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Coastal management – working towards the UN's Decade of Ocean Science for Sustainable Development (2021–2030)

The UN declared 2021-2030 as the Decade of Ocean Science and identified research and technology priority areas to achieve the 2030 Sustainable Development Goals. We reviewed the current status of scientific support for coastal management in South Africa within the context of these priorities and found promising development. However, challenges for the next decade remain, such as rolling out pilot projects into sustainable, national-scale programmes, facilitating greater collaboration and coordination among scientific role players, and achieving long-term commitment and political will for dedicated financial support. Through our lens as natural scientists we focused on the ecological system and coupling with the social system; however scientific support on better characterisation and understanding of the dynamics within the social system is also critical as sustainable development relies heavily on the willingness of the social system to embrace and execute related policies.

Significance:

- The UN Decade of Ocean Science (2021–2030) sets research and technology priority areas to achieve the 2030 Sustainable Development Goals.

- We found promising development in scientific support for coastal management in South Africa.

- Future challenges include greater collaboration and coordination among scientific role players and long-term commitment and political will for dedicated financial support.

Introduction

The rich natural resources of coasts have attracted humans for centuries, through supplying resources that sustain subsistence livelihoods and offering easy access to maritime trade, safe recreational use, and a sense of place. Coastal areas are outstripping the hinterland in terms of development driven by rapid economic growth and coastward migration.[1] Human pressures are changing the character of these areas, most noticeably over the past five decades with the trend expected to continue in future[2], coinciding with global impacts such as climate change, sea level rise, and ocean acidification.

In response to growing threats, the concept of coastal zone management emerged in the early 1970s and was first captured in the USA's *Coastal Zone Management Act*[3], triggered by the visible human impacts on coasts. In the 1980s, the term 'integrated' was added when it became clear that effective management required inter-sectoral collaboration, and inclusion of socio-economic concerns. Numerous scientific studies have since contributed to the body of knowledge on integrated coastal management (ICM) and deepened the understanding of practice worldwide.[3,4]

Despite considerable investment, the implementation of ICM appears to have been deficient because degradation of coastal ecosystems continues.[2] Also, coastal systems are losing their resilience and becoming more vulnerable to environmental disasters. Further, the socio-economic factors responsible for this decline occur increasingly at scales greater than that of the typical (local) scope of ICM. To be effective, an adaptive management strategy[5] needs to be embraced, working across scales, to allow a broader perspective of the workings of coupled coastal social and ecological systems (SESs)[6].

Coastal management has received much attention in South Africa, especially post-1994 since adopting a power-sharing democratic political system. Environmental legislation adopted a pluralistic slant, embracing governance systems such as ecosystem-based management[7] and ICM[3] through laws such as the *National Environmental Management Act* (NEMA) and the *National Environmental Management Act: Integrated Coastal Management Act* (ICM Act). In 2014, South Africa published the first National Coastal Management Programme to assist with ICM implementation.[8,9] While activity-based legislation remains critical, confusion and conflicts often arise from poor understanding of interlinkages and inherent complexities.[10-12]

Despite a significant overhaul of its approach to coastal management, South Africa is struggling to implement the policies to achieve desired outcomes.[13-15] Many factors are responsible for this challenge, not least of which are the high degree of collaboration and resource capacity required to achieve these outcomes.[13] Other major challenges include the absence of political support, inadequate institutional capacity, financial limitations, uncertainties in roles and responsibilities, and limited civil society involvement in decision-making.[15] Potential solutions posed centre on broader representation in ICM initiatives, revitalisation of public interest, improvement of cooperative governance, increased funding to coastal management, and a greater commitment to a more deliberative and collaborative governance approach.[15] Globally, the ineffectual efforts to manage threats on oceans and coasts seriously hamper the ability of nations to achieve the goals of the 2030 UN Agenda for Sustainable Development. In response, the UN declared 2021–2030 as the Decade of Ocean Science for Sustainable Development (UN Decade), aimed at creating

a common framework to strengthen ocean and coastal management for human benefit.[16,17]

