A National Marine Research Plan for South Africa, 2014+

Prepared for

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By

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List of Acronyms

ACCESS	Applied Centre for Climate and Earth System Science
ACEP	African Coelacanth Ecosystems Programme
ADCP	Acoustic Doppler Current Profiler
ASCLME	Agulhas Somali Currents large Marine Ecosystem Project
BEP	Benguela Ecology Programme
BRUV	Baited Remote Underwater Video
CC	Climate Change
COE	Centre of Excellence
CSIR	Council for Scientific and Industrial Research
CTD	Conductivity, Temperature, Density
DACST	Department of Arts, Culture, Science and Technology
DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
DNA	Deoxyribonucleic Acid
DOT	Department of Tourism
DPS	Dynamic Positioning System
DST	Department of Science and Technology
DWA	Department of Water Affairs
EAF	Ecosystems Approach to Fisheries
EEZ	Extended Economic Zone
ENSO	El Niño Southern Oscillation
FAO	Food and Agriculture Organisation
GC	Global Change
GCGC	Global Change Grand Challenge
HBU	Historical Black University
HEI	Higher Education Institution
ICSU	International Council for Science
IPCC	International Panel on Climate Change
LTER	Long Term Environmental Research
MCEN	National Marine and Coastal Educators Network
mRNA	Messenger Ribonucleic Acid
MPA	Marine Protected Area
MW	Mega Watt
NBA	National Biodiversity Assessment
NGO	Non-Government Organisation
NGS	Next Generation Sequencing
NRF	National Research Foundation
NSI	National System of Innovation
ORI	Oceanographic Research Institute
RAD	Restriction site Associated DNA
ROV	Remote Operated Vehicle

SADCO	South African Data Centre for Oceanography
SANCOR	South African Network for Coastal and Oceanic Research
SAEON	South African Environmental Observatory Network
SAIAB	South African Institute for Aquatic Biodiversity
SARChi	South African Research Chairs Initiative
SIBER	Sustained Indian Ocean Biogeochemistry and Ecosystem Research
SNP	Single Nucleotide Polymorphism
SWIOFP	South-Western Indian Ocean Fisheries Programme
S&T	Science and Technology
UCE	Ultra-conserved Elements
UCT	University of Cape Town
UKZN	University of KwaZulu-Natal
UP	University of Pretoria
WIOMSA	Western Indian Ocean Marine Science Association
WIO-SAPPHIRE	Western Indian Ocean LMEs – Strategic Action Programme Policy Harmonization and Institutional Reforms
WSSD	World Summit for Sustainable Development

Executive Summary

This report considers a strategic plan for scientific research into the coastal and marine sectors in South Africa. It is premised on the base of the Global Change Grand Challenge (GCGC) that has a particular relevance for setting the agenda for marine research within the 10 year timeframe (2008-2018) (DST 2009).

The geographical advantage of South Africa derives from its peninsular position at the southern tip of Africa between the Atlantic and Indian Oceans. Here it separates the northerly deflected cold South Atlantic waters via the Benguela Current on the West Coast, from the southerly directed warm Indian Ocean Agulhas Current along the East Coast. Each system will be subject to different spectral changes due to Global and Climate Change dynamics, and all can be observed and researched ideally from South Africa.

The plan considers current international trends and priorities, of which understanding the role of biodiversity in maintaining ecosystems functionality, the relationships between human pressures and ecosystems, and the impact of Global Change on marine ecosystems are fundamental. In addition, several actions are required to address current problems, namely, assessing marine ecosystems health in an integrative way; delivering ecosystems services by conserving and protecting our seas; recovering ecosystem structure and functioning through restoration; managing the seas using the ecosystems approach and spatial planning; and modeling ecosystems for better management.

Themes

Within the Challenge of Global Change four priority areas were identified for research in South Africa, viz. (i) understanding the ocean as part of a coupled regional system, (ii) the risks and responsibilities of ecologically sustainable coastal development, (iii) the response of coastal and marine ecosystems and ecosystem services to Global Change, and (iv) operational capabilities, marine science for society. Consequently three 'Themes' are considered.

