Challenges and Solutions to develop capacity for Deep-sea Research and Management in South Africa

Kerry Sink[1,2], Kirsty McQuaid[1,3], Lara Atkinson[4,2], Ryan Palmer[5,6], Grant Van der Heever[4], Prideel Majiedt[1], Loyiso Dunga[1,2], Jock Currie[2], Robyn Adams[1,2], Michele Wahome[7], Kerry Howell[3] and Angus Angus Paterson[5].

1 South African National Biodiversity Institute
2 Institute for Coastal and Marine Research, Nelson Mandela University
3 University of Plymouth
4 South African Environmental Observation Network
5 South African Institute for Aquatic Biodiversity
6 African Coelacanth Ecosystem Program
7 Strathclyde University

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Executive Summary

After more than a century of global research in the deep ocean, many international collaborations and rapid expansion in deep-sea research outputs, the deep sea in South Africa remains poorly studied with insufficient information, funding, infrastructure, specialists, capacity, and expertise to support deep-sea research and management. This situation not only prevents sound environmental management but limits South Africa's potential to derive benefits from the deep sea. Key obstacles that limit exposure to and participation in the field of deep-sea research include financial, technical and academic capacity challenges, cultural barriers, limited exposure to the deep sea, a lack of access to ships and deep-sea research infrastructure, the perceived irrelevance of the deep sea, and uniform standards in competitive grants and the publication process that disregard current imbalances in skills, capacity and academic leadership. Key pathways of entry and enablers to improve deep-sea research and management capacity include exposure to the ocean and deep sea, dedicated financial support, access to vessels and training, diversity in training approaches and models, academic champions, and mentorship. Further recommendations to support capacity development and transformation in South African deep-sea research are detailed and include five key themes:

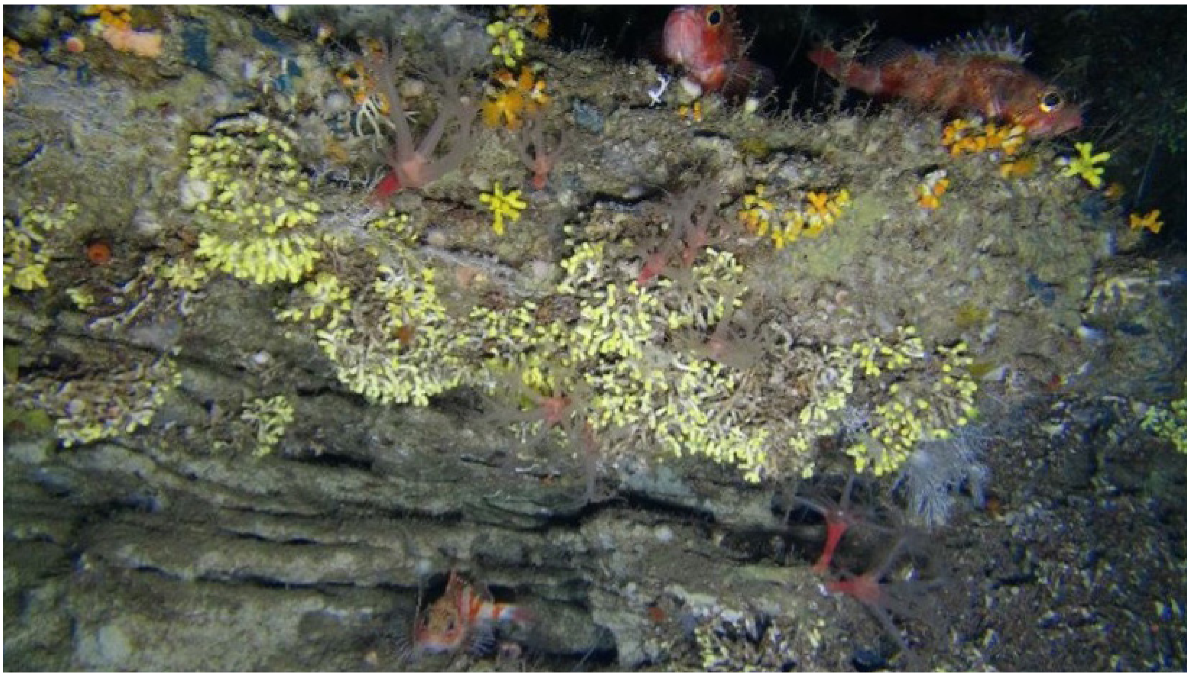
- Mainstreaming to raise the profile and clarify benefits of deep-sea research and effective management
- Exposure and diverse training opportunities for lasting capacity development
- Funding to increase opportunities for education, training, collaboration, monitoring and job security
- Partnerships and research collaboration that promote co-developed, co-led and co-published research
- Technology and infrastructure development, sharing and access

These detailed recommendations are also given for various audiences including:

- Funders (page 34)
- Managers & decision makers (page 35)
- Local scientists (page 36)
- International collaborators (page 36)
- Students (page 37)
- Industry (page 37)

A dedicated strategy is advised for South Africa that can plan for and support the implementation of these 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 research and management in South Africa.

Table of Contents



Deep water corals in Gxulu Canyon support essential fish habitat, ACEP Deep Forests Project.

Full Abstract

The deep sea in South Africa remains poorly studied with insufficient information to underpin the sound environmental management needed to support an expanding ocean economy. Many other countries face similar challenges in developing sustainable ocean economies and there are new global efforts calling for more inclusive and equitable deep-sea science and management. There are frequent requests to share developing country priorities in this context and plans to support such efforts should draw from an understanding of the challenges and opportunities to develop this field. This report examines the South African experience in terms of the key obstacles that limit exposure to and participation in deep-sea research and management, possible pathways to increase entry into the field and proposed actions to improve deep-sea research and management capacity.

In line with global definitions, the deep sea is defined as the ocean depths beyond 200m. South Africa is a maritime nation with territory in three oceans and the deep sea constitutes more than 80% of mainland ocean territory. Despite this, knowledge to support environmental management and spatial planning in the deep sea is inadequate. The current in-country situation reflects very limited local capacity to engage in or apply deepsea research, with efforts to date focused on fisheries and oceanographic research. Most deep-sea sampling has been achieved by international parties, frequently with limited local collaboration. In the last two decades, research effort in the deep sea has declined due to funding limitations, attrition of taxonomic research and expertise, and changing governance arrangements and mandates in fisheries and ocean research and management. Some progress has been made through competitive research calls and the application of towed cameras, deep water drop-cameras and a Remotely Operated Vehicle that has now effectively sampled the seabed within its 300m depth capability. Two tow cameras, rated to 700m, are advancing ecosystem classification and mapping and the understanding of the impacts of key pressures in this depth range. These platforms are collecting valuable imagery, but further investment is needed to extend the sampling depth range, efficiently process and analyse data through the application of modern methods and technology, and integrate data for maximum benefit.

Key challenges and limitations that are hampering the development of deep-sea research and management efforts in South Africa were distilled through interviews with 31 South African scientists, students and managers, in addition to panel and other dedicated discussions in multiple online events in 2020 and 2021. These discussions also covered enabling factors and potential solutions for redress.

Barriers include financial, technical and academic capacity challenges, cultural barriers and challenges linked to integration of traditional knowledge, limited exposure to the deep sea, a lack of access to ships and deep-sea research infrastructure, the perceived irrelevance of the deep sea, poor job prospects and uniform standards in competitive grants and the publication process that disregard current imbalances in skills, capacity and academic leadership. Key pathways of entry and enablers include exposure to the ocean and deep sea, dedicated financial support, access to vessels and training, diversity in training approaches and models, academic champions and mentorship, and mainstreaming efforts to raise the profile of deep-sea research and management. Changes in funding arrangements and international collaborations to enable more equitable research partnerships could play a particularly transformative role in the development of deep-sea capacity in developing countries.

Recommendations to support transformation, improved representation and long-term capacity development in South Africa are detailed by theme and target audience. These are relevant to funders; scientists; science managers, environmental managers, decision makers; students; industry and policy makers. Recommendations span opportunities for redress in ocean literacy, training, job profiles, career development,

technology, national and international partnerships and the science-policy continuum. These efforts should be underpinned by clearer communication of 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. This should enable the inclusion of deep-sea research in national strategies, ensure investment in deep-sea capacity development and transformation, development of long-term job opportunities and institutional capacity in this context. Implementation of these recommendations will allow South Africa to effectively support its emerging ocean economy in a sustainable development framework and with long-term benefits. A dedicated national strategy that plans for implementation of these recommendations in a phased approach is needed to ensure that the resources, infrastructure and human capital exist to support effective deep-sea research and management in South Africa.

Introduction

Despite more than a century of research in the deep ocean, many international collaborations and rapid growth in global deep-sea research outputs, there are few (marine) research fields where such deep inequality in research, funding and outputs continue to persist. Global efforts are needed to better understand and address this legacy, particularly considering the diversification and intensification of marine pressures. Increased capacity and knowledge are needed if South Africa is to effectively support an emerging ocean economy and manage emerging pressures including deepwater petroleum activities, deep-sea mineral exploration and exploitation, offshore aquaculture and overexploitation of shared marine resources.

Background

New international projects, particularly in the Atlantic, have provided opportunities to reflect on and address the current situation for offshore and deep-sea research in South Africa, and there are persistent requests to identify national capacity development needs. The UK Research & Innovation (UKRI) funded One Ocean Hub (OOH) , in particular, has lent impetus to such efforts along with many internal and local discussions, including those sparked by new collaborations. The Horizon 2020 iAtlantic and Mission Atlantic Projects have both expressed an interest in supporting local capacity development and in addition, the developing Challenger 150 initiative and other initiatives linked to the United Nations Decade of Ocean Science for Sustainable Development are working to support capacity development with calls for input from developing countries. In this report, capacity is considered as ''the ability of people, organizations and society as a whole to manage their affairs successfully'' and capacity development as "the process whereby people, organizations 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).

The importance of the deep sea in South Africa

Often referred to as earth's inner space, the deep ocean is frequently framed as the last frontier on earth. Generally considered to constitute those areas deeper than the 200m depth contour, the deep sea covers 65% of the planet surface and more than 95% by volume (Rogers et al. 2015). This realm is increasingly being recognised as crucial in the provision of various ecosystem services that support human well-being, including

[2] https://oneoceanhub.org/ [3] https://www.iatlantic.eu/ [4] https://missionatlantic.eu/ [5] https://challenger150.world/

supporting, provisioning, regulating and cultural services (Thurber et al. 2014, Plate 1 and 2). In South Africa, 85% of our mainland ocean territory falls within the deep sea.

Globally, economic drivers and developing technology have led to the expansion of fisheries, oil and gas production, and imminently seabed mining in the deep sea, with activities such as renewable energy and carbon capture and storage garnering increasing interest (Rogers et al. 2015). Potential for economic growth linked to the deep sea is considered significant, with many governments including plans for expanding activities in the deep sea in their Blue Economy strategies (Novaglio et al. 2020). South Africa is a maritime nation, with territory in three oceans, and increased industrial activity in the deep sea has been identified as a priority by the South African government, as demonstrated by the inclusion of an Oceans Economy Lab in Operation Phakisa , an initiative aimed at unlocking the economic potential of South Africa's oceans. Sink et al. (2019) summarise trends in ocean use and note the expansion and diversification of activities in South Africa's offshore environment (Figure 1 and 2).