South Africa's National Biodiversity Assessment of 2018 considers the coast as including all '…terrestrial and marine ecosystem types with strong coastal affinities…'[18]. Landwards, this includes vegetation types described as purely coastal or having a coastal affinity. Seawards, it includes all ecosystem types influenced by land stretching as far seaward as the inner shelf, including embayments, river-influenced systems, and estuaries. Using this ecological demarcation, we reviewed the current status of scientific support for coastal management in South Africa in the context of the UN Decade's seven research and technology priorities through our lens as natural scientists, focussing on scientific support for management of the coastal, nearshore domain, with less attention on the offshore, deeper oceanic areas.

Role of scientific information and knowledge in coastal management

The coast can be viewed as a SES connected by the flow of ecosystem services (Figure 1).[19,20] Within this system, components can negatively impact each other, for example, environmental hazards can threaten the social component, while human interference can degrade the ecological component. Coastal management is depicted as the 'hands' protecting the system's integrity by coordinating interactions within the SES to sustain co-existence. Practising the scientific method generates reliable evidence-based information that can be used to understand processes within the SES. Scientific knowledge, therefore, is viewed as a knowledge type informing coastal policy development and management rather than advocating specific policy outcomes.[21,22]

The role of scientific information and knowledge in managing coastal SESs not only entails studying the characteristics and dynamics within each component but also determining how they interact with each other.

Scientific studies should take into account place-based values and uncertainties relevant to policy imperatives. In South Africa, collaboration among coastal scientists and policymakers, especially at national and provincial tiers, has been growing since the promulgation of people-centred environmental legislation post-1994.[10,12] It is common practice for government departments to engage with scientists in research councils, institutions, and environmental consultancies, to assist with development of policies, guidelines and management strategies. With a few exceptions (e.g. fisheries), departments do not possess strong in-house scientific capacity and need external support. This, perhaps unintentionally, has led to a close collaboration between scientists and policymakers. It has not, however, lessened the serious challenges facing policy implementation and the growing need for science-based knowledge to lay the foundation for prudent coastal management in future.

UN's Priorities for Decade of Ocean Science for Sustainable Development (2021–2030)

