, financial and academic support, access to vessels and technology, and development of meaningful collaborations. We provide recommendations to increase capacity in five key theme areas: (i) exposure and training, (ii) mainstreaming, (iii) funding, (iv) research infrastructure, and (v) partnerships and research collaborations. These recommendations may inform researchers, funders, managers, decision-makers, industry stakeholders and international collaborators, and may be applicable to other developing nations facing similar challenges.

Keywords capacity development, deep-sea research, deep-sea biodiversity, south africa, africa, ocean equity, global south, research infrastructure, equitable collaboration

Introduction

Despite more than a century of research in the deep ocean (generally considered to be those areas deeper than 200 m), many international collaborations and rapid growth in global deep-sea research outputs, there remain substantial inequalities in access to funding, infrastructure, and human capacity to support deep-sea research, particularly between high-income and low- and middle-income countries (Bell et al. 2023). These disparities have been increasingly recognised through global discussions on equity, access to ocean science and capacity development, which have sought to understand and document their historical and structural drivers (e.g. Salpin et al. 2016, Blasiak et al. 2018, Österblom et al. 2020, Amon et al. 2022a, Bell et al. 2023, Caldeira and Lopes 2023, de Vos et al. 2023, Polejack et al. 2025, Lue Chin et al. 2026).

Reducing inequalities in ocean science capacity is one of the main goals set forth in the Implementation Plan for the United Nations Decade of Ocean Science for Sustainable Development (2021–2030) (IOC-UNESCO 2021). Marine scientific research and access to technology are considered critical for sustainable development (Vierros and Harden-Davies 2020), and strengthening expertise to develop and implement sustainable ocean plans in

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Africa has thus been identified as a priority in the "Ocean Decade Africa Roadmap" (IOC-UNESCO 2022). However, achieving this will require addressing historical inequities and ensuring equitable access to ocean science, technology, and decision-making processes (Polejack et al. 2025). This need is especially acute in the deep-sea context, given the increasing recognition of the deep ocean as a crucial provider of ecosystem services (Thurber et al. 2014, La Bianca et al. 2023), the diversification and intensification of marine pressures (e.g. Halpern et al. 2019, Montserrat et al. 2019, Ryan et al. 2019), and the persistent knowledge and capacity gaps that continue to hinder research, management and decision-making (Rogers et al. 2014, Bell et al. 2023).

Across much of Africa, countries face significant capacity constraints in conducting and applying offshore and deep-sea research (Bell et al. 2022a, McQuaid et al. 2024). For the purposes of this perspective paper, offshore and deep-sea research refer to research conducted beyond nearshore coastal waters (offshore), and beyond the 200 m depth contour (deep sea) (Gage and Tyler 1991). We also consider capacity as "the ability of people, organisations and society as a whole to manage their affairs successfully'' and capacity development as "the process whereby people, organisations and society as a whole unleash, strengthen, create, adapt, and maintain capacity over time in order to achieve development results,'' following definitions developed by the United Nations (UNDG 2017).

South Africa is one such country experiencing capacity constraints. As a maritime nation, 85% of the mainland ocean territory falls within the deep sea and increased offshore industrial activity has been identified as a priority by the South African government (Loureiro et al. 2022). However, the scientific knowledge needed to support management of activities in this environment remains limited. While deep-sea science encompasses many disciplines, this perspective paper focuses on capacity related to deep-sea biodiversity research, including biological sampling, taxonomy, species identification, and image-based surveys. In 2010, it was reported that 83% of more than 2500 collated records of biological samples collected by dredge, grab and trawl in South Africa were from waters shallower than 100 m and less than 1% were from waters deeper than 1000 m (Griffiths et al. 2010). Abyssal systems (forming nearly 65% of South Africa's mainland territorial waters) have never been sampled by South African biodiversity scientists (Anderson & Hulley 2000), with very limited sampling through international cruises. Historically, and to date, much of the research in the South African deep sea proper has been undertaken by international scientists with little if any local collaboration (e.g. the Challenger expedition in the late 1800s and several cruises led by the United States of America). This reflects experiences in other under-resourced parts of the world (e.g. Rayadin and Buřivalová 2022, Amon et al. 2022a, Stefanoudis et al. 2021, de Vos 2022).

However, many institutes are engaged in marine research in South Africa, including government, state-owned entities, universities, science councils and non-governmental organisations (NGOs), and progress is being made. Although most institutes largely focus on coastal research due to technical and logistical constraints, capacity for offshore research has steadily developed to depths of 200 m, with emerging capacity beyond 200 m. Collectively, several of South Africa's marine facilities provide access to some deep-sea research platforms and infrastructure to support biodiversity sampling and ecological research. These are described in Sink et al. (2021), and include research trawls, dredges, grabs, 700 m-rated towed cameras, a 1000 m-rated drift camera, a 300 m-rated observation class remotely operated vehicle (ROV), and emerging 3500 m-rated deep-sea landers with stereo-video (baited or unbaited) and trap capabilities. A 1000 m-rated working class ROV has also recently been acquired but has not yet been tested or used at its full depth capability.

Some of these technologies are deployed from large research vessels, while others are suitable for use off smaller coastal vessels (15 m length). Recent government investment in visual technologies capable of being deployed from smaller vessels has been significant in advancing knowledge, with substantial progress in sampling mesophotic depths $<$ 200 m (Sink et al. 2019). Below 200 m, research trawl surveys constitute the majority of sampling effort (Anderson and Hulley 2000, Griffiths et al. 2010), but emerging research through visual surveys is contributing to progress in documenting South Africa's deep-sea biodiversity (Adams et al. 2023a, Currie et al. 2019, Atkinson 2023).