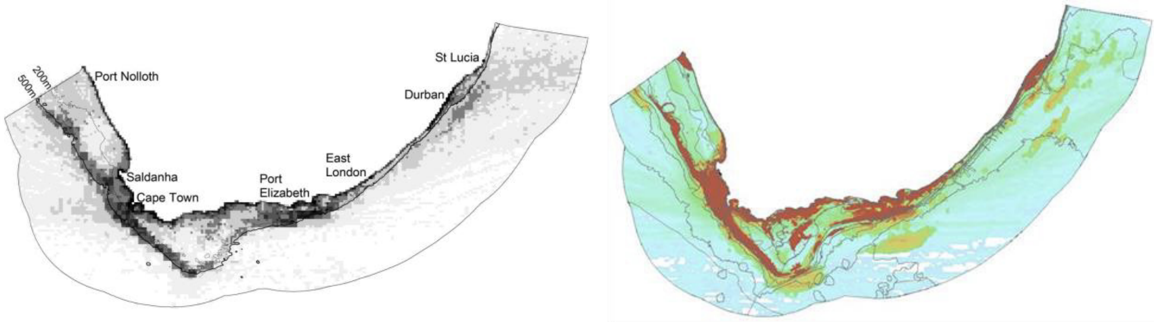


Figure 1. Cumulative pressures in South Africa's ocean territory as reflected in the National Biodiversity Assessments of 2011 (left) and 2018 (right). Maps from Sink et al. 2019.

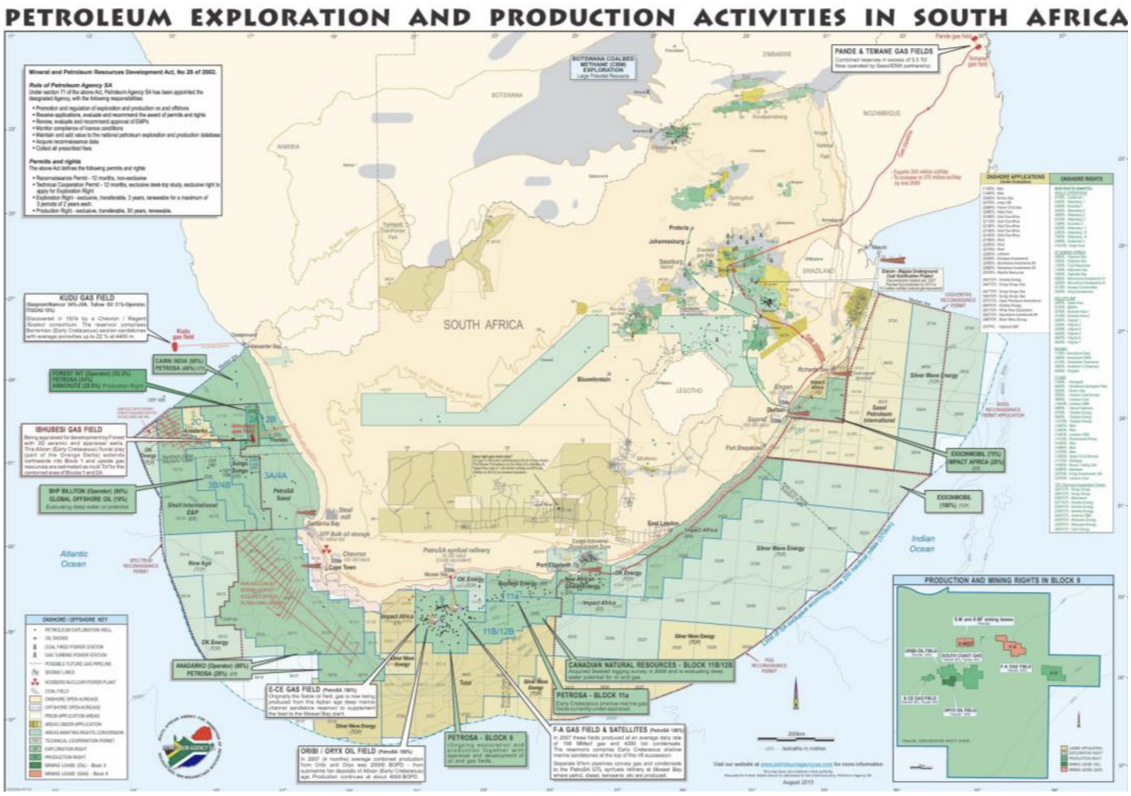


Figure 2. Peak petroleum exploration and production activities in South Africa's Exclusive Economic Zone. Expansion of this sector is a key objective of the Operation Phaksia Oceans Economy Initiative. Map downloaded from the Petroleum Agency South Africa (2013).

[6] https://www.operationphakisa.gov.za/operations/oel/pages/default.aspx

With the advent of industrial expansion in the offshore environment, scientific capacity is crucial to support the management of emerging activities. Responsible and sustainable exploitation of deep-sea resources requires a deep understanding of the risks posed by increased industrial activity to ecosystems and the services they provide, and this is dependent on the acquisition and application of science and technology. In addition, there are potential benefits that South Africa may fail to derive, such as marine natural product discovery, should the lack of knowledge and capacity in deep-sea research persist. Scientific knowledge gaps, including those resulting from a lack of capacity, hinder decision-making (Rogers et al. 2014) and there is general agreement that marine scientific research and access to technology are critical for sustainable development (Vierros & Harden-Davies 2020).

A. B. C D.

Plate 1. Although the deep sea is often thought of dark, remote and irrelevant, deep-sea ecosystems provide many ecosystem services, including supporting and regulating services like carbon storage and nutrient cycling services provided by habitats such as deep-water coral (A) and sponges (B) (ACEP Deep Secrets Project), provisioning (see Plate 2) and spiritual and cultural values (C). Some Nguni cultures consider the most powerful ancestors to reside in the deep sea (ACEP Deep Connections). Deep-sea biodiversity provides a living library of genetic resources that may hold benefits to humans and be critical to future adaptation. Most of these lace coral, soft coral and stony coral samples collected from the deep sea off East London (D) are endemic meaning they are only found in South Africa (ACEP Imida Project).

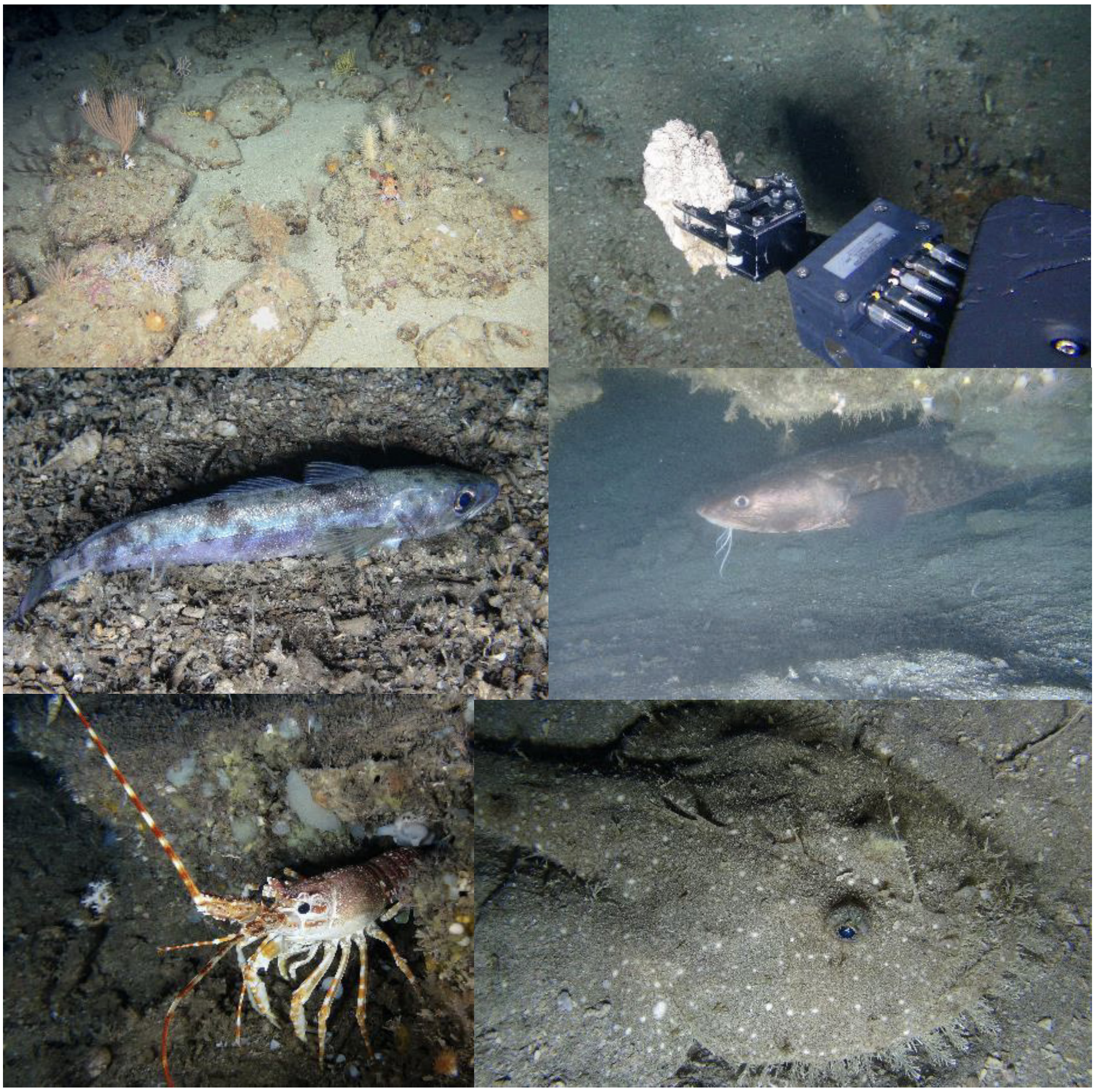


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Plate 2. Important deep-sea taxa that provide benefits to South African society include species with important compounds like this hemichordate (A) Cephalodiscus gilchristi which has produced one of the most powerful compounds ever tested against cancer and sponges which are explored for their biodiscovery potential (B). Economically important deep-sea fisheries resources include hake Merluccius spp. (C), kingklip Genypyterus capensis (D) deep-water rock lobsters Palinurus gilchristi (E); and monk Lophius spp. (F). Images from ACEP Deep Forests and ACEP Deep Secrets projects.

As South Africa strives to grow its economy in marine industrial sectors such as fisheries, petroleum and seabed mining, it should therefore simultaneously increase deep-sea capacity and expertise. Through the National Environmental Management: Biodiversity Act (10 of 2004), the South African government has a mandate to promote research on biodiversity conservation, including sustainable use, protection, and conservation of indigenous biological resources (para. 50). The government must also designate monitoring mechanisms and set indicators to determine the conservation status of South Africa's biodiversity and any negative or positive trends affecting this conservation status (para. 49). Furthermore, the Marine Spatial Planning Act (16 of 2018) provides a framework for marine spatial planning in South Africa that includes establishing a knowledge and information system to house information to develop marine area plans and must include information on ecological processes (para. 7(1a)). The national legislative framework is thus in place to necessitate increased deep-sea research, and provision of scientific advice, which is essential as a key informant of decision making in this context, will depend on this.

Finally, South Africa is a key stakeholder in areas beyond national jurisdiction (ABNJ) and is often considered a leader on the African continent in the context of work linked to international conventions and negotiations. However, participation in these processes can be impeded by a lack of scientific and technological capacity (Salpin et al. 2016) and increased national capacity in deep-sea research is thus essential to support continued participation in international processes.

Aims and audience for this report

This report aims to examine the South African experience in terms of the key obstacles that limit exposure to and participation in deep-sea research and management, pathways of exposure and entry into this field and proposed actions to improve deep-sea research and management capacity in South Africa. The intended audience includes those interested in capacity development including funders, local researchers, international collaborators, science managers, policy makers, educators and students who are working to help build this capacity. The report also aims to provide a record of discussions to date for further planning and deliberation, including ongoing transdisciplinary research conducted by the One Ocean Hub and other collaborative research initiatives.

