frontiers | Frontiers in Marine Science

PERSPECTIVE
published: 30 June 2022
doi: 10.3389/fmars.2022.886373

A Roadmap to Advance Marine and Coastal Monitoring, Biodiversity Assessment, and International Reporting: A Developing Nation Perspective

Kaylee P Smit[1,2]*, *Lara Van Niekerk*[3,4], *Linda R. Harris*[4], *Abigail McQuatters-Gollop*[5], *Lynne J. Shannon*[2] *and Kerry J. Sink*[1,4]

[1] Marine Programme, South African National Biodiversity Institute (SANBI), Cape Town, South Africa, [2] Department of Biological Sciences, University of Cape Town (UCT), Cape Town, South Africa, [3] Coastal Systems and Earth Observation, Council for Scientific and Industrial Research (CSIR), Stellenbosch, South Africa, [4] Institute for Coastal and Marine Research, Nelson Mandela University (NMU), Gqeberha, South Africa, [5] School of Marine and Biological Science, University of Plymouth, Plymouth, United Kingdom

OPEN ACCESS

Edited by:
Vitor H. Paiva, University of Coimbra, Portugal

Reviewed by:
Alida Bundy, Bedford Institute of Oceanography (BIO), Canada

***Correspondence:**
Kaylee Pam Smit
kaylee.smit@uct.ac.za

Specialty section:
This article was submitted to Marine Conservation and Sustainability, a section of the journal Frontiers in Marine Science

Received: *28 February 2022*
Accepted: *23 May 2022*
Published: *30 June 2022*

Citation:
Smit KP, Van Niekerk L, Harris LR, McQuatters-Gollop A, Shannon LJ and Sink KJ (2022) A Roadmap to Advance Marine and Coastal Monitoring, Biodiversity Assessment, and International Reporting: A Developing Nation Perspective. Front. Mar. Sci. 9:886373. doi: 10.3389/fmars.2022.886373

Despite the increasing number of tools and indicators to measure biodiversity status and trends, many developing countries struggle to initiate and advance coastal and marine assessments needed to monitor and track national and international progress in biodiversity targets. We identified five key challenges that hinder progress in this context, based on a national marine assessment workshop held in South Africa, and developed recommendations and tangible actions to address these challenges drawing from multiple national assessments, regional initiatives, and global collaborations over the last 15 years. Challenges include a poor understanding of methods, limited capacity and funding for assessments, a lack of systematic approaches to biodiversity assessment and indicator development, and scattered efforts that often fail to link science to policy. Key actions could enable the development of a coordinated framework to feed into policy and decision-making at multiple scales. We provide South African examples to highlight a developing country's progress toward marine biodiversity assessment and provide a roadmap to integrated monitoring, assessment, and reporting based on positive outcomes. Recommendations to address challenges include building collective understanding of assessment tools and methods, prioritizing pressures urgently needing mitigation measures, using relevant indicators to support reporting at multiple scales, applying coordinated approaches to identify gaps and opportunities, codeveloping coordinated approaches with direct policy links, and leveraging resources and technical capacity for iterative improvement. This roadmap can guide developing and developed countries and support global best practices to collaboratively advance marine and coastal ecosystem monitoring and assessment at multiple scales for meeting many objectives.

Keywords: indicators, marine and coastal biodiversity, global reporting, ecological condition, tangible actions

INTRODUCTION

Increased human pressures in the oceans are linked to unprecedented losses in marine biodiversity and ecosystem services that are essential for human wellbeing (Hooper et al., 2005; Crain et al., 2008; Halpern and Floeter, 2008; Micheli et al., 2014). To mitigate these impacts and maintain healthy oceans, we need sustained measurements of the status and trends of marine biodiversity and ecosystem condition to better assess the effects of human pressures and to apply this information to inform management actions and policy development. Global policies, research initiatives, and biodiversity frameworks have resulted in the development of numerous tools to track progress in meeting biodiversity targets; this has led to the identification of a wide range of methods and indicators for biodiversity monitoring and assessment, particularly in developed countries (Teixeira et al., 2016; Smit et al., 2021). However, this has resulted in confusion and a lack of standardization. Moreover, top-down indicators developed for global synthesis and reporting are often not useful at a national scale, unless validated with country-level data and accurate interpretation of available indicators. Thus, there is a need to identify flexible global indicators that can be tailored to regional- to local-scale requirements, with appropriate institutional support structures, including cross-cutting national indicators that can support meaningful reporting in a global context.

South Africa has made substantial progress in assessing the marine and coastal environment at a national scale and could be regarded as a leader among developing nations [considered here as countries receiving Official Development Assistance (ODA) aid (oecd.org/dac)] in this context. The South African National Biodiversity Institute (SANBI) is mandated to conduct a National Biodiversity Assessment (NBA) every 5–7 years, reporting on two headline indicators; ecosystem threat status and protection level to track the state of biodiversity over time (Skowno et al., 2019). In the most recent NBA, the IUCN Red List of Ecosystems (RLE) criteria (Rodríguez et al., 2015; Bland et al., 2018; Bland et al., 2019) were applied to determine ecosystem threat status at a national scale (Sink et al., 2019a). At a regional level, in the Western Indian Ocean (WIO) a state of the coast report has been developed every few years (UNEP-Nairobi Convention and WIOMSA, 2015), and a recent assessment following the IUCN RLE approach was used to determine the threat status of marine ecoregions in the WIO region (Obura et al., 2021a). In this paper, we refer to biodiversity assessments in a broad sense that encompasses species and ecosystem assessments in the marine environment.

Despite progress made in South Africa and in Africa, developing countries (particularly those in the Global South) face a unique set of challenges in biodiversity monitoring and national assessment, resulting in clear disparities in progress compared with developed countries (OECD, 2020; Obura et al., 2021b). Some of these limitations include data availability, lack of funding, and poor infrastructure that inhibit data collection and assessment at relevant temporal and spatial scales. In addition, there is generally poor harmonization and coordination among relevant research agencies and reporting channels, and this is often underpinned by a lack of responsibility and ownership for assessment at the ecosystem level. A list of data gaps and research needs were identified in the South African NBA that included the need for "measuring and mapping ecological condition, which is crucial for biodiversity assessments, where biological and ecological data and indices of condition need to be explored across a range of ecosystem types to compare such assessments of condition with assessments made through cumulative pressure mapping" (Sink et al., 2019a). A first step toward addressing these needs included a national marine condition workshop that was hosted by SANBI and the University of Cape Town in October 2021, which provided the basis for this paper. The workshop was attended by participants spanning 11 institutions including representatives from national government, research agencies, and non-governmental organizations (NGOs) (a workshop summary is provided in the **Supplementary Material**). Discussions from the workshop led to the identification of key challenges for advancing marine biodiversity assessments in developing countries and provided the basis for a set of recommendations and priority actions that reflected our unified thoughts on how to consolidate fragmented efforts and facilitate a way to move biodiversity assessment in the marine realm through to management and policy level.