While most offshore and deep-sea research in the country has concentrated on important fisheriers resources, oceanography and geology, increasing insights into benthic invertebrate communities have been facilitated through both opportunistic and dedicated sampling efforts (e.g. Sink et al. 2006, Samaai et al. 2012, Karenyi et al. 2016, Makwela 2017, Samaai et al. 2017, Attwood 2018, Sink et al. 2019, Adams et al. 2020, Button et al. 2021, Filander et al. 2021, Ngwakum et al. 2021, Filander et al. 2022, Adams et al. 2023b, Atkinson 2023, Brandt et al. 2023, Brandt et al. 2024, Puccinelli et al. 2024a). Industry collaborations with local scientists have been important in facilitating access to deep-sea data through co-operative research and sampling (e.g. Palan et al. 2020, Sink et al. 2023), and there has also been some progress in offshore marine biodiversity research in South Africa's sub-Antarctic archipelago, the Prince Edward Islands (Haley et al. 2017, von der Meden et al. 2017, Whitehead et al. 2019, Puccinelli et al. 2024b). The history and current status of deep-sea biodiversity research and management in South Africa is further detailed in Sink et al. (2021) and Bridges et al. (2023).

Notwithstanding progress made, there are limitations to the use of this research infrastructure, and aging research vessels, survey time constraints and changes in government ministries and responsibilities have led to reduced efforts on aspects beyond fisheries stock assessment surveys. Much of South Africa's deep sea thus remains inaccessible to the research community, with technology for sampling bathyal (1000 m–4000 m) and abyssal ($>$4000 m) systems lacking.

Against this backdrop, this paper aims to document the experiences of established and early career South African researchers and managers regarding key obstacles limiting offshore and deep-sea biodiversity research and management in South Africa, and to propose potential solutions to address these. Here we offer a perspective from an African country to contribute to discussions on accessibility, equity and capacity development in deep-sea research. The focus herein is on deep-sea research that aims to understand biodiversity, ecosystems and vulnerabilities, to inform marine environmental management. This paper therefore does not consider fisheries resources or physical and biological oceanography, which are considered to have received greater research attention in the country and, in the case of fisheries, are generally well-managed (Sink et al. 2019).

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Approach

Reflections on challenges and enablers for offshore and deep-sea biodiversity research in South Africa were distilled from three main sources: (i) participation by the authors in national and international online events; (ii) discussions within new Atlantic-focussed international projects; and (iii) focused discussions amongst authors of this work and their wider research teams. These reflections represent the experiences, information and insights of 31 participants, including 27 South African scientists and early career researchers (ECRs), and four managers. Collectively, these sources provided perspectives spanning multiple career stages, institutions, and capacity development initiatives relevant to the South African offshore research sector. They should, however, be understood as expert reflections, rather than the results of a formal qualitative survey. It is also important to note that the interpretation of these discussions by the authors and the views expressed herein may not reflect the views of other members of the South African offshore and deep-sea research community. As researchers actively involved in offshore and deep-sea science and capacity development initiatives, the challenges and priorities identified reflect issues most salient to academic researchers and their associated networks.

Information from the above sources was reviewed and synthesised. Notes and key discussion points were examined to identify recurring barriers, opportunities, and proposed solutions relating to offshore and deep-sea biodiversity research in South Africa. Reflections were then categorised into broad recurring themes (Supplementary Tables S1 and S2), with themes retained where they emerged consistently across multiple sources and participant groups, including both established researchers and ECRs. This process enabled the identification of common challenges and solutions, while reducing the influence of isolated viewpoints.

The principal online event from which reflections were derived was part of the United Nations World Ocean Week in 2020. The authors led a session organised by the UK Research & Innovation-funded One Ocean Hub project called "Wonders of the Deep," which explored challenges for entering the field of deep-sea research in South Africa, and potential solutions to overcome these. Additional perspectives were obtained through author participation in other online events in 2020, including a Sustainable Ocean Alliance seminar with discussions on African perspectives on deep-sea mining and an International Union for Conservation of Nature (IUCN)/Deep-Ocean Stewardship Initiative (DOSI) webinar on negotiations for a new Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction (BBNJ Agreement). The latter focused on Marine Genetic Resources and ensuring developing country benefits. Notes capturing discussions in these events were collated and reviewed as above.

New international projects in the Atlantic Ocean basin also provided opportunities to reflect on the current situation for offshore and deep-sea biodiversity research in South Africa. The One Ocean Hub in particular was catalytic in acknowledging capacity gaps and incorporating them into project activities. Similarly, the Horizon 2020 iAtlantic and Mission Atlantic projects both sought to support local capacity development and the Challenger 150 Programme and other initiatives under the United Nations Decade of Ocean Science for Sustainable Development are contributing to work to support deep-sea research capacity development. These international projects prompted requests to the authors to identify national capacity development needs, with the responses recorded and reviewed as above.

Finally, informal internal discussions between the authors and their wider teams provided further insights into common challenges faced by students, researchers and managers, enabling factors, and possible pathways to strengthen offshore and deep-sea biodiversity research and management capacity in South Africa.