The Decade is viewed as '…a once in a lifetime opportunity to create a new foundation, across the science-policy interface, to strengthen the management of our oceans and coasts for the benefit of humanity…' with a vision of '…developing scientific knowledge, build infrastructure and foster partnerships for sustainable and healthy ocean and coasts…' to deliver the underpinning scientific information to achieve the 2030 Sustainable Development Goals.[16,17] Role players, including scientists, are encouraged to go beyond 'business as usual' and develop innovative solutions for ocean and coastal sustainability. Such solutions should support the integration in the SES, and recognise trade-offs within.[23] The Decade aims to achieve six outcomes: oceans (and coasts) are (1) clean,(2) healthy and resilient, (3) predicted, (4) safe, (5) sustainably harvested and productive, and (6) transparent and accessible.[18] Although science is not the only route to success, seven research and technology priority areas are seen as necessary to achieving these outcomes on
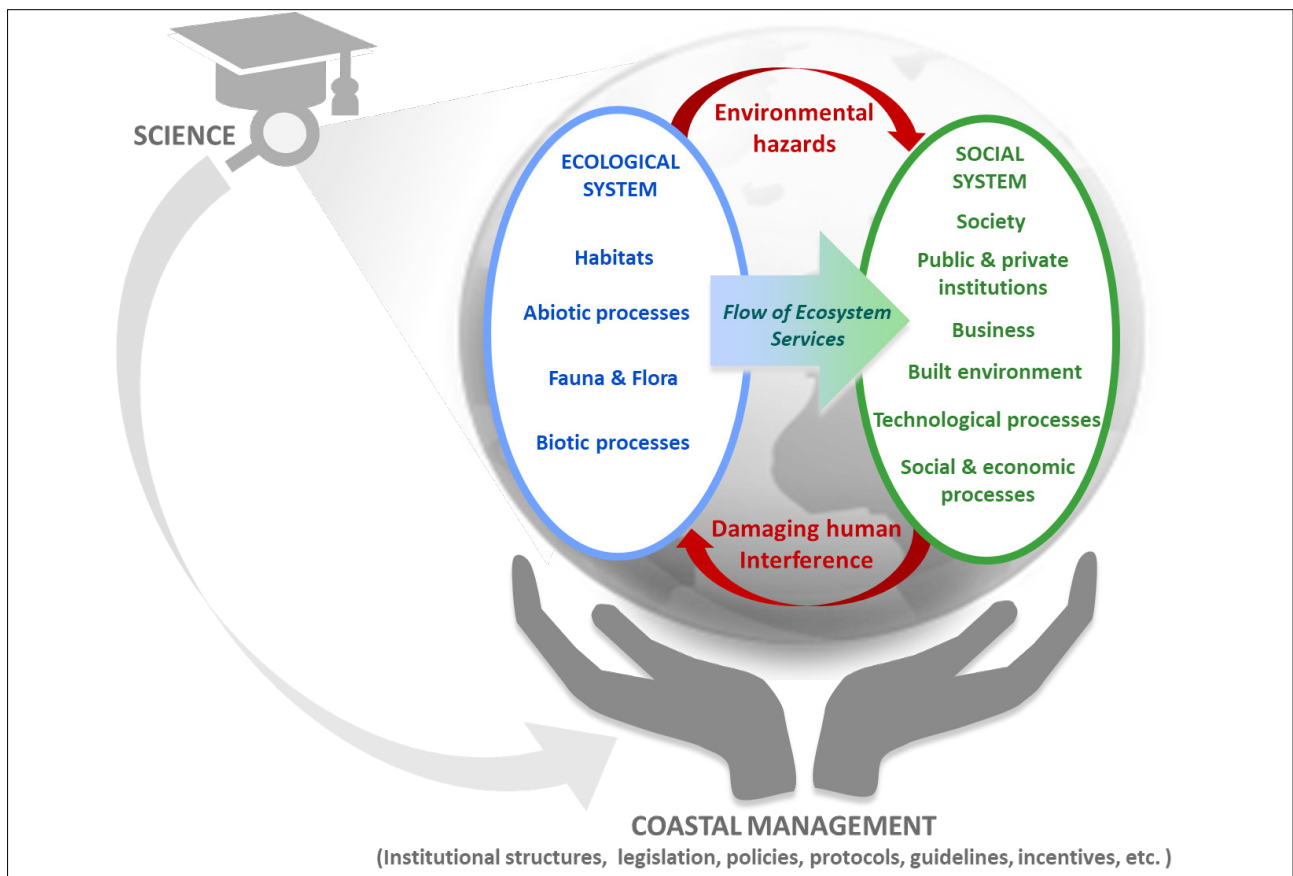

Figure 1: Conceptualisation of a coastal social-ecological system, as well as the role of coastal management and science.

both global and local scales, that is (1) geo-referenced digital atlases, (2) ocean observing systems (especially for major basins); (3) quantitative understanding of ocean ecosystems and their functioning as basis for management and adaptation; (4) ocean data and information portals; (5) integrated multi-hazard warning systems; (6) oceans in earth-system observation, research and prediction (prediction capabilities); and (7) capacity development and accelerated technology transfer, training and education.[16,17]

While the UN Decade aims to facilitate science–policy collaboration at the global ocean scale, its vision, goals and priorities can also guide nested, national-scale initiatives towards achieving the Sustainable Development Goals. We review the status of scientific support for coastal management in South Africa to see if we are on the right track.