Offshore and deep-sea research in this context refer to research beyond the 50m depth contour (offshore), or beyond the 200m depth contour (deep sea), with a focus on research to understand the biodiversity, ecosystems and vulnerabilities, to inform ocean environmental management. Local research in these depths to date has focused on important fisheries resources and oceanography (see overview of current state of knowledge and capacity below), and these aspects are not considered in detail in this report which focuses more on biodiversity and ecological research to guide environmental management. South Africa has excellent fisheries scientists and fisheries are generally considered well managed, although the need for broader ecosystem-based approaches in fisheries management is recognised (Sink et al. 2019).

Current state of knowledge and capacity

History of deep-sea research in South Africa

Historically, international and local research in the deep sea relied on international co-operation and expeditions. In the late 1800s, the Challenger expedition, led by British scientists, was probably the first expedition to sample the deep waters in South Africa, collecting information on the physical characteristics of the seafloor and water column, as well as sampling the biological community off the Cape of Good Hope. Historical government-led surveys from research vessels began under the leadership of John Gilchrist in 1897 (Department of Agriculture 1897) and later (1926 onwards) by his successor, Cecil von Bonde (von Bonde 1928). These surveys were focused on seeking viable fishery resources but also documented broader biodiversity at times (Currie 2017). Consisting mostly of trawl surveys, they routinely sampled depths up to about 400m in the 1930s and on a few occasions collected samples from beyond 500m depth (e.g. von Bonde 1933, Director of Fisheries 1949).

Later, in the 1960s and 70s, several research cruises led by America's National Oceanic and Atmospheric Administration also visited South Africa's deep waters and collected geological samples together with limited black and white imagery of the seafloor. At the same time, local research cruises focussed on sampling biodiversity began off the west coast of South Africa, resulting in qualitative (mainly taxonomic) data which formed the basis of local knowledge of deep-sea systems (Anderson & Hulley 2000).

Data reflecting the distribution of deep-sea taxa in South Africa is sparse with information for fish (Anderson & Hulley 2000), crustaceans (Barnard 1950, Griffiths 1976, Day 1978, Kensley 1978, Beyers 1994), hydroids (Millard 1966, 1975), polychaetes (Day 1967), molluscs (Herbert ref, Gosliner 1987) and echinoderms (Clark and Courtman-Stock 1976). Research efforts in the 1980s were focussed mainly on fisheries resources and systematics and taxonomy (Lang & Griffiths 2014). Additional annual research trawl surveys for stock assessment are carried out by the Department of Forestry, Fisheries and Environment (DFFE) to depths of 800m with occasional trawls to 1000m and even 1500m (Anderson & Hulley 2000). Aging research vessels and survey time constraints (linked to increasing financial constraints) have diminished efforts below 800m in the last two decades. In addition, institutional and governance changes in terms of fisheries and ocean and coastal management mandates (changes in government ministries and responsibilities) led to reduced efforts on aspects beyond fisheries stock assessment surveys.

Institutional landscape and capacity

Many institutes are engaged in marine research in South Africa, including government, state-owned entities, universities and NGOs. South Africa's Department of Science and Innovation (DSI) through the National Research Foundation (NRF) have implemented research instruments to develop marine research, including the South African Research Chair Initiative (SARChI), Centres of Excellence (CoE), South African National Antarctic Programme (SANAP) grants, African Coelacanth Ecosystem Programme (ACEP) grants and South African Network for Coastal and Oceanic Research (SANCOR) grants. SANAP and ACEP are the most relevant in the context of the deep sea.

The South African Institute for Aquatic Biodiversity (SAIAB), a National Facility of the NRF, places a strong emphasis on research platform provision. Through ACEP, SAIAB provides competitive access to marine research infrastructure, technical support and funding, but this is largely limited to supporting coastal research due to technical and logistical constraints. The discovery of coelacanths in South Africa led to the first submersible surveys and later the acquisition of a Remotely Operated Vehicle (ROV) (Plate 3). Currently, ACEP infrastructure includes coastal craft (that operate up to 40nm offshore) and an ROV that operates to a maximum depth of 300m. Their development of deep-water (1000m) landers (currently in use for collecting baited remote underwater video (BRUV) samples) is an example of their intention to expand research capability into deeper water. ACEP, which is funded by the DSI but has a longstanding partnership with DFFE, facilitated access to ship time on the RV Algoa, which has enabled offshore and deep-sea research in the past. SANAP is another DSI/NRF and DFFE funded programme that facilitates offshore and marine research by providing competitive access to research infrastructure. However, it is restricted geographically to Antarctica, the Southern Ocean and Prince Edward Islands. Despite the opportunities provided by the above programmes, much of South Africa's deep sea remains inaccessible to the broader research community and technology for sampling bathyal (1000m - 4000m) and abyssal (>4000m) systems is lacking. Nonetheless, the value of these types of programmes and the ensuing partnerships cannot be overemphasised. SAIAB is currently piloting a collaboration with the Faculty of Engineering at Nelson Mandela University, to work on technical challenges associated with deep-sea research, and new infrastructure or equipment developed through this collaboration will be available to researchers through ACEP.

The South African Environmental Observation Network (SAEON), a Business Unit of the NRF, provides a national observation network for long-term environmental research, with a focus on global change in South African ecosystems and societies. Of seven SAEON nodes, two are focused on the marine realm; an inshore node and an offshore node. SAEON's offshore node undertakes a substantial amount of oceanographic research and leads an initiative to monitor offshore invertebrates during DFFE research trawls (see Atkinson and Sink 2018) and a five-year experimental closure to examine the effects of closing an area to trawling in the deep sea of the western margin of South Africa. Progress made through research enabled by the SAEON tow camera is detailed below.

DFFE has offshore research vessels and some deep-water research infrastructure such as a tow camera system rated to 700 m. Up until the recent past, this department had a predominantly fisheries focus in the marine realm, and research on deep-sea biodiversity beyond fisheries species was limited. The Oceans and Coasts Branch of DFFE have undertaken some deep-water biodiversity research on the west and south coasts and with the recent re-merging of fisheries and ocean and coastal management branches with the environment department, the biodiversity and integrated ecosystem research may continue to grow. The South African National Biodiversity Institute (SANBI) is an entity of DFFE. SANBI leads work to map and assess marine ecosystems in South Africa by collaborating with researchers and students who can contribute (Sink et al;. 2019, Skowno et al. 2019). SANBI accesses vessels and infrastructure through ACEP, collaborations with DFFE and SAEON, and is increasingly pursuing international collaborations in this context.

Deep-sea research progress to date

SAEON acquired a tow camera in 2013, with DFFE having a similar system, first configured and used as a jump camera in the Southern Ocean territory in 2012 but later adapted to a similar configuration as the SAEON tow camera (Plate 3). These cameras, rated to 700m, have been used to conduct foundational research on the outer shelf and slope through provision as an ACEP platform, to support the benthic trawl experiment on the western margin and are supporting multiple postgraduate student research projects. Both tow cameras and their associated technicians contributed to valuable baseline surveys of the outer shelf and slope of the Agulhas ecoregion as part of the ACEP Deep Secrets cruise in 2016 and in 2019, the SAEON system supported similar deep-sea research on the western margin (Currie et al. 2019). In addition, the SAEON tow camera conducted the first deep-sea surveys in the Prince Edward Islands supporting research projects, post graduate student studies and the recent National Biodiversity Assessment (Whitehead et al. 2019).

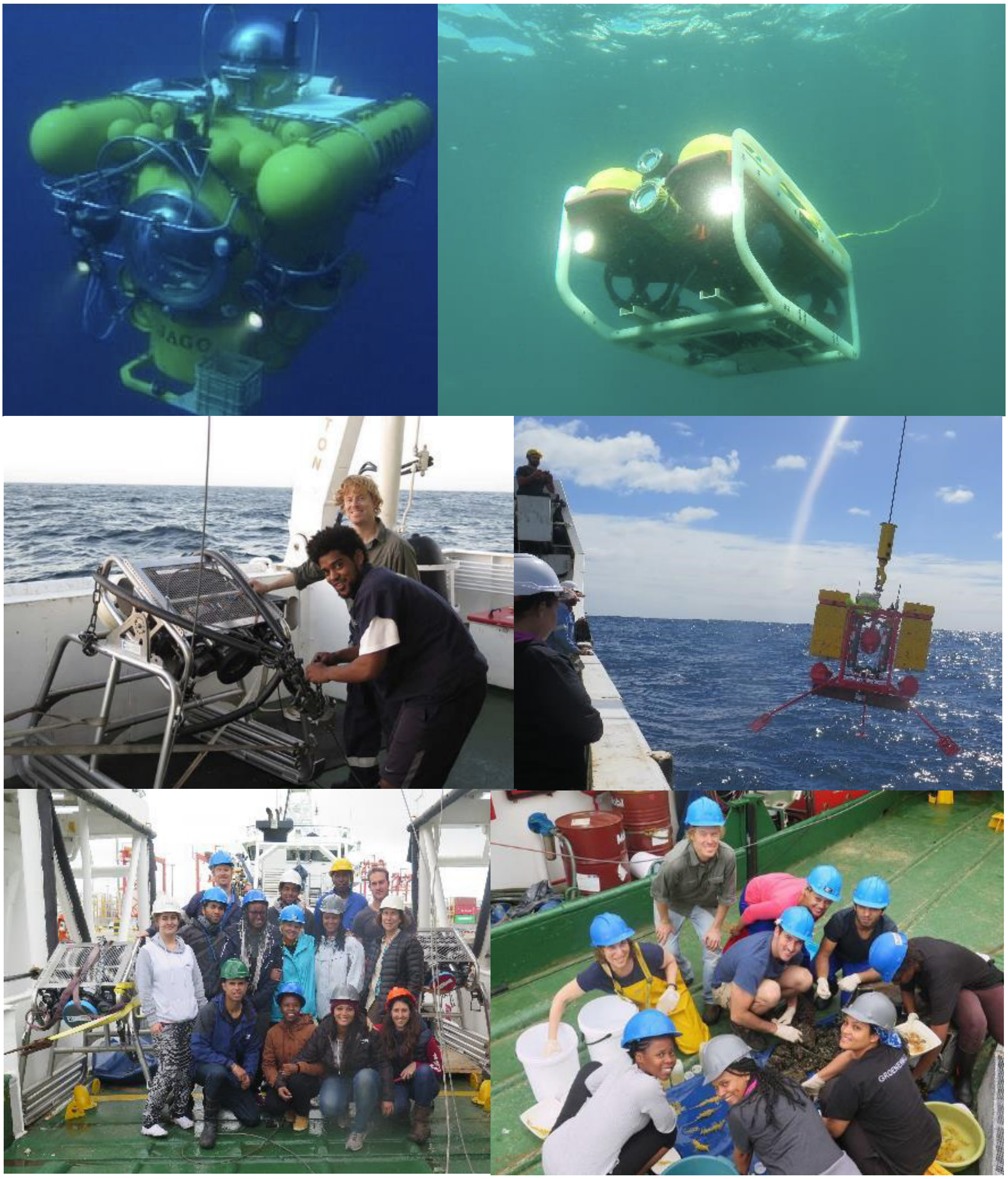

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Plate 3. Deep-sea research in South Africa has advanced through access to specialised infrastructure such as the Jago submersible during coelacanth expeditions in 1990 and 2002-2005 (A) and the (B) Remotely Operated Vehicle that researchers can access through the African Coelacanth Ecosystem Programme (ACEP), tow cameras such as those used for a SAEON led trawl recovery experiment (C), and (D) the SAIAB Deep water Baited Remote Underwater Video (BRUV) systems. Cruises that include a focus on deep sea capacity development such as the ACEP Deep Secrets Cruise (E) where international researchers such as Prof Lisa Levin (F) participated in local expeditions are a great approach for developing local capacity within existing resource and infrastructure constraints.