Challenges, barriers, and limitations

Factors challenging and limiting progress in deep-sea biodiversity research and management in South Africa were thematised into two broad groups, namely (i) entry into deep-sea biodiversity research and (ii) retention and progression in deep-sea biodiversity research. A number of the challenges, barriers and limitations identified in our case study are influenced by South Africa's history, in particular the legacy of apartheid. Apartheid laws such as the Bantu Education Act of 1953 and the Extension of University Education Act of 1959 discriminated against Indigenous Peoples and African cultures, deliberately segregating education by race and restricting Black students from white universities where marine science programmes were offered. This is a historic legacy shared by many other African countries as a result of colonisation. As a result of past laws of segregation, exclusion and discrimination, multiple sectors, including biodiversity, marine science and marine management, are still largely inaccessible to the vast majority of South African citizens, and there are significant societal barriers preventing participation and access to opportunities.

Challenges to entering the field of deep-sea research span a range of issues, from limited exposure to marine and deep-sea research, to unequal access to education and marine spaces, cultural barriers, and challenges in the inclusion of Indigenous and local knowledge. For the few that pursue studies in the field, the challenges of retention and career progression include securing a job in deep-sea science fields, a shortage of academic mentors, limited access to infrastructure to build a research career, a lack of funding to support research, and barriers in accessing and engaging in international research (Table 1, Supplementary Table S1). These barriers, challenges and limitations are explored here in further detail.

Entry into deep-sea biodiversity research

Limited exposure to marine and deep-sea research

Limited exposure to deep-sea science was identified as a major challenge by all participants engaged in these discussions. Until very recently, most school-going learners (i.e. 6 to 18 years old), had very limited marine, let alone deep-sea, content in their school curricula (e.g. Nyman 2018, Department of Basic Education 2020), with many only coming across marine biological studies during or after their tertiary education. Although the current national marine biology curriculum does include some basic deep-sea content and is officially in place, it is offered by only a small number of schools. In most South African universities, specialisation in marine biology is only possible in postgraduate studies, and even then, most students have limited, if any, exposure to marine

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Table 1. Summary of key barriers and challenges limiting participation and progress in deep-sea biodiversity research and management in South Africa, with illustrative participant quotes.

Barriers and challenges	Illustrative quotes
Barriers to entry and limited exposure to marine and deep-sea research	"I assumed that because I never learnt about the deep sea at university that it doesn't exist in South Africa"
	"I always dreamed of seeing the deep sea but even on websites and the internet we only ever saw pictures of the deep sea from developed countries"
	"I want to go to sea but I am so afraid. I feel if I could swim I might be able to cope but my parents always told us the sea is very dangerous"
Shortfall of financial and academic support	"When I was at University and even today, there isn't any local academic staff at any institution who can supervise postgraduate studies"
	"Even if I could study the deep sea, is there scope to find a local job in this field?"
Restricted access to vessels and technology for deep-sea research	"Sea time is REALLY hard to come by"
	"A lack of equipment or access to the technology to work in the deep sea is a major limitation"
Limited participation in international research	"International scientists often struggle to understand our technical limitations and it is sometimes a shock for them to experience our working conditions"
	"I don't want to engage in token partnerships. I would like to contribute to joint publications and earn co-authorship"

Further illustrative quotes are found in Supplementary Tables S1 and S2.

research beyond the shore, particularly field experience (Table 1). Some opportunities for shipboard training are available through the SEAmester course aboard South Africa's research vessel *SA Agulhas II*, but this has a strong oceanography and plankton sampling focus. While invaluable for open-ocean science, it does not currently provide exposure to visual survey techniques increasingly used in marine conservation. Of 31 participants, only one had ever experienced formal training in deep-sea science at university and none had offshore research experience beyond the continental shelf. Although some students in author-associated research teams are now benefiting from offshore field experience through nationally funded projects, this is generally not part of formal tertiary education, reflecting disparities in the experiences available to students at universities in the Global South compared to the Global North.

Inequitable access to education and marine spaces

Limitations in exposure to marine and deep-sea research are exacerbated by socio-economic factors, resulting in unequal access to marine environments and studies. Access to marine spaces has been constrained for certain groups through the historical legacy of Apartheid and the high costs of engaging in marine activities (e.g. transport and equipment). In terms of education, entering tertiary institutions is a major challenge for many students, where fees may be prohibitively high or poor schooling affects grades. In addition, Historically Disadvantaged Institutes (non-white universities and technical colleges established under the Apartheid Government), have significantly lower access to resources and infrastructure to provide opportunities for students to be exposed to or participate in offshore and deep-sea research. Such issues of representative participation and the need for an integrated and holistic approach to science in general are receiving global attention (e.g. Sowman and Malan 2018, Bennett et al. 2021, Valenzuela-Toro and Viglino 2021, de Vos et al. 2023), with an increasing focus on diversity and inclusion in the field of deep-sea research at a global scale (e.g. Amon et al. 2022b, IOC-UNESCO 2021, ISA 2022). Exacerbating access to education are language barriers, where most students must learn in their second or even third language.