Theme 1: Oceans and marine ecosystems under global change

The oceanography of southern African ocean circulation has received much attention in recent years and new understandings are emerging. Current oceanographic research is focusing on mesoscale processes in the Mozambique Channel, the Agulhas retroflection and leakage of warm, salty waters into the Atlantic Ocean, with concurrent studies of their influences on biogeochemical cycles, biological productivity and living marine resources.

It is important that South Africa further develop the capacity for understanding and predicting the state of the ocean and its ecosystems, and the capacity and systems to incorporate such knowledge into policy and management. To do this requires multi-, inter- and cross-disciplinary approaches to marine science with explicit links to stakeholder requirements.

A recent review indicated that there are insufficient baseline data to disentangle short- and medium-term variability from long-term change. Where large-scale ecosystem changes have been observed, it was generally not possible to attribute these changes to specific pressures.

Global change pressures include climate change, increases in sea-level rise and wave heights, and the impact that these changes will have on coastal ecosystems, towns and cities. Increasing water pollution within the coastal zone and reduced river flow to estuaries and the coastal zone are issues to be researched. Coastal bio-invasions, particularly by alien plant and invertebrate species, require attention. Management of coastal ecosystems under global change scenarios requires scientific and socio-economic information for wise management decision making.

The Priority Focus Area of this Theme is the southern African ocean in the coupled earth system. The aims are to attain an understanding of the linkages in the coupled earth system, and the emphasis is on the development of disciplinary knowledge and knowledge at the interface of different disciplines.

Theme 2: Ecosystems, Biodiversity & Biodiscovery

Two sub-themes occur,

A. Biodiversity and Ecosystem responses to global and climate change.

There are three focal areas:

Focal Area 1: Understanding scales of biodiversity from molecular to ecosystem. Whilst a broad understanding of ecosystem functioning is known there are several specific areas where knowledge is weak including modeling, microbial ecology and the very poorly explored sub-tidal and offshore pelagic areas. Habitat mapping and conservation planning, soft sediment biota and smaller taxa/microbial taxonomy are still poorly known or described and investigations into the genetic diversity of marine organisms is in its infancy. Although modern molecular techniques are being applied to identify organisms the development of a reference barcode library is still at an early stage. Linking biodiversity knowledge to ecosystem functioning (in both applied and theoretical fields) is largely non-existent.

Focal Area 2: Connectivity between terrestrial, coastal and marine systems.

Good progress has been made over the last 15 years in understanding river-estuary interactions. This research has been translated into management and scientific decision-making protocols. Further work scaling up from individual systems to regional impacts and understanding the connectivity of systems is required.

Focal Area 3: Understanding natural and anthropogenic drivers of change. The broader understanding of both natural and anthropogenic drivers on natural and transformed ecosystems, especially in terms of predictive capacity, is largely lacking for coastal ecosystems. Coastal fisheries have received some attention, in particular the application of an Ecosystem Approach to Fisheries for the west coast fisheries. There is little to no knowledge on drivers for whole ecosystem functioning on other South African ecosystems in terms of modeling frameworks and scenario building. Questions of limits to system transformation and tipping points of ecosystems have not been addressed for South African marine systems.

B. Biodiscovery & Biotechnology

Marine bioprospecting or biodiscovery and Marine biotechnology have significant potential for achievement of the Grand Challenge 'Farmer to Pharma' and therefore are a relevant subtheme in this plan.

There is a single Priority Focal Area 1: Biodiversity and Biodiscovery. Both sectors are in relative infancy. Some capacity exists in marine natural products chemistry, and there are established international collaborative networks in this area. There is a significant lack of capacity in taxonomy and in particular the molecular taxonomy of marine organisms.

Theme 3: Coastal and marine resources, society and development

Coastal ecosystems are highly vulnerable to human-mediated drivers of global change because they are located at the land–ocean interface and often host centres of urbanisation and development (Mead, *et al*., 2013). At present the physical development of coastal areas is intense and pressures on coastal and marine environments are rising rapidly. Research that focuses on the interface between resources, society and development is of high priority.

Maintaining the long-term prosperity and sustainability of marine fisheries is not only of political and social significance but also of economic and ecological importance.

There has been an upsurge in offshore exploration within the South African EEZ and extensive mineral exploration concessions have been granted for large parts of South Africa's EEZ marine sectors.