Status of scientific support for coastal management in South Africa

Geo-referenced digital atlases

Internet-based digital atlases are increasingly accessible and of great value to role players interested in coastal issues[24], also for South Africa. The recent National Biodiversity Assessment has identified and mapped coastal and estuarine ecosystem types, as well as their ecological condition, ecosystem threat status and protection levels[18,25] (Table 1). Further, the *Green Book – Adapting Settlements for the Future* generated spatially referenced information on current and future settlement patterns and their vulnerability (Table 1). Land-use development planning is captured by municipalities in their Spatial Development Frameworks as mandated under the *Spatial Planning and Land Use Management Act (No. 16 of 2013)*, although these frameworks do not include the area seaward of the high-water mark. Spatial development planning in the coast and oceans is mostly sectoral (e.g. mining, fisheries, conservation), mandated to the responsible national department. With the promulgation of the *Marine Spatial Planning Act (No 16 of 2018)*, national government poses a mechanism for the coordination of spatial development planning within coasts and oceans, supported by a Marine Spatial Planning Tool being developed as part of the national Oceans and Coastal Information Management System (OCIMS) (Table 1) – an initiative between the Department of Forestry, Fisheries and the Environment and the Department of Science and Innovation (DSI) under Operation Phakisa, an initiative aimed at unlocking the economic potential of coastal and ocean resources. OCIMS's vision is to develop a national platform for the dissemination of data from authoritative sources. Also available is a coastal viewer, which provides spatial information pertaining to coastal public property and the coastal protection zone, as defined in the ICM Act.

Table 1: Summary of existing scientific initiatives aligned with the UN Decade's priorities supporting coastal management in South Africa

	UN Decade priorities	EXISTING INITIATIVES IN SOUTH AFRICA
1	Geo-referenced digital atlases	South African National Biodiversity Assessment: Biodiversity GIS (http://bgis.sanbi.org/) The Greenbook (https://greenbook.co.za/) South Africa's National Oceans and Coastal Information Management System (OCIMS) (www.ocims.gov.za/)
2	Observing systems	OCIMS (www.ocims.gov.za/) Transnet National Ports Authority (TNPA) Wavenet (http://wavenet.csir.co.za/) Acoustic Tracking Array Platform (South African Institute for Aquatic Biodiversity) (www.saiab.ac.za/atap.htm) South African Weather Service (http://marine.weathersa.co.za/Observations_Home.html) Ecosystem long-term ecological research sampling stations (https://smcri.saeon.ac.za/SentinelSites/AlgoaBay) Beach water quality monitoring, City of Cape Town (http://www.capetown.gov.za/Explore%20and%20enjoy/nature-and-outdoors/our-precious-biodiversity/coastal-water-quality) Beach water quality monitoring, eThekwini Municipality (http://www.durban.gov.za/City_Services/water_sanitation/Water_Quality/Pages/Beach_Water_Quality.aspx) National Pollution Laboratory, Walter Sisulu University (http://www.wsu.ac.za/waltersisulu/index.php/wsu-hosts-national-pollution-lab/)
3	Building understanding on ecosystem functioning	SANCOR (https://sancor.nrf.ac.za/) *African Journal of Marine Science* (www.ajol.info/index.php/ajms/) NRF Community of Practice (https://www.nrf.ac.za/division/funding/communities-practice)
4	Data and information portals	Southern African Data Centre for Oceanography, hosted by Marine Information Management System (http://data.ocean.gov.za/) National Ocean and Coastal Information Systems (OCIMS) (www.ocims.gov.za/) An interactive web-based information portal – CoastKZN (www.coastkzn.co.za/) South African Estuary Information System (https://saeis.saeon.ac.za/) Estuary botanical database hosted by Nelson Mandela University (http://opus.sanbi.org/handle/20.500.12143/6707) Barcode of Life Data System (BOLD) (http://boldsystems.org)
5	Prediction capabilities	OCIMS (https://www.ocims.gov.za/) SAWS (http://marine.weathersa.co.za/)
6	Multi-hazard warning systems	
7	Capacity building and technology transfer	NRF initiatives: Career Advancement, Thuthuka and Phuhlisa programmes (http://www.nrf.ac.za) NRF's Marine and Coastal Research funding instrument. Marine Research Plan (2014–2024) theme – with coastal and marine resources, society and development as one of the themes (https://www.nrf.ac.za/sites/default/files/documents/Marine%20and%20Coastal%20Research%20Framework%202019.pdf) Marine and Coastal Educators Network, pilot testing inclusion of Marine Science as a subject at school (https://www.aquarium.co.za/blog/entry/new-marine-sciences-school-subject-for-grade-10-learners-in-2019#) One Ocean Hub funded by Global Challenge Research Fund (https://oneoceanhub.org/) Two Oceans Aquarium, Cape Town (https://www.aquarium.co.za/) Ushaka Marine World, Durban (https://ushakamarineworld.co.za/)