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Plate 4. The ACEP ROV being deployed during the ACEP Deep Forests Survey in the Eastern Cape (A) where it recently surveyed at its 300m maximum depth limits with this image showing a stalked Hyalonema glass sponge and jacopever Halicolenus dactylpterus from 290m (B). The ACEP ROV has now successfully collected a range of marine invertebrates including sponges, soft and hard corals, seafans and lace corals (C) and this unidentified seapen (D) which will contribute to research for MSc student Sinothando Shibe (F).

South Africa's first research application of a ROV was in 2005 when this technology was applied to investigate feasibility for coelacanth surveys and canyon exploration in the iSimangaliso Wetland Park in northern KwaZulu-Natal (Sink and Scott Williams 2005). The ROV succeeded and ACEP acquired a SeaEye Falcon ROV in 2009 (Plate 3). This has enabled visual survey work to a depth of 300m and has helped to expand research capacity from scuba diving depths (typically less than 30m) to the mesophotic (30-200m) and to a limited extent into the deep sea (200-300m). ACEP researchers and technicians have steadily increased their depth capabilities (Figure 3, Plate 2 and 3) and the application of the ROV in multiple disciplines and fields. These include foundational biodiversity research at the ecosystem, species and molecular level; geoscience research; bio-discovery and chemistry; pollution research; ecosystem assessment and recently maritime archaeology. In the ACEP Deep Forest project cruises of 2021, the ACEP ROV reached the 300m depth limitation for the first time and extended both the depth and range of specimen collections (Plate 4). The maximum depth of specimen collection is now 130m and the ROV has successfully collected sponges and cnidarians (scleractinian stony corals, stylasterine lace corals, alcyonarian soft corals, pennatulacean seapens and antipatharian black corals). Collections are constrained by technical limitations in terms of sampling and storing multiple specimens at depth with the ROV required to return to the surface after every collection. These collections have facilitated bio-discovery research, taxonomic research and are supporting novel molecular approaches using environmental DNA. In addition, work is underway to develop local capacity to advance image analysis including through the application of artificial intelligence.

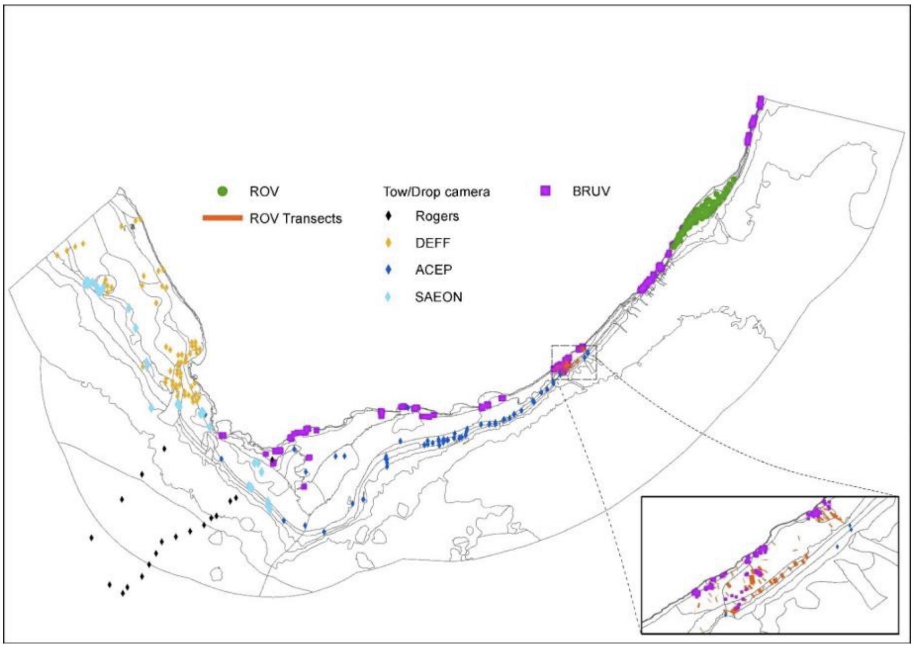

Figure 3. Overview of in-situ visual research activities that supported efforts to classify, map and assess marine ecosystems in South Africa's most recent National Biodiversity Assessment (Sink et al. 2019). The progress in surveys on the outer shelf and the poor coverage in the deep sea are evident.

As underwater cameras become more cost effective and accessible, their use, mounted on a range of platforms, is expanding rapidly, both globally and in South Africa. Their application in the study of marine ecology frequently requires the identification of fauna and flora from images or video, without a physical sample that can be scrutinised by trained taxonomists. As such, the identification of organisms from videos and photographs is an important limitation and skill that influences the efficacy of studies and monitoring programs that rely on underwater imagery. Even without the identification to species level, taxonomic units or morpho-species can contribute valuable assemblage and ecosystem information, if they can be consistently discerned. Because discernible taxonomic units are frequently assigned different names among different research groups or projects, the resulting outputs are not compatible for comparison of results among projects or regions, nor in terms of combining the data for broad-scale analyses. The creation of a standardised reference image database across the region (and eventually globally) has multiple advantages, which include the utility it provides in training students in para-taxonomy; the ability to easily extract information for creating an identification guide for a certain area or taxonomic group; improved data quality and consensus on difficult faunal identifications; and greatly improved scope for integrated datasets and broad-scale analyses if everyone calls the same animal by the same name. For this reason, the creation of a regional underwater reference image database for Southern Africa, funded initially through the One Ocean Hub, is being used to extract faunal images from the towed camera footage collected during the west coast visual survey (Currie et al. 2019), identify the organisms and enter the data into two tables as per the recommendations of Howell et al. (2019).This effort represents the initiation of a large and long-term regional effort that will require coordination among research groups and institutions across country borders. We are aware of approximately 550 visual survey stations (not including historical JAGO footage) conducted in South Africa in the last two decades, representing many hours of video and thousands of images yet to be added to this collection. Researchers and students have frequently created their own ad-hoc reference image sets and where possible, these should be integrated into this regional and standardised structure.

SANBI and SAEON have also engaged in industry collaborations facilitated through the Offshore Marine Area Project, the Offshore Environment Forum and South African Marine Research and Exploration Forum (SAMREF). Co-operative research and some sampling or data acquisition has been achieved through collaborations with the trawl industry and the oil and gas industry, with failed attempts with the diamond mining sector in this context. Collaborations with individual companies (PetroSA, Anadarko and Total) have yielded valuable sediment, seabed imagery and bathymetric samples (Sink et al. 2010, Palan et al. 2020, Plate 5). There is opportunity to increase industry collaborations in this context with the vast majority of potentially useful bathymetric, geological and imagery data collected by industry being unavailable to South African scientists.

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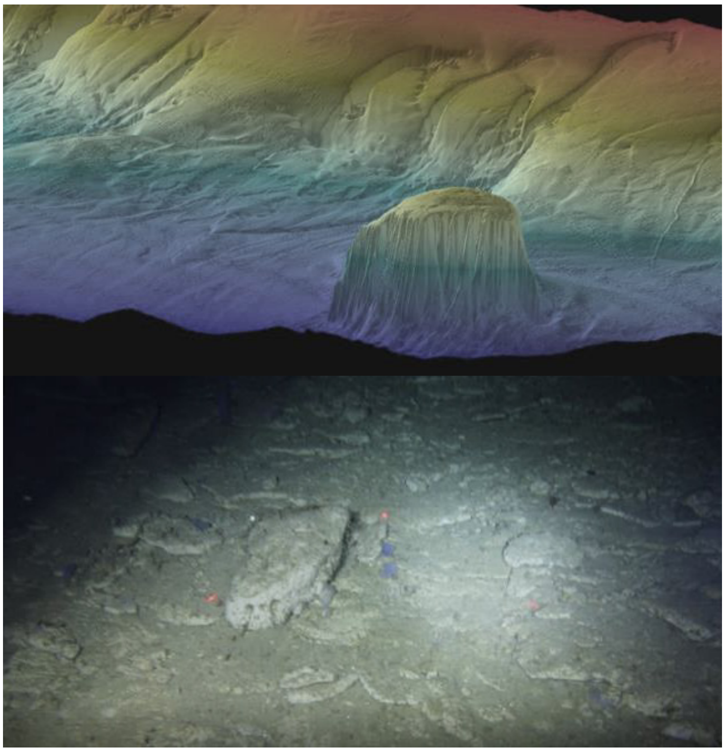


Plate 5. Valuable data from the petroleum industry is supporting mapping of deep-sea ecosystems such as canyons, seamounts and slopes (A) (data provided by Anadarko and Total to the ACEP Deep Secrets project). Palan et al (2020) used this data to study seafloor morphology, fluid flow and associated pockmarks showing how these features may control mass wasting and the development of distinctive seafloor morphologies such as submarine canyons. Recently, seep carbonates were filmed by tow camera in the 600-700m depth range representing an important opportunity for marine scientists in investigating chemosynthetic communities and seep habitats that have not yet been reported in South Africa.

Fisheries and oceanography have been the focus of most offshore research efforts to date and these disparate efforts are difficult to summarise. Griffiths et al. (2010) collated sampling effort data for marine invertebrates as part of the Census for Marine Life. They reported that 83% of the more than 2500 samples collected by dredge, grab and trawl are from water shallower than 100m and less than 1% were from water deeper than 1000m (Figure 4). Unfortunately, these records were unavailable after the census leading to renewed efforts to collate and integrate marine biodiversity data.

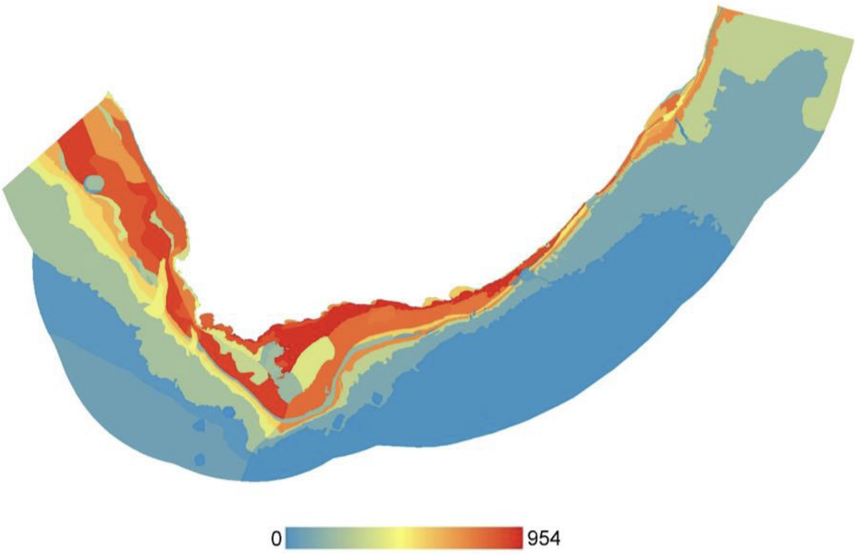


Figure 4. Heat map reflecting the number of data points per ecosystem type from the most recent National Biodiversity Assessment (Sink et al. 2019. Data density clearly decreases with depth.