This paper aims to address the broad challenges identified in the workshop, by providing a roadmap of recommendations and priority actions to facilitate and support national biodiversity assessments. We use South Africa as an example because regular, home-grown national biodiversity assessments (NBAs) have been undertaken since 2004 (Driver et al., 2005; Driver et al., 2012; Skowno et al., 2019), which increasingly draw on and use international approaches in alignment with global best practice, but subject to local constraints (e.g., data or resource requirements). Further, regional and global initiatives are increasingly reaching out to South Africa (among other developing countries) for participation in a variety of new approaches to assessing coastal and marine ecosystems in the Indian, Atlantic, and Southern Oceans. Finally, like many African coastal nations, South Africa is expanding its ocean-based economy (WWF-SA, 2016; Findlay, 2018; AU-IBAR, 2019; Harris et al., 2022b) and must identify, assess, and employ appropriate indicators to monitor the effects of expanding, intensifying, and diversifying activities in support of sustainable development and environmental stewardship.

CHALLENGES AND OPPORTUNITIES FOR MARINE BIODIVERSITY ASSESSMENTS

Measurement of ecological condition is required to inform ecosystem threat status and other national indicators and project objectives (Sink et al., 2019b; Orejas et al., 2020; Harvey et al., 2021; Monaco et al., 2021). However, some of the biggest challenges that hinder the effective use of capacity and resources for marine assessment include uncoordinated reporting on multiple commitments and objectives and an often extensive but scattered marine policy and legislative landscape (Taljaard et al., 2019). For example, a concise list of

common reporting needs, including international strategies and frameworks, systemic assessments, networks, or research platforms and projects, that require indicators from the marine realm are outlined from a South African perspective (**Table 1**). Well-established international assessment frameworks, such as the European Marine Strategy Framework Directive, the Ocean Health Index (OHI), and the IUCN Red List of Ecosystems, have standardized fit-for-purpose indicators, especially suited to high-level national reporting (Borja et al., 2011; Halpern et al., 2012; Andersen et al., 2014; Rodríguez et al., 2015; Rowland et al., 2019; Nicholson et al., 2021). However, there are many limitations and challenges that hinder progress in implementing these frameworks, particularly in developing countries in a local context.

Outputs from the South African workshop (see Introduction) resulted in the identification of five key challenges that need to be addressed at the country level to advance marine biodiversity assessments (**Figure 1A**). These include (1) poor understanding of methods and tools for marine biodiversity assessment; (2) lack of systematic approaches to prioritize pressures and select pressure and state indicators; (3) limited data (and capacity) at a national scale, or at the scale of management objectives; (4) scattered initiatives and poor alignment among scientists, managers, and policymakers; and (5) a lack of funding and resources. It is beyond the scope of this paper to discuss in detail the underlying factors linked to these challenges. However, some common issues, particularly relevant to developing countries, include a history of scattered uncoordinated efforts to monitor and assess marine ecosystems, poor links to management and policy, and a lack of co-development and limited resources (including equipment, human capacity, and funding).

There is an urgent need to develop tangible actions to overcome these challenges to advance marine biodiversity assessment at scales relevant to a range of management and sustainable development objectives. The approach used in the South African National Biodiversity Assessment is effective for estimating ecological condition and threats to marine ecosystems at broad spatial scales covering a large (national) area. However, this approach relies on pressures, as a proxy of ecological condition rather than ecological data and *in situ* ocean observations. Thus, there is a need to groundtruth the country-level assessment, advance the IUCN Red List of Ecosystems assessment methods, and develop national condition assessments using observed (and modeled) data. Harmonization is required among current approaches and methods by identifying synergies, commonalities, and a common set of metrics and indicators that can inform

TABLE 1 | A concise list of marine-related frameworks and policies, integrated systemic assessments, networks, online data sharing platforms, and projects, relevant to marine biodiversity assessment in South Africa and that are commonly referred to in the text.

Category	Reporting channels	Scale	References
Strategy/framework/ policy	National Biodiversity Strategy and Action Plan (NBSAP)	National	Government of South Africa, 2015
	Benguela Current Commission[a]	Regional	https://www.benguelacc.org/
	Marine Strategy Framework Directive	Regional	European Commission, 2010
	CBD Global Biodiversity Monitoring Framework	Global	CBD, 2021
	UN Sustainable Development Goals (SDGs)	Global	https://www.undp.org/sustainable-development-goals
Systematic assessment	South African (SA) State of coast reports	National	e.g., Kirkman et al., 2018
	SA National Biodiversity Assessment (NBA)	National	Sink et al., 2019b
	Critical Biodiversity Areas, Key Biodiversity Areas, Ecologically and Biologically Significant Areas	National	Harris et al. 2022a; Harris et al. 2022b
	Marine Spatial Planning	National	The Department of Environmental Affairs., 2016
	Western Indian Ocean state of the coast report	Regional	UNEP-Nairobi Convention and WIOMSA, 2015
Network/research platform	Global Ocean Observing System (GOOS)	Global	https://www.goosocean.org/
	Marine Biodiversity Observation Network (MBON)	Global	https://marinebon.org/
	Scientific Committee on Oceanic Research (SCOR)	Global	https://scor-int.org/
	the Biodiversity Indicators Partnership (BIP)	Global	https://www.bipindicators.net/
	Integrated Marine Biosphere Research (IMBeR)	Global	https://imber.info/
	Future Earth Project bioDISCOVERY program	Global	https://biodiscovery.earth/
	MarineLife2030	Global	https://marinelife2030.org
Data sharing platform	Biodiversity Global Information System (BGIS)	National	https://www.sanbi.org/link/bgis-biodiversity-gis/
	South African Environmental Observation Network (SAEON) portal	National	http://www.saeon.ac.za/data-portal-access
	Marine Information Management System (MIMS)	National	https://data.ocean.gov.za/about/
	Global Biodiversity Information System (GBIF)	Global	https://www.gbif.org/
	Ocean Biodiversity Information System (OBIS)	Global	https://obis.org/
Project	Mission Atlantic	Regional	https://missionatlantic.eu/
	iAtlantic	Regional	https://www.iatlantic.eu/
	WioSymphony (Symphony Tool)	Regional	https://github.com/WIOSymphony
	One Ocean Hub	Global	https://oneoceanhub.org/
	IndiSeas	Global	http://indiseas.org