Cultural barriers and challenges in the inclusion of Indigenous and local knowledge

The authors noted that Indigenous and local knowledge, including cultural and spiritual values, are often overlooked or undervalued in research planning, limiting the inclusion of diverse perspectives in research processes. Despite the significant ecological understanding of ocean environments embedded within Indigenous and local knowledge, this knowledge is frequently overlooked in marine research and management. This is an issue in many parts of the world (e.g. Loch and Riechers 2021). In addition, many African Indigenous cultures regard the sea as a sacred space, and out of reverence for its spiritual significance, interaction with the ocean outside of established norms is discouraged (Bernard 2013, Dold and Cocks 2014, Dunga et al. 2025). Some of the authors thus also cited cultural principles as contributors to a lack of engagement in ocean research. For some, their families expressed concerns over participation in marine research, often associated with cultural beliefs, the fear of the unknown, and limited familiarity with marine research and its methods. A perceived prerequisite

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to have formal swimming training was also an attributing factor to fear of drowning and discouragement to pursue marine research.

Retention and progression in deep-sea biodiversity research

Shortfall of financial and academic support

Students, researchers and research institutions in South Africa experience financial limitations that severely restrict not only access to, but also progression of, careers and research in offshore and deep-sea environments. In discussions, students reported that there are few bursary options and experienced supervisors available to support postgraduate studies. The near absence of senior academic staff within universities to lead offshore or deep-sea biodiversity research, secure funds and teach, mentor and supervise students and ECRs is a major gap preventing progress in deep-sea research in the country. In addition, for both early career and established researchers, access to funding for salaries, running costs, and analyses for deep-sea biodiversity research poses challenges. Some researchers reported that it is difficult to attract talent in order to contribute capacity in the field, and that in instances where talent is identified, there are often challenges in upskilling individuals as resources are very limited. The lack of financial support extends to poor job prospects, such that retention of students and ECRs in deep-sea research-related positions is untenable. These factors combine to contribute to a paucity of students and academics able to engage in deep-sea research. These obstacles disproportionately affect lower-income individuals who are more likely to be relied upon to support their extended families, thus deepening the divide in access to deep-sea research-related careers.

Restricted access to vessels and technology for deep-sea research

Institutes in South Africa without offshore vessels struggle to obtain access to ships and deep-sea biodiversity sampling technology. Competitive research calls at the national level allow some access to coastal vessels and technology; however, this is spatially and temporally limited, with access from a few ports on the east and south coast, and to only a few projects a year, with an average of 2–3 weeks of sea time per project per year. This limits research efforts in national waters. In addition, until 2025, capabilities for sampling beyond 1000 m were completely lacking for the research community in the country. Some observations beyond this depth have been made using new deep-sea landers, but this is very limited. The oil and gas industry has deep-sea geospatial data, and although progress has been made to share some of this data with the research community, the vast majority of potentially useful bathymetric, geological and imagery observations collected by industry are unavailable to South African scientists. These challenges of access to offshore research vessels and infrastructure deepen already significant global North-South inequalities in deep-sea biodiversity research.

Limited participation in international research

The disparity in access to funding, vessels, and infrastructure also applies to international research cruises where local scientists struggle to compete in international, competitive grants for research in both national and international waters. Uniform standards in competitive grants disregard current imbalances in skills, capacity, access to research infrastructure and academic leadership. Discrepancies in administrative capacity are also significant. Established researchers who were interviewed noted their lack of experience in managing large-budget international projects and administrative challenges linked to the discord in, for example, European Union and national grant management approaches and systems. Local research teams also frequently lack the infrastructure and technical and administrative support readily available to researchers at institutions in the Global North, such as high bandwidth internet connections, data storage and data management solutions, specifically cloud-based data repositories and data managers to manage large datasets.

Some of these challenges extend to the publication process, where developing country researchers experience significant challenges in publishing research due not only to constraints in carrying out research, but also high publication costs. In addition, reviewers frequently criticise work as too parochial or descriptive with limited, if any, appreciation for the significant challenges that need to be overcome in order to advance beyond this phase under current constraints. This translates to challenges in engaging in international conferences, where the deep sea is widely accepted to start at 200 m. Posters and presentations by local researchers have been rejected based on being “too shallow,” limiting conference participation, and making it difficult for local researchers to access networking opportunities and catch up with global standards. Research in Africa also often has an emphasis on socioeconomic benefits and community upliftment embedded in it, rather than a purely “discovery” framing—doing science for science’s sake. The latter is often perceived as more “prestigious” (even though funders are now increasingly interested in impact), further prejudicing against African research.

Finally, several participants reported that involvement of local researchers in international collaborations within national waters is sometimes limited or “token,” with difficulties accessing data even years after sampling has occurred despite local permit conditions. This phenomenon of “parachute science” has been recorded across the globe and is particularly rife in the context of deep-sea research, where restricted access to vessels and technology increase reliance on international collaborators (e.g. Rayadin and Buřivalová 2021, Stefanoudis et al. 2021, Amon et al. 2022a, de Vos 2022, Spalding et al. 2023, Polejack et al. 2025). In South Africa, there are also challenges in securing equal funding in international research partnerships, even when these are directed at capacity development and meeting needs of developing countries. If not addressed, these issues may continue to perpetuate existing capacity gaps.

Enablers and opportunities

Participating researchers identified several avenues through which the challenges outlined above could be addressed, including citing examples that are currently helping in this regard (Supplementary Table S2). These span interventions to broaden ocean literacy, mainstream deep-sea issues into national policy and research funding frameworks, improve representation in marine and offshore research and management, address funding and academic staffing challenges, support technology development,

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access and sharing, further industry collaborations, and reframe research partnerships and collaborations.