To our knowledge, 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. Geologist Professor John Rogers photographed abyssal habitats using a camera in an underwater housing in 1998 (see Figure 3), with evidence of manganese nodules in the South African abyss. Although these deep systems are not currently targeted by any human activities in South Africa, there is increasing global efforts and interest in mining such minerals, both in international (ISA 2021; Petersen et al. 2016) and national waters (Miller et al. 2018). Considering the presence of deep-sea minerals in South Africa's abyssal ecosystems, there is potential that mining may occur in the future. The environmental impacts of seabed mining are currently poorly understood (Jones et al. 2017), although these are expected to be long lasting and lead to a loss of biodiversity (Niner et al. 2018). Effective environmental management of a deep-sea mining industry would require substantial national expertise in abyssal systems, something which is currently completely lacking in South Africa.

Overall, much of the research in the South African deep sea to date has been undertaken by international scientists or by industry stakeholders, with little if any local collaboration. In the case of industry surveys, research has focused on the interests of individual companies or single government departments and data or results have remained unpublished, largely inaccessible and often confidential. As such, deep-sea research has been undertaken in an uncoordinated and fragmented manner. Industrial development is often pursued without sufficient regard for other sectors, whose activities may be spatially incompatible. Some detailed bathymetric maps and datasets have however been shared by some industry stakeholders and these have been used by students and researchers to make significant contributions to our knowledge of South Africa's offshore systems (Sink et al. 2019, Palan et al. 2020).

A deeper understanding of the deep-sea environment and ecosystems, considering all industrial sectors, is clearly needed to ensure optimal and sustainable development of industry in South Africa's deep sea. It takes many years to build the capacity and knowledge to develop and manage activities in the deep sea and if South Africa is to achieve this, more effort is needed to develop research and management capacity in this context. Efforts to develop such capacity should be informed by the current challenges detailed in this report and should note the extensive time required to build up relevant knowledge in this context. South Africa's Marine and Antarctic Research Strategy aims to help address this problem, however there are many obstacles that need to be addressed to achieve this effectively.

Approach to identify key challenges and solutions

Challenges and enablers for deep-sea capacity development were distilled from three main sources: preparation and discussions for the 2020 Wonders of the Deep Session held as part of the online UN World Ocean Week events arranged by the One Ocean Hub (Appendix 1); dedicated internal discussions among authors and associated emerging researchers and students; and discussions within the new Atlantic project teams (iAtlantic and Mission Atlantic) to identify local priorities for capacity development in line with those project goals. In addition, discussions held as part of other online conferences and sessions in 2020 contributed to the conversation. These include a Sustainable Oceans Alliance online seminar (21 May 2020) and associated discussions on African perspectives on deepsea mining featuring South African advocate Thembile Joyini, and an IUCN DOSI webinar that aimed to build ambition for the new High Seas or Biodiversity Beyond National Jurisdiction (BBNJ) Treaty, focused on Marine Genetic Resources and ensuring developing country benefits (5 June 2020). A total of twenty-seven local scientists and post graduate students and four managers provided information and insights to support this report.

Key challenges, barriers and limitations

The discussions and presentations held to date helped to expose different challenges experienced in marine research in South Africa in general, and in deep-sea research and management in particular. Many of these challenges are linked to South Africa's history and are relevant to national challenges linked to the need for transformation. 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 barriers preventing general access to participation and opportunities. Transformation of these sectors is required as well as with the people that serve these sectors. In this context, SANBI considers sustainable transformation as a process of profound and radical change that orients an organization in a new direction and takes it to an entirely different level of efficiency and effectiveness, and implies a change of character, values and ethos that bear little or no resemblance with the past configuration, structure or values.

Barriers for entry and exposure to the deep sea include deficiencies in exposure and training; financial challenges; challenges in terms of access to vessels and technology; cultural barriers, challenges in the integration of traditional knowledge and limitations experienced in terms of accessing and engaging in international research (Table 1).

[7] https://www.youtube.com/watch?v=nGnGBdbRTjg

Limited exposure to deep-sea science was a major challenge for all South African researchers, students and managers engaged in these discussions. Only one of 31 participants ever experienced formal training at university in deep-sea science, and there are clear disparities in the experiences available to deep-sea students at universities in the 'global south'. Most researchers and students in South Africa have had limited, if any, exposure to marine research, especially field experience, beyond the shore (Table 1), with this situation most serious at the Historically Disadvantaged Universities. Transformation challenges persist in marine research in general and the additional challenges in terms of access to offshore research vessels and infrastructure deepen these already significant challenges in deep-sea research. Issues of representative participation in science in general is receiving global attention (for example, see a recent publication from Latin America, Valenzuela-Toro & Viglino 2021), with a renewed focus on diversity and inclusion in the field of deep-sea research being increasingly recognised at a global scale. In this South African analysis, none of the researchers had offshore research experience beyond the shelf in their training and some researchers did not receive any marine biology training before the commencement of their PhDs. Although, students in the relevant research teams were now benefiting from offshore field experience through ACEP projects, including the ACEP Deep Secrets cruise, in most cases, this was not part of their formal tertiary education. Two discussants had gained experience in the Antarctic surveys led by DFFE.

Students, researchers and the research institutions that host researchers experience financial limitations that severely restrict offshore access. Institutes without offshore vessels such as SANBI and SAEON struggle to obtain access to ships and deep-sea sampling technology. This disparity in access to vessels and technology also applies to international research cruises where local scientists struggle to compete in international competitive grants for both local research but also in the high seas. The limited access to these facilities and technology hampers our ability to conduct research in our own waters and participate in research beyond national jurisdiction. The very high cost of deep-sea research is a well-established and understood phenomenon and is not elaborated on further in this report.

Some of these challenges are exacerbated by economic interests in the deep sea, particularly in the context of petroleum and minerals. Because development is often driven by corporate funding that transcends political boundaries, but research funding and opportunities much less so (if at all), there is a dangerous disparity growing between the knowledge needed to inform management decisions and the pressures to exploit the deep sea of developing countries. This is in addition to the pressure to develop economically and grow job opportunities in these same countries.

Some emerging researchers also cited cultural barriers that may contribute to a lack of participation in ocean research and field work. Several indigenous cultures regard the sea as sacred, and swimming is discouraged out of reverence to spirits and ancestors who reside there (Bernard 2013, Dold and Cocks 2014). Culture and belief can be shaped by traditional knowledge and although there may be challenges in the integration of traditional and scientific knowledge, this is important. During discussions with students and interns, some noted limited opportunities for formal swimming training and an instilled fear of drowning as barriers to marine research. Some young marine biologists reported that their families expressed concerns that using cameras in the deep sea may be unsafe and disrespectful, but others shared their experiences in overcoming this by convincing their families of the importance of work at sea and explaining the precautions taken to do research in a safe and respectful manner. Recently, open discussions about spiritual and ancestral connections to the sea allowed some students to feel more comfortable in undertaking measures to pay respects during field operations, such as during recent ACEP expeditions. Often, traditional, cultural and spiritual values from some cultures are dismissed by others but acknowledging, respecting and accommodating such values is important within research teams even when beliefs are not shared.

There are also challenges in terms of engaging in international research and conferences, and in securing equal funding in research partnerships, even when these are directed at capacity development and meeting needs of developing countries. Limited field experience in deep-sea research due to financial, vessel and technological capacity makes it challenging for local researchers to participate in deep-sea conferences where the deep sea is usually considered to start at 200m. Posters and presentations by local researchers have been rejected on these grounds, limiting conference participation, and making it difficult for local researchers to catch up with global standards.

Finally, a further difficultly is that uniform standards in competitive grants and the publication process disregard current imbalances in skills, capacity, access to research infrastructure and academic leadership. Developing country researchers experience significant challenges in publishing research due to constraints imposed by vessels, equipment, limited sea time and other inequalities across the north-south axis. Reviewers frequently criticise work as too parochial or descriptive and it is a significant challenge to advance beyond this phase under current constraints. Taxonomic limitations are relevant in this context and discrepancies in administrative capacity and constraints are also significant. Even established researchers in this field noted their lack of experience in large budget international projects and administrative challenges linked to the discord in for example EU and national grant management approaches and systems. Lastly, the small research teams in South Africa frequently lack the infrastructure and technical support taken for granted by researchers at leading institutions, such as high bandwidth internet connections, data storage and data management solutions. These challenges, if not addressed, may continue to perpetuate the current situation.

Table 1. Illustrative examples of key challenges and barriers to deep-sea capacity development, from key informant interviews.

Barriers and challenges	Illustrative quotes
Limited exposure to the offshore environment and the deep sea at school, home and at universities	"We don't know anything about our deep sea, especially in our own country. We can't teach kids about things we know nothing about" "I never learnt a thing about the deep sea in my whole 6 years at University. There wasn't a single mention in a lecture, a seminar, not even in a guest lecture. It was as though we don't have a deep sea in South Africa" "I assumed that because I never learnt about the deep sea at university that it doesn't exist in South Africa" "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" "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 had no idea we had deep water coral reefs and all these animals until ACEP and DEFF scientists started sharing local images. These are so inspirational. It is so encouraging to believe that there are still things that I might discover" "When I was at University and even today, there isn't any local academic staff at any institution who can supervise post graduate studies. Although there are researchers outside of academic institutes who are willing to play this role there is no-one based at a University who has sufficient experience to lead and develop this field. Current academic staff have limited experience in this field and lack confidence to lead projects and students in this area of research"
Challenges due to limited access to vessels and technology.	"We never had any opportunities to go to sea at university not even in honours. We once went on a boat in an estuary and that was a highlight" "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" "I really wanted to study offshore but my supervisor told me that in this competitive world it is more sensible to work in an accessible ecosystem where you can get your own data. He was right at that time but this is something I want to make sure is not the same for future generations in South Africa. Sandy beach and rocky shore biology is excellent in South Africa and provides critical information for ecosystem and resource management but we also need information for beyond the shore. "

Barriers and challenges	Illustrative quotes
Lack of job prospects and limited scope for research, impact assessment and management in the deep sea	“As far as I know, there is not a single department, laboratory or research group in South Africa, perhaps Africa, with a focus on biodiversity in the deep sea.” ‘’Even if I could study the deep sea, is there scope to find a local job in this field?” “Petroleum companies generally hire international consultants to undertake scoping work and assessments and this means that local evidence is often excluded from assessments and reduces opportunities for local consultants.” “’There is very little information provided to managers about deepsea. Working groups focus on coastal issues and deep sea matters are not raised’’

Barriers and challenges	Illustrative quotes
Barriers in terms of international collaboration and research outputs	"Just because we are from Africa we worry that our science may not be up to standard or that we can't get there. We need to build international relationships with the right people but making these connections is difficult. We are mindful of approaching busy people and don't want to add to their workloads" "International research cruises provide exposure to technology that we can't access and are unlikely to be able to afford. Although it is a privilege and it is inspirational to participate in such projects, there is an element of frustration in that we çan seldom work with this gear. International scientists often struggle to understand our technical limitations and it is sometimes a shock for them to experience our working conditions.'' "I actually felt like I didn't belong at the Deep Sea Biology Symposium. When people asked me what I did and I explained our work with Remotely Operated Vehicles focused in the 50-150m depth range, some responded that this doesn't technically qualify as the deep sea. There is a limited appreciation of our vessel and technical constraints, conditions or circumstances". "I don't want to engage in token partnerships. I would like to contribute to joint publications and earn co-authorship. Even in 2019 we have had scientists tell us that we don't need to be involved in data analysis but not to worry because our names will be included on outputs. "I was privileged to be exposed to deep-sea technology early on in my career but even though the research was taking place in our waters, the gear and equipment belonged to international partners who directed its use. We struggled to obtain a copy of the data collected and there are several instances where even though this was a requirement in permit conditions, no copy could be obtained. Even now, requesting copies of data collected in our country can be unsuccessful. In 2019, in planning an international cruise, I was asking whether copies of deep-sea footage from local waters would be available and international partners explained this wouldn't be feasible until much later in the project after data analysis was completed. When trying to suggest that a copy should remain in South Africa when the vessel left the local port, a researcher replied that they had never had to do that before." "Despite deep inequalities in access to funding and research infrastructure, equal standards apply in grant application and publication processes. Even when local progress is made, international journals often reject research outputs as too parochial".