While progress has been made with the development of platforms to collate digital, spatially referenced environmental data and information relevant to coastal management, the challenge ahead is to expand the spatial coverage, and ensure its longevity through proper institutionalisation and allocation of dedicated resources. These platforms often experience a slow decline following the termination of initial development funding or the departure of enthusiastic champions who usually push their development. The production of countrywide digital coastal atlases cannot be achieved by government alone and will require formalised and funded partnerships with coastal scientists across tertiary and scientific institutions. Furthermore, cross-coordination and collaboration between platform custodians is critical, not only to ensure compatibility (e.g. standardisation of spatial mapping tools and protocols), but for quality control and cross-verification of spatial information to prevent overlap or conflicting messages.

Observing systems

The primary purpose of observing systems is to gather long-term data for the purposes of (1) building understanding on physical, chemical and biological processes and genetics; (2) characterising and understanding long-term changes and the role of global processes such as climate change; (3) understanding and quantifying specific and cumulative impacts of anthropogenic pressures; and (4) characterising and understanding the impacts of, and resilience to, extreme events.[26-28]

The South African coast is geomorphologically and ecologically complex and diverse, and supports at least 216 ecosystem types.[18] This complexity and diversity poses unique challenges for coastal ocean observing systems such as locating observing stations to develop representative pictures of regional and local conditions.[29] Operational management of health and safety associated with coastal and maritime activities such as maritime commerce, commercial fishing, recreation, search and rescue, and pollution management benefit greatly from coastal ocean observing systems.[29,30]

In South Africa, the national fisheries department has had the most success in sustaining long-term observing systems, linked to sustainable fisheries management initiatives.[31] Other observing systems were launched but were generally small in scope with unproven sustainability.[26] Transnet, the National Ports Authority, runs a network of buoys that collect real-time wave and wind data at major ports (Table 1), primarily to guide shipping operations but they have also proven valuable in assessing coastal vulnerability. Observing systems currently operational on the OCIMS platform include vessel movement tracking, harmful algal blooms, coastal sea state, and marine predators. The South African Institute for Aquatic Biodiversity manages the Acoustic Tracking Array Platform (Table 1), in partnership with the Canada-based global Ocean Tracking Network, using acoustic telemetry to track the movement of various species, especially those pertaining to resource management.[32]

Robotics (e.g. wave gliders) provides a cost-efficient survey technique that can function over large spatial and temporal scales.[33] The South African Weather Service (SAWS) have developed observing capacity in the country's coastal oceans using in-situ and remotely sensed tools (Table 1). Observations include sea-surface temperature and height, and surface currents. Remotely sensed satellite data (e.g. sea-surface temperatures, altimetry, ocean colour) are also increasingly applied in coastal observing systems through OCIMS (Table 1). Some metropolitan municipalities (e.g. City of Cape Town and eThekwini) support beach water quality observing systems, while a National Pollution Laboratory has been established at Walter Sisulu University to house coastal pollution observing systems (Table 1).