[a]*The Benguela Current Commission is one example of numerous conventions and policies that South Africa is signatory to (see Taljaard et al., 2019).*

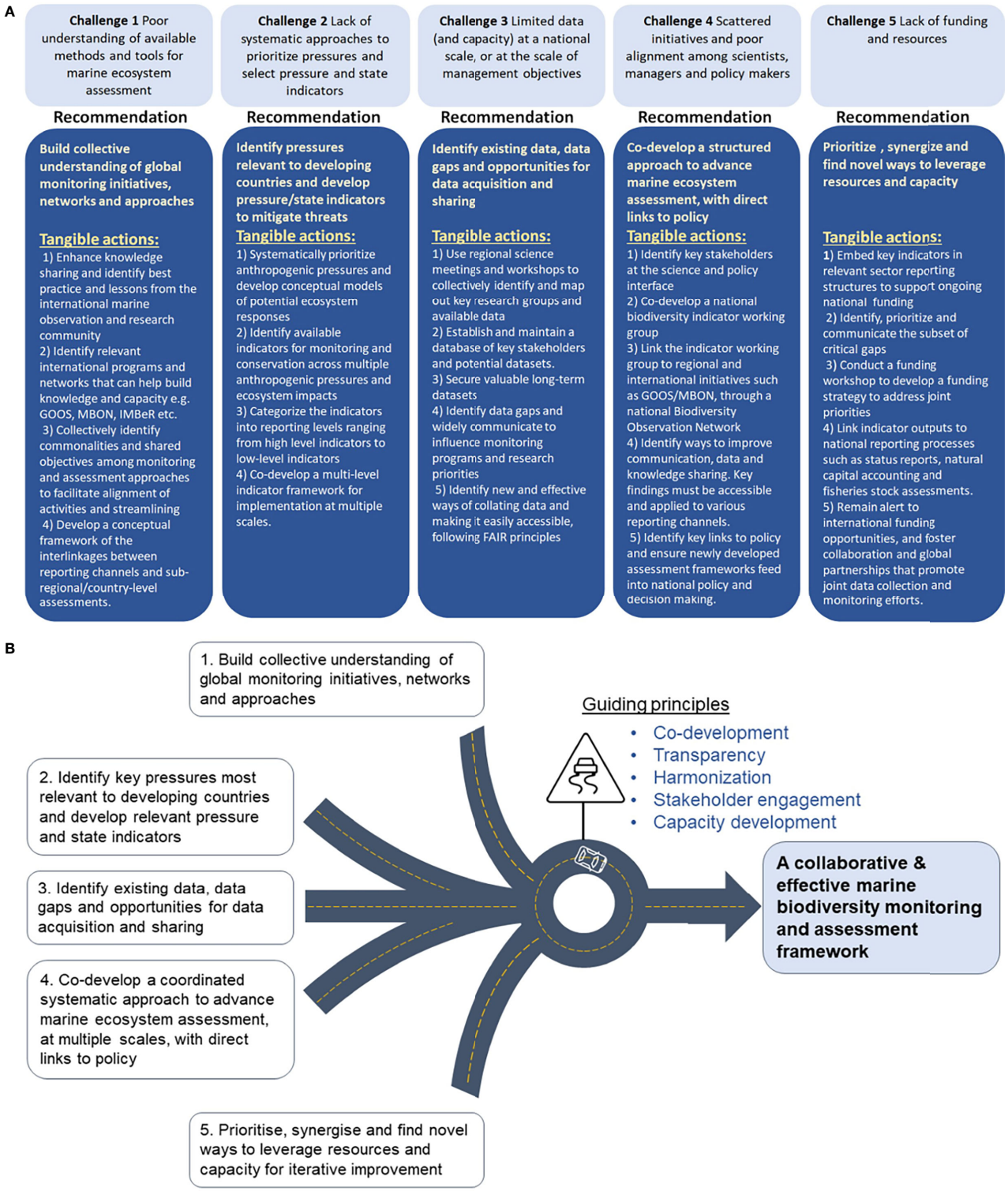

FIGURE 1 | **(A)** Schematic showing the five identified challenges that hinder progress for national marine biodiversity assessment in developing countries, recommendations (in bold text at top of each pillar), and tangible actions to overcome these challenges. **(B)** A roadmap illustrating how the five recommendations, linked to each identified challenge, should be collectively applied to advance marine biodiversity monitoring and the co-development of an assessment framework. These steps need to be guided by a set of key principles that will enable a harmonized, coordinated, equitable, and sustainable iterative process.

assessments at multiple scales and for multiple reporting objectives (**Table 1**) (Borja et al., 2019; Evans et al., 2019; McQuatters-Gollop et al., 2019; Pavlidou et al., 2019). Key to this will be to find ways to harness available data, resources, and technical capacity to codesign an indicator and assessment framework for national marine monitoring and assessment. The question is, how do countries go about doing this practically?

A ROADMAP: RECOMMENDATIONS AND PRIORITY ACTIONS TO ADDRESS KEY CHALLENGES IN COASTAL AND MARINE BIODIVERSITY ASSESSMENT

The challenges presented here (**Figure 1A**) are not unique to developing countries but are often harder to overcome where limited technical capacity and resources hinder achieving goals and targets. A set of recommendations and priority actions was identified from discussions and key outputs from the national workshop held in South Africa to address each challenge (**Figure 1A**). This roadmap can guide developing and developed countries and support global best practices and networks to advance ecosystem monitoring and assessment at multiple scales for multiple sustainability objectives. This roadmap is targeted at researchers, managers, and decision-makers, to guide the efforts of those who are directly or indirectly involved with conducting marine biodiversity assessments. However, we note here that this roadmap will be most useful for national governments and research agencies who are responsible for national reporting and whose mandate is to monitor the status and trends of marine biodiversity and measure the condition of ecosystems.

The actions for implementing the proposed recommendations should be guided by a set of underlying guiding principles that will enable collaborative support for the co-development of an indicator and assessment framework for national marine biodiversity assessment (**Figure 1B**). Guiding principles were identified by participants during the workshop and drew from international literature (Ojaveer and Eero, 2011; Goldsmith et al., 2015; Haase et al., 2018; Muller-Karger et al., 2018; Skern-Mauritzen et al., 2018; McQuatters-Gollop et al., 2019) to identify enabling conditions to advance marine assessment. These principles include co-development with key links to policy, transparency, harmonization of assessment methods to include global best practices, stakeholder engagement, transparency, and capacity building to ensure iterative improvement of assessments (**Figure 1B**). The roadmap (**Figure 1B**) demonstrates how achievement of recommendations (and associated tangible actions) could lead to a collaborative and effective marine monitoring program and assessment framework. We propose that a successful implementation of priority actions (**Figure 1A**) could help to facilitate improved alignment of marine biodiversity assessment in developing countries, supported by international and regional efforts, and increase standardization of methods, indicators, and outputs to advance assessments in the developing world.