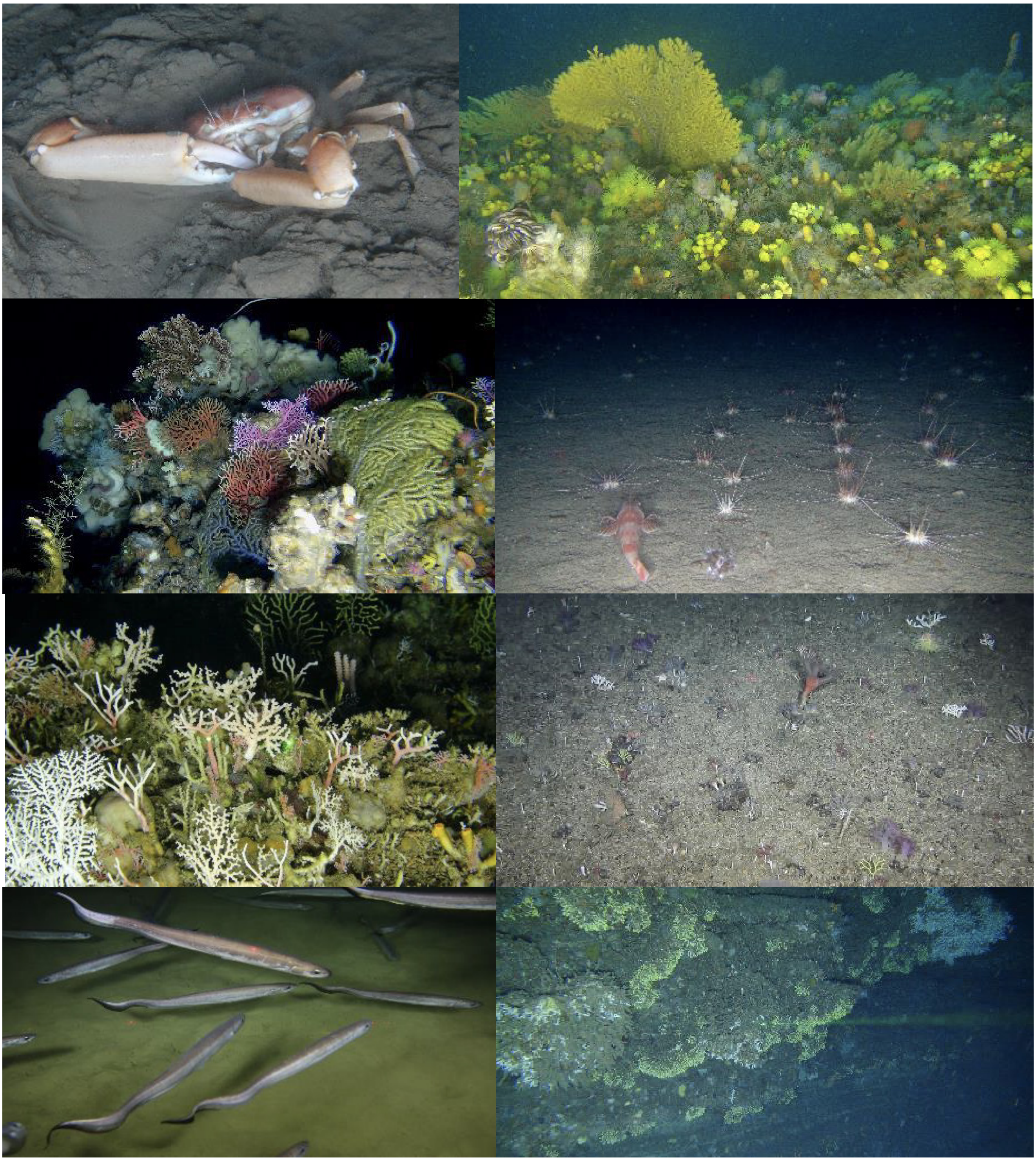
Key enablers and opportunities

Participating researchers identified several avenues by which the challenges outlined above could be addressed, including citing examples that are currently helping in this regard (Table 2). These span interventions to broaden ocean literacy, include deep-sea content in teaching and training at all levels, improve representivity in marine and offshore research and management including through targeted capacity development initiatives, address funding challenges, further industry collaboration and modify international research partnerships and collaborations.

The following key elements in enabling capacity development were identified:

- **Exposure** at primary school and inclusion of deep-sea content in the new marine science curriculum (high school).
- **Training** through inclusion of deep-sea content in undergraduate courses and opportunities to develop and transform deep-sea capacity in post graduate studies.
- **Academic champions** who can lead research, secure funds, teach at universities and supervise students. A deep-sea research chair should be considered.
- **Dedicated funding** opportunities including bursaries for students, conference sponsorship, travel support and opportunities for local researchers to lead local deep-sea research efforts. • Research experience for emerging researchers to build academic and technical experience.
- **Mentorship**, including international mentors such as the new program developed by the Deep Sea Biology Society.
- New opportunities to **access vessels and technology**. The African Coelacanth Ecosystem Program provides a competitive call for access to ROVs and is a good model. South Africa needs to increase depth capabilities and access to existing deep water research equipment.
- **Technological development** and sharing, including sharing of designs for low-cost cameras and other technology that can support local infrastructure. Other key areas for technological improvements include data flow, management and storage, computer vision and machine learning, genetic research (eDNA) and biotechnology.
- **Develop local, shared infrastructure** platforms and integrate research to meet multiple objectives for added value. Linking monitoring to capacity development is one recommended approach for multiple benefits (Bax et al. 2018).
- Deep-sea research **science engagement** including live-streaming of offshore research with a dedicated science communication component.
- Increased **industry collaborations** to ensure scientific knowledge keeps pace with emerging industries. The petroleum industry is already working in depths beyond those where biodiversity sampling has taken place.
- New and **equitable international research partnerships** with co-developed research questions and plans with international partners with equal funding. These should include developed country participation in developing country research (under local conditions with local vessels and gear).
- Dedicated **training cruises** and piloting new approaches for capacity development and transformation.

- 'Each one teach one' approach for sharing **mentorship**, training, co-authorship and access to instruments and funding opportunities when international scientists plan to conduct research in developing countries.
- Prioritisation of oceans' research and maritime capacity in **national strategies and plans** to complement economic aspirations and support South Africa's leadership on these topics.



A B
C D
E F
G H

Plate 6. Deep water ecosystems recently showcased in the MzanSea Ocean Literacy initiative (www.mzansea.org.za) including muddy shelves (A); mesophotic reefs (B,C); sandy shelves (D); slope ecosystems such as these rocky and gravel slopes (E,F) in the Southwest Indian Ocean (F); sandy slopes in the Southeast Atlantic (G) and submarine canyons such as Gxulu canyon (H) with it's cold water corals off East London (ACEP Deep Secrets, Spatial Solutions and Deep Forests Projects and the SAEON led benthic trawl experiment team).

Table 2. Illustrative examples of helpful elements in developing capacity and research partnerships for offshore and deep-sea research and management, as discussed in key informant interviews.

Potential solutions	Illustrative quotes
Building ocean literacy, including the deep sea, in curriculum content and undergraduate degrees and offering opportunities through internships, atsea experience and in postgraduate study	“Being able to see the South African deep sea opened my eyes and my mind. I got drawn in and now I want to help others see and visualise our offshore environment in three dimensions” “If I never did an internship at SANBI, I wouldn’t have seen the ocean in South Africa. These images need to be shared more widely. All South Africans deserve to see the deep-sea environment” “We need to recognise existing connections to the ocean and diversify ocean literacy efforts. Exposing young people to the deep sea will not only open up options in marine careers but can help ensure that people care about the deep sea. If you don’t know something exists you cannot care about it” “Although we may not be able to host dedicated deep-sea post graduate studies, South Africa is making progress in including elements of deep-sea work in some projects and is striving to develop skills that can be applied when local scientists are able to have increased access to the deep sea”
v	“We need human diversity for us to be able to penetrate and understand the diverse issues we are dealing with. There is not going to be enough knowledge if we are not including as much diversity as possible. And for people like Kerry Howell and Kerry Sink, the responsibility lies with you - as leaders in this field – to make sure that there are opportunities, to make sure that we advocate for this diversity. Can you imagine a team of scientists sitting around one table discussing how best to conserve a specific ecosystem- remember all the different ideas that can be brought to the table when all these different backgrounds are represented?” “Different models of training need to be considered when training developing country scientists. Taking people with deep-sea experience into developing countries is a model that needs wider consideration. This approach is able to reach so many more scientists including early and mid-career professionals”

Potential solutions	Illustrative quotes
Development of new posts and diversification of existing positions to support and secure local research and management in the deep sea	"We need to build momentum as a science and demonstrate a case for the importance of this work so that decision makers help fund positions, projects and institutions that focus on this unexplored realm. But it's a challenge to do so when you have few opportunities to attract or retain students and emerging researchers." "Having a more solid idea of where deep-sea research may secure me a job in the future in South Africa would make it more appealing and secure to follow this field of research."
Mentorship and role models	"From a young scientist point of view, I personally believe that there is no substitute for going out there and doing the work. But this basically links to supervisors, and it puts the onus on supervisors to play an active role in the careers of young scientists. And I understand that supervisors are busy, you have a lot of students, but just putting in that extra 5% or pointing the student in right direction, putting them in contact with the right people can play an incredible and big role in their careers. I was lucky enough to have had supervisors and have supervisors who are playing a big and active role in my career, and you can see its making a big change. They provided me with this platform and without them I wouldn't be speaking to you guys today. It just shows the importance of the supervisor's role". "I have seen a local initiative where post grads mentor undergrads and this approach may work in the local offshore research context". "'Active mentorship creates opportunities and can drive independent thinking. Besides providing advice and guidance during postgraduate studies, mentors should instil soft skills such as establishing, growing and navigating relationships for national and international collaborations. These skills are invaluable but are often not taught discretely. The onus rests on the student to actively extract value from interactions with their mentors.'' ''International collaborators can play a transformative role in local capacity devilment if they are willing to supervise, co-supervise and mentor local students. Developing countries often lack the academic champions with sufficient access to the deep sea to start the development of this field".

Potential solutions	Illustrative quotes
Partnerships to support innovation, technical development and research capacity	"Local collaboration between scientists and engineers could innovate new technology to serve the needs of marine biologists, oceanographers and geologists in a single platform designed for local conditions. This would also be much cheaper" "Establishing working groups that can co-develop technical solutions and innovate together will help prevent different people trying to solve challenges in isolation and is more efficient and less wasteful. This approach can leverage new capacity, spark novel approaches and support standardised approaches for more comparative results" "One area where we can greatly benefit from experts or leaders of the field and rapidly improve capacity at relatively low cost, is if protocols and effective workflows or solutions for data management, annotation and analyses can be shared with us. That way our small teams don't have to reinvent the wheels." "Industry collaborations have unlocked some incredible data sets and there is scope for increased co-operative research that can be mutually beneficial and jointly build the knowledge base for development and decision making. In a developing country with limited resources for deep-sea research, it is imperative that industry partnerships are fostered to support access to technology and research opportunities for building the information needed for decision making. Permitting and environmental authorisation processes must support this".