Invest in early and increased exposure

To overcome barriers to entry and limited exposure to marine and deep-sea research, ocean literacy programmes will be key. This could include incorporating the deep sea into curriculum content at all educational levels, including primary school and high school (secondary school), as well as undergraduate degree programs. This integration into formal education is expected to be more impactful than once-off capacity development initiatives (Johnson et al. 2021). Engaging with existing marine education organisations to incorporate deep-sea content in their materials is an achievable first step, and there are resources available online that could be drawn on for this (e.g. NOAA Ocean Exploration and Ocean Exploration Trust education resources, including lesson plans). Innovative science communication methods, such as live-streamed offshore research delivered in African languages via telepresence and remote-learning, could foster more inclusive and accessible platforms to engage diverse audiences in deep-sea science, while actively involving educators, communicators, and artists (e.g. Barnhill et al. 2023). It is important to note, however, that these and other online learning approaches identified below depend on reliable high-speed internet access, which remains a barrier in many contexts.

Existing opportunities for online learning in deep-sea research and cruise leadership can also provide valuable training, such as Ocean Discovery League's Accessing the Deep programme, and the Deep-Sea Expedition Leadership Master Class offered by the Crustal Ocean Biosphere Research Accelerator (COBRA), although these are mostly global in scope. Internships and at-sea training are next steps that would provide those with an interest in the deep sea valuable experience to support progression into deep-sea research and an opportunity to explore this as a career path. There are growing global opportunities for ECRs to receive at-sea training, including initiatives like the Nippon Foundation and Partnership for Observation of the Global Ocean (NF-POGO) Shipboard Training Fellowships, the Schmidt Ocean Institute berths of opportunity, and South Africa's SEAmester course. Increasing awareness of these opportunities amongst ECRs and encouraging applications will be important.

These programmes, however, tend to focus on training aboard large research vessels and so equally, if not more important for advancing national scientific capacity, will be the development of training programmes using smaller, locally accessible vessels and equipment, alongside the integration of practical, at-sea training into formal curricula. Existing international programmes can provide a starting point for the design of such programmes, although these would need to be adapted to local contexts (e.g. Brodte et al. 2025). Rethinking training approaches could also help to empower future leaders in the field. In 2023, a capacity development initiative under the One Ocean Hub project demonstrated an alternative model to training whereby ECRs designed, planned, executed and led a research cruise in South Africa's offshore environment (Adams et al. 2023a).

Finally, where access to ship time for student training and data collection is limited, alternative means of learning and applying deep-sea biodiversity research skills should be explored and incorporated into education (e.g. Sánchez et al. 2020, Barnhill et al. 2023, Daniels et al. 2025). The use of open-access deep-sea data can, for example, help to engage students in deep-sea research without requiring participation in research expeditions or at-sea data collection (e.g. McQuaid et al. 2020, McQuaid et al. 2023, Gerringer et al. 2023). Practical, confidence-building measures, including swimming classes and scuba training, may also help to reduce barriers to participation in marine and deep-sea research.

Built into all of the above should be diversified approaches to more inclusive and equitable training, piloting new approaches for capacity development and change that promote racial and cultural diversity. These must consider the safety of underrepresented groups and take steps to ensure safe working spaces at sea (Amon et al. 2022b, WOS 2021). These should also include efforts to acknowledge, respect, and include Indigenous and local knowledge, including cultural and spiritual values, within training, even when beliefs are not shared (Harden-Davies et al. 2022a, Bennett et al. 2021, Caldeira et al. 2025). Recently, open discussions about spiritual and ancestral connections to the sea within research teams created space for some students in South Africa to feel comfortable taking measures to pay respects as part of field operations during local expeditions (Morgera et al. 2024). Additionally, some researchers described their experiences in overcoming family concerns about deep-sea research, which were rooted in cultural beliefs, including through ceremonies and rituals and by sharing their journeys of discovery and learning in marine science with their families through various methods, such as storytelling and art (Morgera et al. 2024). Following this, some families started showing keen interest and support.

Strengthen financial and academic support

To address the shortfall of financial and academic support for offshore and deep-sea biodiversity research, targeted investment in people, posts and long-term institutional support is required. Established researchers in South Africa are actively seeking and creating opportunities for inclusion of ECRs in deep-sea research activities early in their careers to support skills transfer, preserve institutional memory and tackle gender and racial imbalances. However, dedicated bursaries (with criteria to support equitable opportunity and running costs), funded research positions and visiting fellowships are needed for ECRs to build technical and academic skills for deep-sea research. A key factor in realising this is academic champions who can lead research, secure funds, teach at universities and supervise students to support, in particular, postgraduate studies. This could be facilitated through the establishment of a dedicated deep-sea research chair (such as through the DSI/NRF South African Research Chairs Initiative), to drive long-term research, capacity development, and transformation. Funded visiting research positions for international researchers could also be important for skills exchange. Mentorship programmes connecting undergraduates, ECRs and established researchers, including international mentors, would provide opportunities for networking, sharing of knowledge and expertise, and support for professional growth. Development of new job posts and diversification of existing positions would support and secure local research talent, as would opportunities for ECRs to earn income

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while developing skills (drawing on examples such as the COBRA Deep-Sea Expedition Leadership Master Class or the Ocean Exploration Trusts' Science & Engineering Internship Program). Such initiatives are most effective when embedded within long-term, structured partnerships that combine academic training, practical research experience, mentorship and clear career pathways, thereby strengthening both individual and institutional capacity (Johnson et al. 2021).