High-resolution observing systems are especially important in urban nodes, with them often situated along sheltered bays where anthropogenic pressures and management interventions are the most critical. Responding to this need, the Elwandle Coastal Node of the South African Environmental Observation Network (SAEON) launched the Algoa Bay Sentinel Site (Port Elizabeth and surrounds) in 2008, setting up several in-situ sensor moorings and acoustic receivers, estuary sensor moorings, and pelagic long-term research sampling stations (Table 1). Recently, the DSI, in conjunction with the National Research Foundation (NRF) and Nelson Mandela University (NMU), launched the shallow marine and coastal infrastructure initiative to provide instrumentation and platforms for the long-term observation of coastal regions and offshore islands.[34]

While there has been progress in expanding coastal observing systems, many of these are still in pilot phases, or are limited to specific areas, and will require extensive resources and commitment to roll out at the national scale. Remote sensing is a priority for future large-scale coastal and marine observing systems but cannot generate data on sub-surface processes. Deployment of fixed moorings and technologies such as autonomous floats and drones will be necessary to explore relationships among physical, chemical and biological processes and environmental change – critical for effective coastal management. Development of observing systems faces many challenges. Setting up instruments at sea, deploying vessels and ship's time are all costly. With dwindling financial resources, advances in observing systems will need to be prioritised and more effort made to coordinate use between role players such as government departments, public institutions such as the CSIR, SAWS, and SAEON, and private sector collaborators.

Building understanding on ecosystem functioning

In contrast to coastal ecosystem observing systems, South Africa has a rich history of coastal research undertaken by academic institutions, independent research organisations and science councils. National funding bodies such as the NRF and Water Research Commission have consistently supported research within the coastal space, as have international organisations including the Global Environmental Fund and United National Environmental Programme. Serving an advisory role, the South African Network for Coastal and Oceanic Research (SANCOR) is a non-statutory body established to generate and communicate knowledge and advice for policy development, use and management of coastal resources (Table 1) such as SEAChange, a successful research programme of which outcomes have been summarised in a special issue of the *African Journal of Marine Science* (Table 1). This journal also publishes papers on the conservation and management of living resources, relevant social science and governance, and new techniques. These knowledge sources provide a comprehensive bank of evidence-based information available to support government in formulating coastal policy and making ecologically prudent management decisions.

However, there is much still to be learnt, especially in the realm of global impacts on coastal ecosystems. With dwindling funding and growing competition for limited financial resources, interdisciplinary collaboration across institutions will be required to address such issues. In the past, large thematic research programmes created successful collaborative platforms such as the Benguela Ecology Programme, African Coelacanth Ecosystem Programme, and KwaZulu-Natal Bight Project.[25,35] Currently, the NRF's Marine and Coastal Research funding instrument together with the 2014–2024 Marine Research Plan, supports research and capacity development in coastal sectors (Table 1). The NRF's Community-of-Practice research programmes (Table 1) promote multidisciplinary SESs research, for example in Algoa Bay.[36]

Data and information portals

Since the 1960s, the Southern African Data Centre for Oceanography has curated, archived and disseminated marine and coastal data, now hosted through the Marine Information Management System (Table 1). At provincial level, CoastKZN is an interactive web-based information portal providing information on KwaZulu-Natal's coastal and estuarine environments (Table 1). SAEON has developed the South African Estuary Information System to ensure long-term data are archived and made accessible as a national asset (Table 1). NMU hosts an Estuary Botanical Database[37] that stores information on area coverage and species composition of habitat types in South African estuaries (Table 1).