Potential solutions	Illustrative quotes
Co-developed, codesigned international research collaborations with equitable funding and meaningful partnerships across all phases of research	"We really need research to take place in our deep sea. It is far more meaningful to train local scientists in a local setting. Then we learn more than the technical skills but also about our own ecosystems, fostering knowledge and a sense of ownership of our own ecosystems" "Capacity building is a two-way street, while we in the UK can offer training and experience in use of technology like ROV and AUVs for deep-sea research, researchers from South Africa have much to teach us about conducting deep-sea research with more limited resources. I feel we in the UK have forgotten, or in some cases never knew, that you don't necessarily need a £5 million robot and a large ship to do deep-sea research. The point is we have a lot to learn from each other, and fair and equitable partnerships are really key to this." "Using existing international image classification schemes and annotation software in a local context helped me. Developing country partners help us when they are able to share experience, technological designs and expertise with awareness of our local context" "I think we need fair partnerships. Funders should examine the budgets across these big international projects to make sure the funding is relatively equal and that research is mutually beneficial" "It really helps when scientists from other countries engage us from the outset. And then it helps when they are able to really listen to our needs and priorities and we can meaningly co-design research that is mutually beneficial." "Long-term partnerships are needed that foster trust, that provide funding over the duration of the life cycle of research projects from design to publication and policy recommendations"

Other international projects can expand on the opportunities presented by the OOH. One such project is the iAtlantic Project. South Africa (represented by SANBI, SAEON, UWC, UKZN, and DFFE) was provided an opportunity to communicate our needs to the broader iAtlantic Consortium of international experts. Specific areas of academic research identified for capacity development and enhancement communicated to the iAtlantic Project to date include:

- Training on deep-water marine taxonomy, particularly for invertebrates.
- Identification and biology of seep ecosystems.
- Identification and management of vulnerable marine ecosystems (VMEs).
- Impacts of climate change on deep water systems, specifically cold-water corals.
- e-DNA approaches to ecosystem characterisation.
- Use of ROVs, Autonomous Underwater Vehicles and landers in deep water.
- Sharing of technical design of deep-water sampling equipment such as cameras and landers to enable local manufacture.
- The application of machine learning in image processing and annotation.
- Training in systematic conservation planning and Marxan, with further technical support needed to sustain spatial analyses and prioritisation in the marine realm.

The iAtlantic Consortium have already responded to some of the needs identified above through online training seminars, with all seminars made accessible to the general public at https://www.iatlantic.eu/events-calendar/iatlantic-webinar-archive/. In 2020, seminars were presented on seeps, with seminars in 2021 covering VMEs and cold-water corals and climate change.

Information sharing such as the seminars described above are valuable starting points for capacity development but co-ordinated new approaches with opportunities to develop and apply skills, gain field experience and participate in deep-sea research are needed in South Africa. Such opportunities must be accompanied by interventions for funding, job development and retention and to develop long term capacity in this context.

Enablers and opportunities to overcome the barriers and challenges for improving research and management capacity for the deep sea are detailed in Table 3, followed by detailed recommendations for multiple audiences.

Table 3. Summary of key challenges and opportunities to increase capacity in deep-sea research and management.

Barriers and Challenges	Enablers and opportunities for redress
Barriers to entry and exposure to marine research and challenges in unequal access to marine environments because of socio-economic factors, historical and cultural practices and limited marine content in curricula and university. This is most pronounced in the case of the deep sea.	• Ocean literacy programmes. Exposure at school to marine science related content and introductions to marine environments. See Plate 6 and www.mzansea.org.za for initial progress in this context. • Dedicated ocean literacy initiatives diversified to recognise and build on existing ocean connections. • Inclusion of deep-sea content in high school curriculum and undergraduate university teaching. • Swimming classes and scuba training for interested students. • Live-streaming of offshore research with participation by science communicators, educators and artists. • Opportunities for emerging researchers to build technical and academic skills through internships and at-sea training. • Mentorship networks. • Dedicated transformation initiatives with a focus on historically disadvantaged entities and students. • Efforts to acknowledge, respect and accommodate traditional, cultural and spiritual values within research teams even when beliefs are not shared.
Students face significant challenges in gaining **access to funding** programs for offshore research and there are few academics able to engage in deep-sea research	• Dedicated bursaries to enable skill development towards deep-sea research. Transformation criteria should be included in such bursaries. • Funding and visiting fellowships for emerging researchers to build technical and academic skills. • Support for academic champions. • Funding Research chairs and visits for international researchers in South Africa. • Mentorship networks. • Build new relationships between academics and institutes with vessel and infrastructure access and develop opportunities for university staff to lead and participate in deep-sea research. • Mainstreaming deep-sea research to raise its profile.

Barriers and Challenges	Enablers and opportunities for redress
South African research institutions have limited opportunities to conduct deep-sea research because of financial limitations, access to deep-sea **research technology, training limitations and challenges in terms of access to vessels**	• National funding allocations to support research and transformation in this priority area. • International funding to enable greater participation and collaboration with international partners and access to international research cruises. • International collaborations with co-developed research questions and plans. • Shared technological development and shared technical resources and protocols from leading researchers or institutions. • Industry collaborations. • Innovative partnerships for local technology development. • Developed country participation in developing country research (under local conditions with local vessels and gear). • Increased collaboration with historically disadvantaged universities and a focus on transformation. • Providing access to vessels and technology through competitive research calls, dedicated programs and international platforms. • International collaborations with co-developed research questions and plans; shared data and joint outputs. • Establish national and international “working groups” to share experience, knowledge, protocols and technology. • Integrate research to meet multiple objectives for added value. For example, linking monitoring to capacity development is one recommended approach for multiple benefits.

Barriers and Challenges	Enablers and opportunities for redress
Lack of **job prospects** and limited scope for research, impact assessment and management in the deep sea	• "Make the case" i.e clearly communicate the rationale, need and benefits of deep-sea research and management in South Africa and raise the profile of the deep sea in this context. • Engage with leaders and decision makers to profile deep-sea activities, the importance of research and share potential solutions. • Prioritise the field in national policy and research strategies. • National policy can support institutional capacity to uphold South Africa's leadership position in international ocean science through: i. Setting aside funding to support academic positions and research funding; ii. Promoting and prioritising South African evidence in national, regional and international decision-making.
Barriers to participation and collaboration in **international research** cruises.	• Developed country participation in developing country research (under local conditions with local vessels and gear). • International collaborations with co-developed research questions and plans. Co-led research cruises that collect mutually beneficial data and jointly analysed and published results. • Diverse training approaches and opportunities for emerging researchers to develop skills while earning.

Recommendations

A substantial number of recommendations were developed to support the development and transformation of research and management capacity for the deep-sea in South Africa. These are first presented by theme and then in further detail for different key audiences to facilitate ease of uptake among relevant stakeholders. In the longer term, a strategy is needed for more co-ordinated implementation of these recommendations.

Recommendations by theme

1. Mainstreaming

- Strengthen the inclusion of deep-sea research in **national research strategies and priorities** to ensure investment in deep-sea capacity development and development of long-term job opportunities and institutional capacity.
- Clearly communicate the **rationale, need and benefits** of increased deep-sea research and management capacity in addition to the risks and consequences of maintaining the status quo.

- Engage with **industry** to establish research priorities for sustainable development of various sectors to support relevant research and ensure uptake of research.

2. Exposure and training

- Implement existing and develop new ocean literacy programs, curriculum content, and science engagement programs to improve exposure during primary and high school and tertiary education to deep-sea related content, including diversified content to recognise and foster existing ocean connections. The **MzanSea project** (www.mzansea.org.za) has developed resources to support the inclusion of the deep sea in ocean literacy but a lack of funding limits implementation of these products. Develop dedicated, diverse **training approaches and opportunities** for emerging researchers to build technical, academic and other relevant skills while earning, including **dedicated bursaries**, **internships, at-sea training, swimming classes, scuba diving and mentorship arrangements**. These initiatives must enable transformation and start by building marine skills before specialising into more specialised deep-sea technical and academic skills.
- Encourage ongoing science engagement particularly for the deep sea including **livestreaming and social media** to share deep-sea and other marine research.
- **Build capacity and skills** for South Africans to engage in national and global deepsea issues across the **science-policy continuum,** including biodiversity beyond national jurisdiction (BBNJ).

3. Funding

- Provide dedicated bursaries and funding for emerging researchers and managers to build academic, technical and management skills through tertiary education and participation in training.
- Fund research chairs, **academic champions** and other positions within universities for senior academic staff who are able to mentor and develop emerging researchers and actively participate in deep-sea research.
- Provide funding to enable greater **participation and collaboration** among international partners, visits for international researchers in South Africa, and access to international research cruises.
- **Ensure funding reduces inequity** in research partnerships and supports co-designed collaborative research and equitable, meaningful partnerships.
- 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.

4. Partnerships and Research Collaboration

- Increase **international collaborations** with co-developed research questions and plans, shared data that are mutually beneficial, sampling under local conditions with local vessels and gear, and joint outputs.
- Develop **co-led research cruises** that collect mutually beneficial data and jointly analysed results with joint research outputs.
- Ensure **funding** of local participant's time on international projects during initial engagements in international collaborations and clarify **expectations** in international partnerships to ensure institutional alignment and that sufficient support is provided not only for project work but also to meet complex international reporting and administration requirements.

- Increase **national collaborations** between academics and institutes or industry partners with vessel and infrastructure access with particular consideration of historically disadvantaged universities.
- Acknowledge, respect and accommodate **traditional, cultural and spiritual values** within research teams even when beliefs are not shared.
- 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.
- Foster **innovative mentorship arrangements** between researchers, students and managers across and within countries.
- Support the **supervision or co-supervision** of developing country students by experienced researchers from developed countries.

5. Technology

- Develop innovative **local technology** and encourage **sharing** of technology and effective protocols with national and international partners.
- Provide **access** to vessels and technology through competitive research calls, dedicated programs, local and international platforms and multiple partnerships.
- Ensure capacity development initiatives consider and account for **available technology and resources**
- Develop **technical working groups** to coordinate research efforts, foster innovation, fast-track sharing of protocols, technical solutions and standardised methods.
- Develop **shared infrastructure platforms** that integrate research to meet multiple objectives for added value.

Recommendations by audience

1. Funders

- Provide **dedicated bursaries and funding** for emerging researchers to build technical and academic skills through tertiary education and participation in training. Prioritise historically disadvantaged students to support transformation in deep-sea research.
- Fund **research chairs, academic champions and other positions** within universities for senior academic staff who are able to mentor and develop emerging researchers and actively participate in deep-sea research.
- Fund **positions and fellowships** at universities or research organisations for emerging researchers and junior academics so that a cohort of skilled deep-sea researchers can be grown.
- **Avoid funding parachute science** that does not benefit local research or capacity.
- Support **innovative approaches** to meaningful capacity development and transformation and fund project components that pilot new approaches in this context.
- Provide funding to enable **greater participation and collaboration** among international partners, relationships and knowledge transfer between scientists and managers, visits for international researchers in South Africa and access to international research cruises.

- Ensure funded projects in developing countries have **meaningful participation** from local researchers from the project outset (conceptualisation phase) and that funding is equitable with solid plans for **lasting capacity development**.
- **Ensure funding reduces inequity** in research partnerships and supports co-designed collaborative research and equitable partnerships.
- Provide funding for **shared infrastructure** platforms and **integrated research** that meets multiple objectives for added value. Linking monitoring to capacity development is one recommended approach for multiple benefits (Bax *et al.* 2018).
- 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.
- Ensure funding addresses neglected areas at the **science-policy interface** (see Gustafsson *et al.* 2020). This includes support for **training** for managers and participation of managers in relevant local and international fora to support good decision making in the deep sea.
- Encourage **industry participation** in offshore research.