DISCUSSION

The proposed roadmap addresses the five key challenges that developing countries face in undertaking marine biodiversity assessments and presents a key recommendation and tangible actions for each challenge. If implemented, these actions could help to advance and synergize biodiversity monitoring and assessment for sustainable development. The roadmap illustrates the progress that can be made by developing countries to reduce the disparities with biodiversity assessment and monitoring in developed countries. The underlying challenges and proposed actions, with examples from South Africa's progress in overcoming some of these challenges, are discussed with lessons for other African and developing nations.

To address the first challenge, which centers on a poor understanding of methods and assessment approaches, an online national workshop was held in South Africa with the purpose of harmonizing marine biodiversity assessments at multiple scales, upon which the basis of this paper was developed. The workshop brought together relevant stakeholders, to provide a joint understanding of different methods and tools, and to investigate application in a local context. The intended outcome was to align global approaches (like those used in the EU Mission Atlantic project, the Ocean Health Index, and the Marine Strategy Framework Directive) (**Table 1**), with South Africa's upcoming fourth iteration of the NBA. Stakeholders improved their understanding of the different assessment approaches and indicators, culminating in a conceptual framework of how the different approaches can fit together in South Africa and potential ways to overcome some of the challenges that hinder progress in this context.

For other developing countries, we recommend actions like this collaborative workshop to build collective understanding of approaches, networks, and potential interlinkages and to identify commonalities and shared objectives among monitoring and assessment approaches for key reporting channels (**Figure 1A**). In doing so, research and management agencies can facilitate the alignment of activities and streamline assessment efforts and reporting to increase harmonization and reduce duplication of effort without reinventing the wheel. For example, monitoring and assessment should also learn from, and align with, relevant networks and research platforms (**Table 1**). International networks often offer opportunities for collaboration with current research programs that can provide additional resources and technical capacity (i.e., funding, equipment, or data). We recommend that countries establish their own national working group or an official Biodiversity Observation Network (BON) that can facilitate these steps locally and provide support for collaboration, harmonization, and knowledge generation.

South Africa is making progress toward addressing the second challenge, the lack of a systematic (holistic,

methodological, and repeatable) approach for identifying key pressure and state indicators to facilitate biodiversity actions. A total of 31 human pressures are measured and mapped at a national scale for the NBA (Majiedt et al., 2019), with expert-driven scoring to quantify ecosystem impacts. Although the assessment provides a comprehensive overview of pressures in the EEZ, some sectors are poorly quantified. Further, there is a need for uncertainty to be accommodated, especially in the case of risks imposed on biodiversity by synergistic pressures. Recently, South Africa applied the Options for Delivering Ecosystem-Based Marine Management (ODEMM) approach to prioritize key sectors, pressures, and affected ecosystem components. Further, a literature review of indicator types and assessment approaches was conducted for country-level application (Smit et al., 2021). Key marine indicators are now being categorized for inclusion in a revised National Biodiversity Framework. However, there is still a need to codevelop a multilevel/hierarchical indicator framework of indicators that can be implemented at multiple scales, using global best practices as a departure point.

To address the second challenge, we recommend that a set of smaller projects be conducted that can test selected global indicators with available measured data for sensitivity/viability, and the hosting of a suite of focus workshops with managers and researchers to discuss and distill findings. From this, a hierarchical indicator framework can be built, with time frames (and possible funding streams) to facilitate this. Toward this, other countries could also investigate the use of the ODEMM approach, which is useful for identifying management objectives and guiding indicator selection for biodiversity assessment (Knights et al., 2011; Pedreschi et al., 2019). Further, a DPSIR (Driver Pressure State Impact Response) approach can help better quantify the links between drivers, pressures, and ecosystem state and inform management responses (Piet et al., 2015; Oesterwind et al., 2016; Patrício et al., 2016). Management agencies in developing countries should identify available indicators for marine assessment and categorize them according to reporting levels and relevant scale, like ecosystem threat status which is applied at a national scale, or Essential Ocean Variables (EOVs), which are applied at a more local scale (e.g., phytoplankton biomass) (Edgar et al., 2016; Miloslavich et al., 2018; Bax et al., 2019; Obura et al., 2019). These processes can help to identify existing gaps to monitoring ecosystem change under current and future pressures, with a view to informing appropriate management actions. Development of an indicator and assessment framework should be an objective, transparent, and inclusive process, which generates support for co-development (scientists, managers, and policymakers) and obtains consensus among stakeholders (McQuatters-Gollop et al., 2019; Stephenson et al., 2019; Lear et al., 2020; Karcher et al., 2022). Key to this is sector buy-in from government departments tasked with data collection, biodiversity assessment, and reporting.

For the third challenge of limited data, there are often more marine and coastal data available than are realized, and the challenge (and opportunity) is to increase collaboration to harness existing data and resources for biodiversity assessment. Using regular science gatherings, such as the Southern African Marine Science Symposium (SAMSS), can provide a platform to identify key stakeholders in the marine community and available datasets. In 2015, a national marine monitoring workshop was conducted to identify key marine datasets and identify monitoring needs for South Africa (Atkinson et al., 2016). South Africa also uses various national data platforms to make a range of datasets freely available for use and easily accessible (see examples in **Table 1**). The challenge here is to identify novel and innovative tools to increase collaboration and to develop a national database of key stakeholders and datasets, following FAIR (Findable, Accessible, Interoperable, and Reusable) principles. A potential way to do this is through the development of a mobile phone app or website to monitor students, researchers, and projects, including an incentivized program to implement this. Alternatively, a new database could be supported by existing data platforms, as seen in **Table 1**, which is already well supported in South Africa.