The financial constraints underpinning many of the challenges identified in this perspective piece are partly linked to the relatively low profile of deep-sea research within national policy and research funding frameworks. Mainstreaming efforts to raise the profile of deep-sea research in national policy and research funding frameworks will therefore be important. Greater engagement with leaders and decision makers is required to communicate the rationale, needs and benefits of deep-sea biodiversity research for ocean management, to prioritise deep-sea research and capacity in national strategies and plans in complement of economic aspirations. Prioritising the field in national policy and research strategies could increase funding allocations for research-related activities, including scholarships and bursaries, academic positions, travel support, and funding for local deep-sea research efforts (including for technology development). This should include criteria and requirements to support equitable opportunity and promote racial and cultural diversity. Beyond supporting ocean management in-country, national policy can support institutional capacity to uphold South Africa's leadership position in international ocean science through promoting and prioritising South African evidence in national, regional and international decision-making.

Increase access to vessels and technology

To address the infrastructural barriers to deep-sea biodiversity research, access to vessels and technology for the research community must improve, building on the progress already made. Procurement of such equipment requires increased national funding (including the mainstreaming efforts mentioned above) and both national and international collaboration. Additional research calls for competitive access to existing vessels and technology, with emphasis on integrated research to meet multiple objectives, will be important. For example, linking monitoring to capacity development is one recommended approach for multiple benefits (Bax et al. 2018). In the coastal zone, an analogous programme is the previously mentioned ACEP that specifically supports competitive multidisciplinary projects. ACEP provides research infrastructure, technical support, bursaries and running costs.

While international funding is also needed to support participation in collaborative research and access to international research infrastructure, developed country participation in developing country research under local conditions with local equipment will also be key to making the most of international collaborations. Such partnerships can support the development of new, low-cost technologies for deep-sea research that are appropriate for local contexts (e.g. Bell et al. 2022b, de Vos et al. 2023). This is a growing field globally, with opportunities to learn from international researchers and build new collaborations (e.g. Phillips et al. 2019, Dominguez-Carrió et al. 2021, Giddens et al. 2021, Amon et al. 2022a, Bell et al. 2022b, Motsenbocker et al. 2024). National and international working groups could support sharing of experience, knowledge, technology and protocols.

Finally, partnerships amongst local researchers and between academia, government and industry to support innovation and technical development will be key to building local infrastructure capacity and increasing depth capabilities. Efforts should be made to build new relationships between academic staff and institutes with access to vessels and technology, particularly with Historically Disadvantaged Institutes. In addition, improved industry collaboration can help to ensure that scientific knowledge keeps pace with emerging industries. This is most apparent in the petroleum industry, where work is already occurring in depths beyond those where biodiversity research has taken place. The value of industry data has been recognised, and the South African research community is now leveraging opportunities to obtain deep-sea data for ecosystem classification, mapping, assessment and spatial planning. However, as noted in similar contexts elsewhere globally (e.g. Lue Chin et al. 2026), industry collaborations to improve access to technology, seagoing opportunities and development of local expertise will be important.

Transform collaborations

To respond to the barriers to meaningful participation in international research and inclusion of Indigenous and local knowledge, radical transformation of research collaborations is needed. The integration of Indigenous, local and Western scientific knowledge is increasingly being recognised in global policy (e.g. the BBNJ Agreement; IOC-UNESCO 2021, CBD 2024), with successful examples of this approach influencing marine conservation and management in different parts of the world, such as Canada (Beaty et al. 2024, Du Preez et al. 2024), Hawai'i (Quiocho et al. 2023), New Zealand (Paul-Burke et al. 2020, Brough et al. 2025) and Rapa Nui (Aburto et al. 2020). Although challenging, when grounded in principles and practical safeguards that protect both Indigenous and local knowledge and the people who hold it, such approaches can produce more equitable research collaborations and contribute to more effective and locally appropriate marine conservation and management (e.g. IOC-UNESCO 2026). This approach is recognised in the new BBNJ Agreement, which has key provisions on the inclusion of relevant traditional knowledge of Indigenous Peoples and local communities (e.g. BBNJ Agreement, art. 7 and throughout the other Parts of the Agreement), while there is growing discourse around the need to better address this in South Africa's marine spatial planning processes (Metuge 2024, Dunga et al. 2025).

To ensure more equitable international research partnerships between developed and developing nations, a fundamental shift in attitudes and approaches is needed to build a shared understanding of what meaningful collaborations look like. This is a crucial step towards ocean equity, which has been highlighted across the globe (e.g. Rayadin and Buřivalová 2021, Stefanoudis et al. 2021, Mwampamba et al. 2022, de Vos et al. 2023, Spalding et al. 2023, Polejack et al. 2025). Such collaborations should involve meaningful participation across all phases of research, including co-development and co-design of research questions and programs of work, shared leadership, equitable funding arrangements, mutually beneficial data

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collection and sharing, and joint analysis and publication of results (Rayadin and Buřivalová 2021, Woodall et al. 2021, de Vos et al. 2023). This is important for two-way knowledge sharing, but more importantly, to ensure that research partnerships in the waters of developing nations are guided by, and deliver meaningful benefits to, local researchers and institutions (Rayadin and Buřivalová 2021, Woodall et al. 2021, Mwampamba et al. 2022, de Vos et al. 2023). Co-developed partnership principles, or codes of practice, can be used to clarify expectations and support effective collaboration (e.g. UNDESA 2019). As mentioned, co-developed programmes in developing countries working under local conditions with local vessels and technology will be important. This would expose international collaborators to local constraints and would help to avoid scenarios where local researchers are trained in the use of technology that cannot be accessed, maintained, or operated nationally (Harden-Davies et al. 2022b).