2. Science managers, environmental managers, and decision makers

- Include deep-sea research in national **research strategies and priorities** to ensure investment in deep-sea capacity development.
- Support the **development and retention** of emerging researchers and institutional capacity through long-term positions that advance the field.
- Support dedicated, diverse **training approaches** and opportunities for emerging researchers to build technical and academic skills while earning, including internships, at-sea training, swimming classes and scuba diving.
- Encourage staff and support applications that can help build technical, academic and management skills through tertiary education, participation in training and other **career development** opportunities.
- Support the development of **ocean literacy and science engagement** programs and encourage staff participation in deep-sea research and outreach.
- Support the development of funding and other opportunities to enable greater **participation and collaboration** among international partners, visits for international researchers in South Africa, and access to international research cruises.
- Foster **international links** and opportunities for equitable research partnerships.
- Encourage **national collaborations** between institutes, particularly new links with historically disadvantaged universities.
- Encourage collaboration within institutes and within and between government departments to facilitate **knowledge exchange** and the application of scientific advice in decision making.
- Encourage **industry** to share vessels, infrastructure, and data with researchers and ensure permitting supports such arrangements.

- Develop **innovative technology hubs** and encourage sharing of technology with national and international partners.
- Provide **access to vessels and technology** through competitive research calls, dedicated programs and international partnerships.

3. Local scientists

- Support the implementation of existing and development of new curricula content, ocean literacy programs and science engagement initiatives to **improve exposure to deep-sea content** during school and tertiary education, including content that highlights human and ocean connections.
- Provide dedicated, **diverse training** approaches and opportunities for emerging researchers to build technical and academic skills while earning, including internships, at-sea training, swimming classes and scuba diving.
- Support **emerging scientists** in network and research collaborations.
- Acknowledge, respect and accommodate **traditional**, **cultural and spiritual values** within research teams even when beliefs are not shared.
- Build **international relationships** and share research progress, limitations and priorities.
- Develop **partnerships** across disciplines and with industry to support innovative local technology, leverage new research opportunities and encourage sharing of technology with national and international partners.
- Supervisors should invest in **mentoring**, including provision of career development advice, helping students connect with other researchers and sharing of key training and development opportunities.
- **Communicate** research priorities, research technical constraints and capacity development challenges to science managers, funders and international collaborators.
- Clarify eligibility for funding including funding of local participant's time on international projects during initial engagements in international collaborations. **Seek clarity on roles, budgets, responsibilities and deliverables** before entering into formal partnerships in international collaborations.
- Clarify expectations in international partnerships and ensure **institutional alignment** and that sufficient support is provided not only for project work but also to meet complex international reporting and administrative requirements.

4. International collaborators

- **Involve developing country scientists** in a meaningful way, including project conceptualisation and design.
- **Listen** to developing country needs, priorities, constraints and concerns.
- Acknowledge, respect and accommodate **traditional, cultural and spiritual values** within research teams even when beliefs are not shared.
- **Co-develop** research questions and plans for mutual benefits.

- Ensure **equitable research funding and partnerships**, enabling greater research capacity rather than a burden on already-stretched researchers. Support diversity in research teams and South Africa's transformation efforts.
- **Share data** in a mutually beneficial way.
- Consider supervising, co-supervising or mentoring developing country students and support developing country researchers in their **capacity development** efforts.
- Support inclusive science: always engage with and include local researchers in any science and research outputs you conduct in foreign countries.
- Consider highlighting exclusion of relevant local authors during the **review process.**
- Consider joining **local expeditions** to participate in sampling under local conditions with local vessels and gear.
- **Communicate and share research activities** and programs broadly including through print and social media and livestreaming as this inspires developing country researchers and indirectly supports capacity development.
- Invest in the development of **lasting capacity** that will benefit the country beyond the lifespan of any project

5. Students

- Communicate your **career development** needs to supervisors and mentors.
- Take advantage of t**raining and mentorship** opportunities and develop your skillset for your career path.
- Approach scientists with your ideas and enthusiasm and apply for research assistant positions with them if possible. If they do not have paid positions, consider volunteering your time to assist researchers if feasible.
- Actively **build your network** through conference attendance, seminars, mentorship and any other opportunities to interact with established researchers or enthusiastic peers in your field.
- Register on deep sea and other relevant **marine science mailing lists** to stay up to date with learning, academic and funding opportunities.
- **Share** your learning and help mentor younger students or scholars.

6. Industry

- Preferentially employ **local consultants** for impact assessments, management planning and other relevant work.
- Contribute to knowledge development and consider participation in **co-operative research** to help build capacity and information for decision making.
- Engage with **local scientists** to develop mutually beneficial research and monitoring opportunities.
- Share information, research priorities, data and expertise to **help develop capacity** and advance the field.

- **Uptake research** into industry with appropriate acknowledgements.
- **Communicate** research priorities and opportunities through existing fora, networks and by fostering relationships with researchers.

Further discussion and research are underway to support a deeper understanding of challenges and refinement of these recommendations, particularly in a regional and global context. This may be included in an international publication that could draw together experience from multiple developing countries. A dedicated strategy is recommended for South Africa that can plan for and support the implementation of these 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 research and management in South Africa and the region.

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Appendix 1. Overview of the One Ocean Hub Wonders of the Deep session

The One Ocean Hub Wonders of the Deep session was one of a series of engagements for World Ocean Week with the overall aim of:

1. Further establishing an authoritative and engaging voice for the One Ocean Hub internationally.
2. Sharing Hub and related project research findings and researcher experiences across a range of topics, and further advancing research and research planning in conversation with government, UN and non-governmental partners across the world.
3. Bringing local perspectives into the international conversation on ocean governance.
4. Increasing the reach of the Hub and Hub Network.

The Wonders of the Deep event had an additional specific aim to distil key lessons and opportunities for improved capacity for research, policy and management of the deep ocean. A recording of the event can be accessed on youtube (https://www.youtube.com/watch?v=JvUJvqPB6is)

This event shared experience and insights from British researchers: Prof Kerry Howell (University of Plymouth), Kelsey Barnhill (University of Edinburgh) and South African researchers: Prof Kerry Sink (SANBI and Nelson Mandela University), Grant van der Heever (SAEON), Loyiso Dunga (SANBI and Nelson Mandela University) and shared postdoctoral researcher Dr Kirsty McQuaid (University of Plymouth and SANBI). Researchers shared their journeys of increasing depth, featuring imagery from the deep ocean to share personal stories about their experience of deep-water research. The imagery was designed to showcase the range of deep-sea ecosystem types studied by these researchers, from shallow water kelp forests to mesophotic reefs, sandy and muddy shelves, the shelf edge, slopes, deep coral reefs, sponges, seamounts and the abyss. Researchers explained the importance of these habitats from a scientific perspective as well as for the realisation of the Sustainable Development Goals. In addition, researchers shared the story of deep-sea collaborations developed through the One Ocean Hub, which built on research collaboration fostered through the Coelacanth Ecosystem Program projects, including ACEP Deep Secrets (Grant number 97971), ACEP Deep Forests (Grant number 110765) and ACEP Deep Connections (Grant number 129216).

The focus of each presentation was to distil the key relevant experiences in defining challenges, barriers and enablers for deep-sea capacity development. Each speaker explained how they entered into deep-sea research (including catalysts), some amazing things they have experienced, pivotal moments in their careers, and why the deep sea matters to them. This covered key ecosystem services of the deep sea, pressures to these systems and steps to better manage the deep sea, key obstacles for entry into this field, and experience in overcoming challenges (Appendix 1). Members of the audience were able to ask the researchers about the mysteries of the deep sea and exchange views on how best to develop deep-sea research capacity and convey scientific findings to relevant policy processes at the national and international levels. Information distilled from the Wonders of the Deep event and other local discussions was included in related presentations and discussions held at an IUCN DOSI webinar.

Table A1. Overview of the key elements covered by each speaker during the OOH Wonders of the Deep event. The event can be watched in full here: https://www.youtube.com/watch?v=JvUJvqPB6is

Speaker	Story	Ecosystems, species	Service	Pressure	Barriers	Entry points and Enablers	Video
Kerry Howell	**Deep Impact** Fisheries impacts Government to research **Deep Solutions** UK protected areas Research to solve problems **Deep Connections** Story of the Pheronema sponge grounds and the UK-SA links leading to the One Ocean Hub collaboration	UK deep sea, Seamounts, Sponge grounds	Fisheries/ biomedical discoveries	Fisheries challenges		Value of academic champions Vessel access Technology	Seamount video
Kelsy Barnhill	**Perseverance** **Reaching out** Include Nautilus and importance of livestreaming **Crumbing Corals**	Coral mounds Cold water corals	Food production Biogeoche-mical cycling	Climate change	Limited academic coverage (until 4th year of college)	Ted Talks (Robert Ballard) Vessel opportunities (EV Nautilis) Outreach livestreaming links and importance of imagery International collaborations Participation of science communicators	Nautilus live Coral mounds Scottish reefs etc (UoE material)

Speaker	Story	Ecosystems, species	Service	Pressure	Barriers	Entry points and Enablers	Video
Kerry Sink	**Into the Depths** Coelacanths to Offshore MPAs and mainstreaming **Heaven and Earth** Oil and gas negotiations **Deep Secrets** Visual surveys in MPA proclamation Collaborations (Lisa)	Shelf edge, what is the deep sea – in SA shelf break spans 50m to 700m, canyons	Intangible benefits	Oil and gas Mining	Capacity Technology Vessel Lack of academic leadership	Aquaria, Trimix diving and coelacanth discovery Conferences Collaborations International scientists visiting developing countries and collaborating in local cruises Vessel access Industry collaboration	Shelf edge, coelacanths, 3 MPA sites
Grant van der Heever	**Deep Dreams** Koel baai ...deep-sea diver **Off the Deep-end** (Andromeda) First demersal survey- ....sea sickness., 800m trawls....life on the trawl deck transition to visual surveys **Deep Vision** Technological barriers and advances	Essential fish habitat Secret Reef? Kingklip Agulhas sole	Food and job security	Trawling	Lack of vessel access Technology limitations	Seaside camping A special teacher Library books TV coverage Vessel access Mentorship Access to new technology	BTE Childs Bank Deep Secrets video Tow camera surveys (WCVS)

Speaker	Story	Ecosystems, species	Service	Pressure	Barriers	Entry points and Enablers	Video
Loyiso Dunga	**Deep Forests** Inspiration…Images, curiosity…. Kelp forest…..different deep-sea ecosystems…muds **Medicine and Magic** Cancer fighting compounds – Sangoma; cleansing….commanding animals…healing abilities of animals…. **Heaven in the Deep**	Animal forests/ VMEs	Cultural and spiritual, medicine		Cultural barriers Academic barriers Lack of swimming training and experience No opportunities for sea going experience	Teachers Exposure to visuals Opportunities to swim and participate in offshore research	NA
Kirsty McQuaid	**Leaving the Shore** Teachers…to Offshore MPAs **Into the Abyss** To ISAs…. transition SA to international waters, learning experiences **Coming home**	Abyssal ecosystems	Minerals	Seabed mining	Limited exposure Lack of university based academic staff to supervise deepsea research Vessel and technological access challenges	Teaching, training Deep-sea content at university Exposure to deep-sea issues Academic leadership Mentorship Research opportunities Funding- ISA	Abyss video