While there has been progress in the development of web-based portals to support coastal management, their sustainability depends on the support of the scientific community and government's commitment

to long-term quality control, management and portal maintenance. Issues of data accessibility, ownership, quality, lack of awareness, and fragmentation in the acquisition and management of data across institutions often hamper the optimal use of resources. Frequently different formats and standards hamper efficiencies in locating, assembling and using available data, thus necessitating valuable time in acquiring even the most basic data and information, or recreating existing data sets. A solution is the development of portals with common web-based interfaces that provide fast and easy access to coastal data and information sources, both historical and real-time.[38] Global examples of open-source information on marine data include the Ocean Biogeographic Information System (OBIS) that stores data submitted through regional nodes (e.g. AfrOBIS).[39] The Barcode of Life Data System houses genetic information on South African species (Table 1), including coastal species.[28]

Prediction capabilities

Increasingly, conflicting uses of coastal resources are making uncoordinated silo-based (or sector-based) planning and management ineffective.[12] Integrative, scientific capabilities such as those of numerical and system dynamics modelling are required to provide support in addressing such inefficiencies, especially within high-use urban nodes[40], providing pro-active means of forecasting future scenarios for negotiation among all decision-makers[17,41]. Through OCIMS, South Africa is progressing with forecasting of key environmental variables such as winds, currents, and waves (i.e. the Coastal Operations at Sea Platform), as is SAWS, by applying technologies such as remote sensing, numerical modelling, and machine learning (Table 1).

Inclusion of emerging technologies, such as machine learning and artificial intelligence, holds great advantages for future predictive capabilities, while system dynamics modelling allows for contextualising responses to future scenarios in complex systems.[42,43] Concepts such as 'Building with Nature'[44] can be combined with coastal environmental sciences through disciplines such as engineering and architecture to align natural and engineered systems for future benefits. While these technologies and approaches are being applied to coastal planning at the project level and in forecasting change in specific variables, they have not yet been applied to resolving complex cross-disciplinary ecosystem dynamics, or in testing multi-use strategies for ICM. Advancements in future predictive capabilities in support of ICM will benefit greatly from such transdisciplinary collaboration.

Multi-hazard warning systems

Pro-active responses to hazards require early warning systems, preferably for responding simultaneously to multi-hazards associated with coastal erosion, flooding, sea level rise, storm surges and cyclones.[17,45] Effective early warning systems are not restricted to detection, monitoring and forecasting, but also include risk analysis, timeous dissemination of warnings, and preparation of appropriate emergency plans.[46]

Through OCIMS, progress is being made in providing a consolidated platform for detection, monitoring and forecasting of coastal hazards along South Africa's coast (Table 1). For example, the Coastal Flood Hazard Decision Support Tool aims to identify coastal areas at risk of flooding, and the Fisheries and Aquaculture Decision Support Tool will provide a capability for monitoring and assessing risk of harmful algal blooms. SAWS also have been developing early warning hazard support tools such as the Storm Surge Forecasting System (Table 1). However, key elements, such as timely dissemination of warnings and wide-scale formalisation of emergency response plans, need to be further developed. Also, early warning information on the African continent needs to address language barriers and consider available mobile phone technologies.[47,48]

Capacity development and technology transfer

The elements essential to achieve science support for coastal management include human potential, infrastructure, cooperation, resources, and adequate social conditions for successful R&D.[18] For the UN Decade objectives, countries like South Africa will need to strengthen

their capacity and technological know-how through education and training.[49] At national level, the DSI and NRF Centres of Excellence and National Research Chairs aim to address such capacity building. Eight Research Chairs focus on coastal research, strengthening the ability of universities to produce high-quality research and capable students. Dedicated university institutes, such as the Institute for Coastal and Marine Research (at NMU), International Ocean Institute of Southern Africa (at University of the Western Cape) and Marine Research Institute (at University of Cape Town), also contribute to research capacity. NMU, in collaboration with CSIR, CapeNature, the Western Cape government, and the Department of Forestry, Fisheries and the Environment, also offers a longstanding training programme on estuary management. Numerous initiatives under the NRF also are at work to advance marine sciences (Table 1). The SEAmester, launched in 2016, is the first floating university introducing postgraduate students and interns to marine science.[50] South Africa has a long history of international collaboration on coastal and marine research – another important avenue for building capacity and ensuring high-quality research outputs. A recent initiative driving SES research is the One Ocean Hub funded by the Global Challenge Research Fund, which seeks to bridge current disconnections in law, science and policy and integrate governance frameworks to balance multiple ocean uses with conservation (Table 1).