So far, positive outcomes from South Africa have provided examples of how to address the first three challenges; however, there are still many gaps that need to be filled, particularly related to the fourth and fifth challenges (**Figure 1A**). The recommendations and tangible actions outlined for these challenges require large effort with a few champions to drive these processes, yet to be achieved in South Africa. To address the fourth challenge of scattered initiatives and poor alignment, there is a need to develop an effective coordinated structure and framework of policymakers, practitioners, and scientists to enable co-development of assessment frameworks that are nested across multiple scales, linking to common objectives. The high number of sector role players tasked with managing activities and/or resources in the coastal and marine environment (e.g., fishing, water, biodiversity management, mining) (Taljaard et al., 2019) underpins the issue of scattered initiatives. A single management or research agency (e.g., SANBI in South Africa) needs to take ownership or responsibility of conducting biodiversity assessments at a national level, through collaborated efforts across sectors and stakeholder groups (Sink et al., 2019b). It is recommended that spatially explicit assessments at a national scale will be more effective for communicating results to policy and decision-makers than piecemeal assessments of individual ecosystem types (Botts et al., 2020). Through workshops and other training initiatives, improved knowledge generation and capacity building should be conducted with key actors in the policy and science realms, which will also enable the codesign of monitoring and assessment methods (McQuatters-Gollop et al., 2019; Rochette et al., 2019). Communicating results in an effective way for a specific target audience and being ready for new legislative developments are also key enabling conditions to improve co-development and collaboration between scientists and policymakers (Evans et al., 2019; Botts et al., 2020; Hetherington and Phillips, 2020). There is a need to develop a formal science-to-policy framework to improve communication and collaboration along these channels.

Tangible actions identified for the fifth challenge, relating to a lack of funding and resources, include the inclusion of indicators and biodiversity assessments into existing funded processes, as is done in the case of the National Biodiversity Assessment (Sink et al., 2019b). Ecosystem-level indicators are still missing from existing, regular national environmental and fisheries status reports. However, efforts are currently underway to develop ecosystem status reports that can be added to reports such as the annual "Status of the South African Marine Fisheries Resources" (DEFF, 2020). Government and management agencies should identify novel ways to leverage funding opportunities and sustainable financing solutions to minimize reliance on (not exclude) international donor funding (see other tangible actions in **Figure 1A**). Possible examples are provided by Emerton et al. (2006); Binet et al. (2015), and Riddell et al. (2020), including, but not limited to, payment for ecosystem services, environmental taxes, debt (i.e., blue bonds and debt-for-nature), and microfinance. In South Africa, progress has also been made in including natural capital accounting (including ocean accounts) into formal national budgets and economic reporting, which is supposed to help streamline funding channels for environmental activities and sustainable development (Potgieter, 2018; Findlay et al., 2020; Van Niekerk et al., 2020; Statistics South Africa, 2021). South Africa has also drafted a "Green Finance Taxonomy," which was published for consultation in June 2021, as a regulatory framework for sustainable finance including key objectives linked to marine resources (Government of South Africa, 2022).

Successful implementation of the proposed recommendations and tangible actions could lead to a more inclusive, coordinated, and holistic approach to managing marine and coastal resources, centered on environmental stewardship and effective use of available resources and capacity. Steps achieved in South Africa provided positive examples of how to overcome some of the challenges identified. The solution is to not reinvent the wheel but to apply international best practices in a local context to harness available data and capacity in a joint approach toward identifying key indicators that can be used for multiple sustainability objectives. The roadmap is presented to help guide an enabling environment with tangible actions to support the development of a codesigned indicator and assessment framework that can be taken up into policy. This framework would also guide biodiversity monitoring programs and research priorities, while achieving multiple reporting obligations.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**. Further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

All authors participated in the workshop from which this paper was developed. KPS drafted the manuscript and substantial input and revision was provided by LVN, LRH, LJS, KJS and AM-G. All authors contributed to the approved submitted version.

FUNDING

This project has received funding from the European Union's Horizon 2020 research and innovation program under Grant Agreement No. 862428 (MISSION ATLANTIC). LVN's involvement was funded through the Department of Science and Innovation (DSI) CSIR Parliamentary Grant. KJS acknowledges the ACEP Deep Connections project funded through the National Research Foundation (Grant 129216).

ACKNOWLEDGMENTS

We would like to thank all of the participants who attended the SANBI/UCT/Mission Atlantic ecosystem assessment workshop held in October 2021, from which the ideas and content from this paper were developed. We also thank the funders of the Mission Atlantic project, and we are also very grateful to Andrew Skowno for the valuable input on the manuscript. We would also like to thank the reviewer, Alida Bundy, for her comments and suggestions to improve the manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.886373/full#supplementary-material

REFERENCES

Andersen, J. J. H., Dahl, K., Göke, C., Hartvig, M., Murray, C. C., Rindorf, A., et al. (2014). Integrated Assessment of Marine Biodiversity Status Using a Prototype Indicator-Based Assessment Tool. *Front. Mar. Sci.* 1. doi: 10.3389/fmars.2014.00055

Atkinson, L., Sink, K., Raven, H., Franken, M.-L., and Terrapon, H. (2016). *SeaKeys Monitoring Working Group Workshop Report*. (South African Environmental Observation Network: Gqeberha, South Africa).

AU-IBAR (2019). *Africa Blue Economy Strategy* (African Union – Inter-African Bureau for Animal Resources:Nairobi, Kenya).

Bax, N. J., Miloslavich, P., Muller-Karger, F. E., Allain, V., Appeltans, W., Batten, S. D., et al. (2019). A Response to Scientific and Societal Needs for Marine Biological Observations. *Front. Mar. Sci.* 6. doi: 10.3389/fmars.2019.00395

Binet, T., Diazabakana, A., and Hernandez, S. (2015). *Sustainable Financing of Marine Protected Areas in the Mediterranean: A Financial Analysis*.Vertigo Lab, MedPAN, RAC/SPA, WWF Mediterranean, 114 pp.

Bland, L. M., Nicholson, E., Miller, R. M., Andrade, A., Carré, A., Etter, A., et al. (2019). Impacts of the IUCN Red List of Ecosystems on Conservation Policy and Practice. *Conserv. Lett.* 12, 1–8. doi: 10.1111/conl.12666

Bland, L. M., Watermeyer, K. E., Keith, D. A., Nicholson, E., Regan, T. J., and Shannon, L. J. (2018). Assessing Risks to Marine Ecosystems With Indicators , Ecosystem Models and Experts. *Biol. Conserv.* 227, 19–28. doi: 10.1016/j.biocon.2018.08.019

Borja, A., Galparsoro, I., Irigoien, X., Iriondo, A., Menchaca, I., Muxika, I., et al. (2011). Implementation of the European Marine Strategy Framework Directive: A Methodological Approach for the Assessment of Environmental

Status, From the Basque Country (Bay of Biscay). *Mar. pollut. Bull.* 62, 889–904. doi: 10.1016/j.marpolbul.2011.03.031

Borja, A., Garmendia, J. M., Menchaca, I., Uriarte, A., and Sagarmínaga, Y. (2019). Yes, We can! Large-Scale Integrative Assessment of European Regional Seas, Using Open Access Databases. *Front. Mar. Sci.* 6. doi: 10.3389/fmars.2019.00019

Botts, E. A., Skowno, A., Driver, A., Holness, S., Maze, K., Smith, T., et al. (2020). More Than Just a (Red) List: Over a Decade of Using South Africa's Threatened Ecosystems in Policy and Practice. *Biol. Conserv.* 246, 108559. doi: 10.1016/j.biocon.2020.108559

CBD (2021). First Draft of the Post-2020 Global Biodiversity Framework. Third meeting of the Open Ended Working Group on the Post-2020 Global Biodiversity Framework. 23 August – 3 September 2021. CBD/WG2020/3/3. Available online at: https://www.cbd.int/article/draft-1-global-biodiversity-framework.