The new BBNJ Agreement has a dedicated section on Capacity-Building and the Transfer of Marine Technology (CBTMT, Part V) that places emphasis on inclusive and equitable participation in marine scientific research, including through country-driven, transparent and participatory approaches. These provisions reflect calls for the need to build equitable partnerships for long-term outcomes (Harden-Davies et al. 2022b). Opportunities for redress on a global scale also include changes to funding agreements, standards in competitive grants and the publication process that take into account current imbalances in skills, capacity, access to research infrastructure and academic leadership.

Recommendations

From our findings, we have distilled recommendations to support the development of deep-sea biodiversity research and management capacity in South Africa. Many of these mirror recommendations made in comparable contexts around the world (e.g. Amon et al. 2022a, de Vos 2022, Caldeira and Lopes 2023, de Vos et al. 2023, Lopes et al. 2026). These are presented under five themes, addressing the interconnected challenges previously identified: exposure and training; mainstreaming; funding; research infrastructure; and partnerships and research collaborations. These recommendations are also framed for different audiences (funders; science managers, environmental managers, and decision makers; local scientists; international collaborators; students; and industry) in the Supplementary Material (Supplementary Table S3).

Exposure and training

These recommendations respond primarily to barriers to entry in deep-sea research, particularly limited exposure to deep-sea science, inequitable access to marine education, and cultural barriers to participation.

1. Implement existing and develop new ocean literacy programs, curriculum content, and science engagement programs to support early and increased exposure to deep-sea-related content during school and tertiary education, including diversified content to recognise and foster existing ocean connections.
2. Develop dedicated, diverse training approaches and opportunities for ECRs to build technical, academic and other relevant skills while earning, including dedicated bursaries, internships, at-sea training, remote learning, swimming classes, scuba diving and mentorship arrangements.
3. Encourage ECRs and postgraduate students to mentor undergraduate students.
4. Encourage public engagement with marine and deep-sea biodiversity research, including through live-streaming and social media.
5. Acknowledge, respect and include Indigenous and local knowledge, including cultural and spiritual values, within training programmes, even when beliefs are not shared.

Mainstreaming

These recommendations respond to the underrepresentation of deep-sea biodiversity research within national policy and funding frameworks and the resulting constraints on sustained financial and institutional support.

1. Communicate to decision-makers the rationale, needs, and benefits of increased deep-sea research and management capacity in addition to the risks and consequences of maintaining the status quo.
2. Embed deep-sea biodiversity research in national research strategies and priorities to ensure investment in capacity building and development of long-term job opportunities and building of institutional capacity.

Funding

These recommendations address the shortfall of financial resources for research, academic support, technology, and equitable collaborations.

1. Invest in foundational deep-sea science, including integrated taxonomy.
2. Invest in the acquisition of deep-sea sampling technology.
3. Provide dedicated bursaries and funding (with criteria to support equitable opportunity and promote racial and cultural diversity) for ECRs and managers to build academic, technical and management skills through tertiary education and participation in training.
4. Fund research chairs, academic champions and other positions within universities for senior academic staff to mentor and develop ECRs and actively participate in deep-sea biodiversity research.
5. Provide funding to enable greater participation and collaboration with international partners, visits for international researchers in South Africa, and access to international research cruises.
6. Ensure funding reduces inequity in research partnerships and supports co-designed, collaborative research and equitable, meaningful partnerships, including with Indigenous Peoples and local communities.
7. Ensure developing countries are eligible to receive funding for project time. This may involve including developing country institutes on lists of eligible organisations for various funding instruments.

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Research infrastructure

These recommendations respond to infrastructural barriers identified, particularly restricted access to vessels, deep-sea sampling technology and associated technical support.

1. Develop innovative local technology and encourage sharing of technology and effective protocols with national and international partners.
2. Provide access to vessels (including national vessels capable of deep-sea research) and technology through competitive research calls, dedicated programs, local and international platforms and partnerships.
3. Develop technical working groups to coordinate research efforts, foster innovation, fast-track sharing of protocols, technical solutions and standardised methods.
4. Develop shared infrastructure platforms that integrate research to meet multiple objectives for added value.
5. Strengthen and expand infrastructure for the curation, management, and long-term preservation of South Africa's deep-water biological collections, including the consolidation of existing collections and the development of bio-banking facilities.

Partnerships and research collaboration

These recommendations address barriers to equitable research collaborations and limited academic support . They also recognise the importance of considering Indigenous and local knowledge and values within deep-sea research and management, while acknowledging that this area warrants further substantive development.