Oceanariums, such as the Two Oceans Aquarium and uShaka Marine World (Table 1), play an important role in stimulating public awareness, as do non-government organisations such as the Wildlife & Environment Society of South Africa, WildOceans, Oceans Research, Knysna Basin Research, Sustainable Seas Trust, and the African Marine Waste Network. To promote coastal sciences within the education system, the Marine and Coastal Educators Network, a group affiliated with SANCOR, coordinates activities, and shares experiences and materials to energise upcoming generations in marine and coastal sciences. The inclusion of Marine Science as a subject at school level is an important advance that was pilot tested in 2019 (Table 1).

Reflection on the way forward

We reviewed the current status of scientific support for coastal management in South Africa within the context of the seven research and technology priority areas of the UN Decade. While good progress has been made in developing platforms for collating *spatially referenced environmental atlases*, the challenge ahead is to expand the spatial coverage of data and information, and ensure its longevity through proper institutionalisation and allocation of dedicated resources beyond the development funding phases, and to facilitate cross-coordination and collaboration between platform custodians. Similarly, development of coastal *observing systems* and *web-based data and information portals* for coastal management has also progressed but will require extensive effort and commitment to roll out at the national scale. With dwindling financial resources, advances in observing systems will need to be prioritised and more effort made to coordinate use between role players. *Building understanding on ecosystem functioning* can be strengthened through large-scale thematic research programmes necessary to provide a quantitative understanding of coastal ecosystems.

Future *predictive capabilities*, especially within high-use urban nodes, will require integrative capabilities to address cross-sectoral interdependencies and conflicts. Inclusion of emerging technologies, such as machine learning and artificial intelligence, hold great advantages in term of such predictive capabilities, while system dynamics modelling can assist with assessing the complexities inherent in coastal social-ecological systems and provide useful ways of visualising and testing system behaviour within different development scenarios. Solutions through concepts like 'Working with Nature' and 'Building with Nature' can also facilitate collaboration with engineering and architecture to achieve greater harmonisation between natural and engineered systems. Initiatives, like OCIMS, are giving the environmental aspects of *early warning systems* along South Africa's coast renewed attention. However other key elements of multi-hazard warning systems, such as timely dissemination of warnings and wide-scale formalisation of emergency response plans, need to be further developed, as early

warning information may not always reach those at highest risk. *Capacity development* is supported by many national efforts that should be upscaled to ensure transformation and quality research outputs. Both national and international networks are important in developing skills and expertise.

Promising development has been occurring in many of the UN Decade priority areas for research and technology. However, challenges for the next decade remain, such as rolling out developmental phases into sustainable, national-scale programmes, facilitating greater collaboration and coordination among role players, and achieving long-term commitment and political will for dedicated financial support for human and technological capacity development, both in the generation and dissemination of related scientific knowledge. Our lens focused on the ecological system and coupling with the social system, but scientific support on better characterisation and understanding of the dynamics within the social system is also critical. Ultimately, sustainable development within the coastal social-ecological system relies heavily on the willingness of the social system to embrace and execute related policies.

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Competing interests

We have no competing interests to declare.

Authors' contributions

S.T.: Formulation of overarching construction and content of manuscript; experiential knowledge and analysis of available data and information; preparation and creation of manuscript. J.A.: Experiential knowledge and analysis of available data and information; significant contribution to preparation and creation of manuscript.

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