Crain, C., Kroeker, K., and Halpern, B. S. (2008). Interactive and Cumulative Effects of Multiple Stressors in Marine Systems. *Ecology* 11, 1304–1315. doi: 10.1111/j.1461-0248.2008.01253.x

Department of Environmental Affairs (2016). National Protected Area Expansion Strategy for South Africa 2016. Department of Environmental Affairs:South Africa. http://bgis.sanbi.org/protectedareas/Nationa_Protected_Area_Expansion_Strategy.pdf.

DEFF (2020). *Status of the South African Marine Fishery Resources* (Department of Environment, Forestry and Fisheries:Cape Town, South Africa). Available at: https://www.azores.gov.pt/NR/rdonlyres/D21CF49B-EF59-4E76-88BD-5D0EEC3A2D4F/1098978/PlanoARPLAlcool.pdf.

Driver, A., Maze, K., Rouget, M., Lombard, A. T., Nel, J., Turpie, J. K., et al. (2005). *National Spatial Biodiversity Assessment 2004: Priorities for Biodiversity Conservation in South Africa* (Pretoria: Strelitzia 17).

Driver, A., Sink, K. J., Nel, J. N., Holness, S., Van Niekerk, L., Daniels, F., et al. (2012). *National Biodiversity Assessment 2011: An Assessment of South Africa's Biodiversity and Ecosystems* (Pretoria, South Africa: Synthesis Report). Available at: https://scholar.google.ch/scholar?hl=en&q=National+Biodiversity+Assessment+2011%3A+An+assessment+of+South+Africa's+biodiversity+and+ecosystems.+Synthesis+Report&btnG=&as_sdt=1%2C5&as_sdtp.

Edgar, G. J., Bates, A. E., Bird, T. J., Jones, A. H., Kininmonth, S., Stuart-Smith, R. D., et al. (2016). New Approaches to Marine Conservation Through Scaling Up of Ecological Data. *Ann. Rev. Mar. Sci.* 8, 150807173619006. doi: 10.1146/annurev-marine-122414-033921

Emerton, L., Bishop, J., and Thomas, L. (2006). *Sustainable Financing of Protected Areas : A Global Review of Challenges and Options* (The World Conservation Union (IUCN):Gland, Switzerland and Cambridge, UK). doi: 10.2305/iucn.ch.2005.pag.13.en

European Commission. (2010). Commission Decision of 1 September 2010 on criteria and methodological standards on good environmental status of marine waters. *Official Journal of the European Union, L 232/14(C(2010) 5956).*

Evans, K., Chiba, S., Bebianno, M. J., Garcia-Soto, C., Ojaveer, H., Park, C., et al. (2019). The Global Integrated World Ocean Assessment: Linking Observations to Science and Policy Across Multiple Scales. *Front. Mar. Sci.* 6. doi: 10.3389/fmars.2019.00298

Findlay, K. (2018). Operation Phakisa and unlocking South Africa's ocean economy. *Journal of the Indian Ocean Region*, 14(2), 248–254. doi: 10.1080/19480881.2018.1475857

Findlay, K., Obura, D., and Milligan, B. (2020). Policy Briefing Ocean Accounts: A Seachange Approach in Ocean Decision-Making. Policy Briefing 199. South African Institute of Internal Affairs.

Goldsmith, K. A., Granek, E. F., and Lubitow, A. (2015). Information Needs Assessment for Coastal and Marine Management and Policy: Ecosystem Services Under Changing Climatic, Land Use, and Demographic Conditions. *Environ. Manage.* 56, 1502–1513. doi: 10.1007/s00267-015-0576-z

Government of South Africa (2015). (National Biodiversity Strategy and Action Plan, Department of Environmental Affairs: Pretoria).

Government of South Africa (2022). *South African Green Finance Taxonomy 1st Edition.* (National Treasury, Republic of South Africa:Pretoria, South Africa).

Haase, P., Tonkin, J. D., Stoll, S., Burkhard, B., Frenzel, M., Geijzendorffer, I. R., et al. (2018). The Next Generation of Site-Based Long-Term Ecological Monitoring: Linking Essential Biodiversity Variables and Ecosystem Integrity. *Sci. Total Environ.* 613–614, 1376–1384. doi: 10.1016/j.scitotenv.2017.08.111

Halpern, B. S., and Floeter, S. R. (2008). Functional Diversity Responses to Changing Species Richness in Reef Fish Communities. *Mar Ecol Prog Ser* 364, 147–156. doi: 10.3354/meps07553

Halpern, B. S., Longo, C., Hardy, D., McLeod, K. L., Samhouri, J. F., Katona, S. K., et al. (2012). An Index to Assess the Health and Benefits of the Global Ocean. *Nature* 488, 615–620. doi: 10.1038/nature11397

Harris, L.R., Holness, S.D., Kirkman, S.P., Sink, K.J., , P., , M., Driver, A., et al. (2022a). National Coastal and Marine Spatial Biodiversity Plan Version 1.2 (Released: 12-04-2022). Nelson Mandela University, Department of Forestry, Fisheries and the Environment, and South African National Biodiversity Institute, South Africa.

Harris, L. R., Holness, S. D., Finke, G., Amunyela, M., Braby, R., Coelho, N., et al. (2022b). Practical Marine Spatial Management of Ecologically or Biologically Significant Marine Areas: Emerging Lessons From Evidence-Based Planning and Implementation in a Developing-World Context. *Front. Mar.* Sci. 9, 1–25. doi: 10.3389/fmars.2022.831678.