1. Transform international collaborations to be co-led, with co-developed research questions and plans, shared data that are mutually beneficial, joint analysis and joint outputs, including sampling under local conditions with local vessels and gear.
2. Ensure funding of local participants' time on international projects during initial engagements and clarify expectations in international partnerships to ensure institutional alignment.
3. Ensure that sufficient support is provided to local collaborators not only for project work but also to meet complex international reporting and administration requirements.
4. Increase national collaborations between academics and institutes or industry partners to unlock vessel and infrastructure access, with particular consideration of Historically Disadvantaged Institutes.
5. Acknowledge, respect and include Indigenous and local knowledge, including cultural and spiritual values, within research and management, even when beliefs are not shared.
6. Establish working groups to build the knowledge base around key themes, to standardise approaches for broader benefits, build capacity and to strategically advance key areas of research.
7. Foster mentorship arrangements between researchers, students and managers both nationally and internationally.
8. Support the supervision or co-supervision of developing country students by experienced researchers from developed countries.

Discussion

Although South Africa faces constraints in conducting and applying deep-sea biodiversity research, it has made important progress in developing and harnessing technology in the 200–1000 m depth zone. As the country strives to grow its economy in marine industrial sectors such as fisheries, petroleum and seabed mining, it must simultaneously consolidate and advance its research capacity and expertise into deeper waters to inform decision-making.

This perspective paper brings together reflections from the research and management community in South Africa to provide a practitioner-informed view of the factors shaping national deep-sea biodiversity research and management capacity, including both the barriers that constrain it and the opportunities that may strengthen it. We highlight how interconnected challenges across funding, infrastructure, human capacity and partnerships collectively influence the country's ability to generate and apply deep-sea knowledge, providing a foundation for prioritising future capacity-strengthening interventions. This work is timely and perhaps urgent as South Africa fast-tracks its ocean economy and opportunities are emerging to build on recent progress.

Although the reflections presented here are drawn from a select group of deep-sea biodiversity researchers and managers in South Africa, and are inevitably shaped by the participants' own experiences and positionalities, many of the challenges and opportunities identified echo those documented elsewhere in Africa (Bell et al. 2022a, McQuaid et al. 2024). In particular, recent assessments found that funding, human capacity and access to vessels are major constraints on deep-sea research across Africa, while training and improved access to technology and data tools have been identified as key opportunities for strengthening capacity (Bell et al. 2022a, McQuaid et al. 2024). Many of the challenges in this perspective piece are also shared with developing nations under economic pressure beyond the African continent (e.g. Bourrel et al. 2018, Amon et al. 2022a, Caldeira and Lopes 2023, de Vos et al. 2023, Spalding et al. 2023, Lue Chin et al. 2026). Outside of deep-sea research specifically, African conservation scientists working across disciplines have reported funding constraints, inadequate institutional support, administrative challenges, and inequitable international partnerships as persistent barriers to conducting research and developing capacity on the continent (Mwampamba et al. 2022). While grounded in the South African context, our reflections illustrate challenges likely to be shared by other nations in Africa seeking to strengthen capacity for deep-sea biodiversity research and management, although these will be country and context specific. In the future, research should examine how systemic barriers that undermine capacity might be removed, rather than mitigated through capacity development interventions.

The implications of the capacity challenges identified in this paper extend beyond research and management within South African waters, to the country's engagement in the governance and use of areas beyond national jurisdiction (ABNJ). While South Africa has played an active role in international ocean governance processes in ABNJ, contributing to negotiations under the BBNJ Agreement and in the work of the International Seabed Authority (IISD 2022, DFFE 2025, ISA n.d.), increased deep-sea research capacity will be important for supporting the country's

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full and effective participation in ABNJ-related activities (Harden-Davies et al. 2022b, Salpin et al. 2016, Vierros and Harden-Davies 2020, Caldeira and Lopes 2023, RSA 2023). Many of the potential solutions identified here, including access to infrastructure, knowledge and data sharing, and awareness-raising, are reflected in the types of CBTMT set out in Article 44 and Annex II of the new BBNJ Agreement, from which South Africa may benefit. Emerging knowledge-sharing initiatives such as the International Platform for Ocean Sustainability (IPOS) may also help improve access to the knowledge and evidence needed to support participation in international ocean governance (Harden-Davies et al. 2024).

In South Africa, the national legislative framework to necessitate increased deep-sea research is in place through the National Environmental Management: Biodiversity Act (10 of 2004) and the Marine Spatial Planning Act (16 of 2018), but implementation to date has been limited. This collection of reflections proposes a way forward for addressing some of the key challenges that continue to constrain progress; however, a dedicated strategy is needed for co-ordinated implementation of the recommendations. This could include a more detailed inventory of infrastructure and current skills, a road map that plans the way forward in a phased approach and a focus on resources including budgets and infrastructure to develop and transform human capital for effective deep-sea biodiversity research and management in South Africa and the region. Building on South Africa's growing success in offshore and deeper waters, both in terms of infrastructure and technical skills acquired, there should be continued investment in developing this capacity to further depth capabilities in a stratified approach, by bringing a deep-water focus to existing and new national and regional research strategies, programs, and initiatives. This should include national marine research strategies, National Biodiversity Strategies and Action Plans (NBSAPs), research infrastructure and platforms, and research funding or access programmes. International initiatives under the UN Decade of Ocean Science for Sustainable Development (2021–2030), such as the Challenger 150 Programme and its African Network of Deep-water Researchers, together with the new BBNJ Agreement, also present potential pathways to leverage support to strengthen capacity for deep-sea biodiversity research in South Africa and the wider region.

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Author contributions

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Supplementary material

Supplementary material is available at *ICES Journal of Marine Science* online.

Conflicts of interest

None declared.

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