Harvey, C. J., Fluharty, D. L., Fogarty, M. J., Levin, P. S., Murawski, S. A., Schwing, F. B., et al. (2021). The Origin of NOAA's Integrated Ecosystem Assessment Program: A Retrospective and Prospective. *Coast. Manage.* 49, 9–25. doi: 10.1080/08920753.2021.1846110

Hetherington, E. D., and Phillips, A. A. (2020). A Scientist's Guide for Engaging in Policy in the United States. *Front. Mar. Sci.* 7. doi: 10.3389/fmars.2020.00409

Hooper, D. U., Chapin, F. S.III, and Ewel, J. J. (2005). Effects of Biodiversity on Ecosystem Functioning: A Consensus of Current Knowledge. *Ecol. Monogr.* 75, 3–35. doi: 10.1890/04-0922

Karcher, D. B., Cvitanovic, C., Putten, I. E., van, Colvin, R. M., Armitage, D., Aswani, S., et al. (2022). Lessons from bright-spots for advancing knowledge exchange at the interface of marine science and policy. 314, 114994.

Kirkman, S. P., Huggett, J., and Crawford, R. J. M. (2018). South Africa's ocean and coasts annual science report. Report No. 18. Department of Environmental Affairs, Pretoria, South Africa.

Knights, A. M., Koss, R. S., Papadopolulou, N., Cooper, L. H., and Robinson, L. A. (2011). Sustainable Use of European Regional Seas and the Role of the Marine Strategy Framework Directive, in *Deliverable 1, EC FP7 Project, (244273) 'Options for Delivering Ecosystem-Based Marine Management* (Liverpool, United Kingdom: University of Liverpool), 165 pp, ISBN: .

Lear, D., Herman, P., Van Hoey, G., Schepers, L., Tonné, N., Lipizer, M., et al. (2020). Supporting the Essential - Recommendations for the Development of Accessible and Interoperable Marine Biological Data Products. *Mar. Policy* 117, 103958. doi: 10.1016/j.marpol.2020.103958

Majiedt, P., Sink, K., Reed, J., Franken, M., Holness, S., Adams, L., et al. (2019). "Chapter 4: Pressures on the Marine Environment," in *National Biodiversity Assessment 2018 Technical Report Volume 4: Marine Realm*. Eds. N. Kareyni and S. Kirkman (Pretoria: South African National Biodiversity Institute). Available at: http://hdl.handle.net/20.500.12143/6372.

McQuatters-Gollop, A., Mitchell, I., Vina-Herbon, C., Bedford, J., Addison, P. F. E., Lynam, C. P., et al. (2019). From Science to Evidence - How Biodiversity Indicators can be Used for Effective Marine Conservation Policy and Management. *Front. Mar. Sci.* 6. doi: 10.3389/fmars.2019.00109

Micheli, F., Mumby, P. J., Brumbaugh, D. R., Broad, K., Dahlgren, C. P., Harborne, A. R., et al. (2014). High Vulnerability of Ecosystem Function and Services to Diversity Loss in Caribbean Coral Reefs. *Biol. Conserv.* 171, 186–194. doi: 10.1016/j.biocon.2013.12.029

Miloslavich, P., Bax, N. J., Simmons, S. E., Klein, E., Appeltans, W., Aburto-Oropeza, O., et al. (2018). Essential Ocean Variables for Global Sustained Observations of Biodiversity and Ecosystem Changes. *Glob. Change Biol.* 24, 2416–2433. doi: 10.1111/gcb.14108

Monaco, M. E., Spooner, E., Oakes, S. A., Harvey, C. J., and Kelble, C. R. (2021). Introduction to the NOAA Integrated Ecosystem Assessment Program: Advancing Ecosystem Based Management. *Coast. Manage.* 49, 1–8. doi: 10.1080/08920753.2021.1846109

Muller-Karger, F. E., Miloslavich, P., Bax, N. J., Simmons, S., Costello, M. J., Pinto, I. S., et al. (2018). Advancing Marine Biological Observations and Data Requirements of the Complementary Essential Ocean Variables (EOVs) and Essential Biodiversity Variables (EBVs) Frameworks. *Front. Mar. Sci.* 5. doi: 10.3389/fmars.2018.00211

Nicholson, E., Watermeyer, K. E., Rowland, J. A., Sato, C. F., Stevenson, S. L., Andrade, A., et al. (2021). Scientific Foundations for an Ecosystem Goal,

Milestones and Indicators for the Post-2020 Global Biodiversity Framework. *Nat. Ecol. Evol.* 5, 1338–1349. doi: 10.1038/s41559-021-01538-5

Obura, D. O., Aeby, G., Amornthammarong, N., Appeltans, W., Bax, N., Bishop, J., et al. (2019). Coral Reef Monitoring, Reef Assessment Technologies, and Ecosystem-Based Management. *Front. Mar. Sci.* 6. doi: 10.3389/fmars.2019.00580

Obura, D., Gudka, M., Samoilys, M., Osuka, K., Mbugua, J., Keith, D. A., et al. (2021a). Vulnerability to Collapse of Coral Reef Ecosystems in the Western Indian Ocean. *Nat. Sustain* 5, 104–113. doi: 10.1038/s41893-021-00817-0

Obura, D., Katerere, Y., Mayet, M., Kaelo, D., Msweli, S., Mather, K., et al. (2021b). Integrate Biodiversity Targets From Local to Global Levels. *Science* 373 (6556), 746–748. doi: 10.1126/science.abh2234

OECD (2020). "Sustainable Ocean for All: Harnessing the Benefits of Sustainable Ocean Economies for Developing Countries," in *The Development Dimension* (OECD Publishing:Paris). Available at: 10.1787/bede6513-en

Oesterwind, D., Rau, A., and Zaiko, A. (2016). Drivers and Pressures - Untangling the Terms Commonly Used in Marine Science and Policy. *J. Environ. Manage.* 181, 8–15. doi: 10.1016/j.jenvman.2016.05.058

Ojaveer, H., and Eero, M. (2011). Methodological Challenges in Assessing the Environmental Status of a Marine Ecosystem: Case Study of the Baltic Sea. *PloS One* 6, e19231. doi: 10.1371/journal.pone.0019231

Orejas, C., Kenchington, E., Rice, J., Kazanidis, G., Palialexis, A., Johnson, D., et al. (2020). Towards a Common Approach to the Assessment of the Environmental Status of Deep-Sea Ecosystems in Areas Beyond National Jurisdiction. *Mar. Policy* 121, 104182. doi: 10.1016/j.marpol.2020.104182

Patrício, J., Elliott, M., Mazik, K., Papadopoulou, K.-N., and Smith, C. J. (2016). DPSIR—Two Decades of Trying to Develop a Unifying Framework for Marine Environmental Management? *Front. Mar. Sci.* 3. doi: 10.3389/fmars.2016.00177

Pavlidou, A., Simboura, N., Pagou, κ., Assimakopoulou, G., Gerakaris, V., Hatzianestis, I., et al. (2019). Using a Holistic Ecosystem-Integrated Approach to Assess the Environmental Status of Saronikos Gulf, Eastern Mediterranean. *Ecol. Indic.* 96, 336–350. doi: 10.1016/j.ecolind.2018.09.007

Pedreschi, D., Bouch, P., Moriarty, M., Nixon, E., Knights, A. M., and Reid, D. G. (2019). Integrated Ecosystem Analysis in Irish Waters; Providing the Context for Ecosystem-Based Fisheries Management. *Fish. Res.* 209, 218–229. doi: 10.1016/j.fishres.2018.09.023

Piet, G. J., Jongbloed, R. H., Knights, A. M., Tamis, J. E., Paijmans, A. J., van der Sluis, M. T., et al. (2015). Evaluation of Ecosystem-Based Marine Management Strategies Based on Risk Assessment. *Biol. Conserv.* 186, 158–166. doi: 10.1016/j.biocon.2015.03.011

Potgieter, T. (2018). Oceans Economy, Blue Economy, and Security: Notes on the South African Potential and Developments. *J. Indian Ocean Reg.* 14, 49–70. doi: 10.1080/19480881.2018.1410962

Riddell, A. M., Esmail, N., Samoilys, M., Musembi, P., Kawaka, J., and Momanyi, J. (2020). *Review of Sustainable Financing for Community Based Marine Management Final Report* (CORDIO:Mombasa, Kenya).

Rochette, A. J., Akpona, J. D. T., Akpona, H. A., Akouehou, G. S., Kwezi, B. M., Djagoun, C. A. M. S., et al. (2019). Developing Policy-Relevant Biodiversity Indicators: Lessons Learnt From Case Studies in Africa. *Environ. Res. Lett.* 14, 035002 doi: 10.1088/1748-9326/aaf495

Rodríguez, J. P., Keith, D. A., Rodríguez-Clark, K. M., Murray, N. J., Nicholson, E., Regan, T. J., et al. (2015). A Practical Guide to the Application of the IUCN Red List of Ecosystems Criteria. *Philos. Trans. R. Soc B. Biol. Sci.* 370, 20140003. doi: 10.1098/rstb.2014.0003

Rowland, J. A., Bland, L. M., Keith, D. A., Juffe-Bignoli, D., Burgman, M. A., Etter, A., et al. (2019). Ecosystem Indices to Support Global Biodiversity Conservation. *Conserv. Lett.* 13, e12680. doi: 10.1111/conl.12680

Sink, K., Skowno, A., Holness, S., Franken, M., Majiedt, P., Atkinson, L., et al. (2019a). "Chapter 7: Ecosystem Threat Status," in *South African National Biodiversity Assessment 2018 Technical Report Volume 4: Marine Realm*(South African National Biodiversity Institute:Pretoria, South Africa). Eds. K. Sink, P. Majiedt, M.v. d. Bank, L. Harris, L. Atkinson, S. Kirkman, et al. Available at: http://hdl.handle.net/20.500.12143/6372.

Sink, K., van der Bank, M., Majiedt, P., Harris, L., Atkinson, L., Kirkman, S., et al. (2019b). *South African National Biodiversity Assessment 2018 Technical Report Volume 4: Marine Realm* (Pretoria, South Africa). Available at: http://hdl.handle.net/20.500.12143/6372.

Skern-Mauritzen, M., Olsen, E., and Huse, G. (2018). Opportunities for Advancing Ecosystem-Based Management in a Rapidly Changing, High Latitude Ecosystem. *ICES J. Mar. Sci.* 75, 2425–2433. doi: 10.1093/icesjms/fsy150

Skowno, A. L., Poole, C. J., Raimondo, D. C., Sink, K. J., Van Deventer, H., Van Niekerk, L., et al. (2019) *National Biodiversity Assessment 2018: The Status of South Africa's Ecosystems and Biodiversity - Synthesis Report*. Available at: http://opus.sanbi.org/handle /20.500.12143/6362.

Smit, K. P., Bernard, A. T. F., Lombard, A. T., and Sink, K. J. (2021). Assessing Marine Ecosystem Condition: A Review to Support Indicator Choice and Framework Development. *Ecol. Indic.* 121, 107148. doi: 10.1016/j.ecolind.2020.107148

Statistics South Africa (2021). "National Natural Capital Accounting Strategy," in *A Ten-Year Strategy for Advancing Natural Capital Accounting in South Africa*. Report 04-01-00. (Statistics South Africa, Republic of South Africa::Pretoria, South Africa)

Stephenson, R. L., Hobday, A. J., Cvitanovic, C., Alexander, K. A., Begg, G. A., Bustamante, R. H., et al. (2019). A Practical Framework for Implementing and Evaluating Integrated Management of Marine Activities. *Ocean Coast. Manage.* 177, 127–138. doi: 10.1016/j.ocecoaman.2019.04.008

Taljaard, S., van Niekerk, L., and Weerts, S. P. (2019). The Legal Landscape Governing South Africa'S Coastal Marine Environment – Helping With the 'Horrendogram.'. *Ocean Coast. Manage.* 178, 104801. doi: 10.1016/j.ocecoaman.2019.05.003

Teixeira, H., Berg, T., Uusitalo, L., Fürhaupter, K., Mazik, K., Lynam, C. P., et al. (2016). A Catalogue of Marine Biodiversity Indicators. *Front. Mar. Sci.* 3. doi: 10.3389/fmars.2016.00207

UNEP-Nairobi Convention and WIOMSA (2015). *The Regional State of the Coast Report: Western Indian Ocean* (UNEP:Nairobi, Kenya).

Van Niekerk, L., Taljaard, S., Adams, J. B., Lamberth, S. J., and Weerts, S. P. (2020). *Experimental Ecosystem Accounts for South Africa's Estuaries: Extent, Condition and Ecosystem Services Accounts* (South Africa: Council for Scientific and Industrial Research (CSIR). Available at: https://seea.un.org/content/experimental-ecosystem-accounts-south-africas-estuaries-extent-condition-and-ecosystem. Report produced by theReport No CSIR/SPLA/SECO/IR/2020/0026/A.

WWF-SA (2016). *Oceans Facts and Futures: Valuing South Africa's Ocean Economy* (WWF-SA:Cape Town, South Africa).

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Copyright © 2022 Smit, Van Niekerk, Harris, McQuatters-Gollop, Shannon and Sink. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.