The development of ocean energy is inherent with diversifying the supply of renewable energy. Ocean energy offers the potential for long-term carbon emissions reduction but is unlikely to a significant short-term contribution before 2020 due to its early stage of development.

Two sub-Themes are identified.

A. Sustainable coastal and ocean development: vulnerability, risks and responsibility. The Focal Area here is Physical coastal processes (including extreme events): Predicted changes in the rate of sea-level rise, as a result of global warming, will have important impacts on the coastal zone. Estimated that runoff from rivers on the west and south coasts would decline with the percentage runoff change in southern Africa amongst the highest in the world. Understanding responses to change is a critical scientific goal to inform policy makers and managers.

B. Marine Technology. Many scientific projects and programmes are actively developing and using 'marine technologies'. This important sphere of activity is at present largely in the hands of industry, and international academia, and in South Africa is unfocused and un-coordinated at present, and therefore requires further attention.

Research in marine technology could embrace issues such as: compact and robust sensors and loggers, shipboard measurement systems solutions to biofouling, mooring and material solutions to biofouling, remotely operated and autonomous vehicles, ocean drifters, harnessing ocean energy, swarm technologies, and nano-technology exploration

Human Capital Development

The training and development of a new cohort of marine and coastal researchers' representative of society is just beginning. A focused development programme will address both the skills shortage and transformation in the marine sector.

The skills spectrum that is required in the sector is broad and includes the need for having interdisciplinary and trans-disciplinary competencies as well as skills in modeling, scenario development and communication, advanced statistics, sustainability science, policy and governance, and taxonomy, especially of invertebrates and microalgae.

One of the difficulties faced by marine researchers is the lack of suitable career paths, and the problem of studying for higher degrees with limited bursary funding. Strategies are required to promote the acquisition and retention of suitably trained post-graduates.

Platforms and Infrastructure
In South Africa there already is significant research infrastructure and capacity in the marine sector. Research infrastructure is dispersed across several government departments, institutions and laboratories. The principle of equal, open but competitive access is a strategic fundamental for such research to take place. Agreements are needed between government departments as well as the key institutions to ensure this interdependence is upheld and facilitated

National Research Infrastructure that requires investment includes Sentinel sites & LTER network; Biodiversity collections and associated labs; Operational Oceanography; Estuarine & Coastal research platforms; Offshore research platforms and Remote sensing, data & computing facilities

An end-to-end operational oceanography system (in-situ instrumentation, data assimilation, modeling, data products, hind casting and forecasting) needs to be established. This will embody a centralised operational oceanographic 'agency' to provide operational and *in situ* infrastructure and services.

Marine research requires centres for integrative modelling, data collection and data archiving; access to remotely sensed data; advanced measurement and analytical capability; sufficient bandwidth and High-performance Computing; and systems to collate and serve spatial biodiversity data.

Public Awareness and Understanding of Science
A national strategy for public engagement in marine science should be underpinned by inter-departmental cooperation.

The public need to understand phenomena such as global warming and sea-level rise that disrupt normal weather patterns. Periodic red tides experienced under particular conditions can cause massive loss of marine life and the poisoning of filter-feeders such as mussels and oysters.

Currently, marine education is under-represented in environmental education in South Africa. With increasing numbers of South Africans living by the coast, there is growing pressure on the marine and coastal environment. Education is the key in raising awareness to protect our coasts and oceans.

Through taking a catchment-to-coast approach to the aquatic environment, which includes the importance of our rivers to the health of marine and coastal ecosystems, efforts should be extended inland to increase awareness about the oceans and to support environmental and other educators working in the aquatic environment.

The South African Network for Coastal and Oceanic Research (SANCOR), with the National Marine and Coastal Educators Network (MCEN), are established bodies that can drive a unified approach to marine education and outreach.

A communication strategy should be developed, based on best practice and experience from elsewhere, modified for local implementation. It will be important to use a variety of media resources. The net effect should be to enhance awareness, ensuring the research is properly aligned with the issues to be addressed, and that the results of the research have a conduit to the appropriate policy or management systems.

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Contents

1. Introduction

1.1 Background

South Africa is a maritime nation, surrounded on all but its northern boundaries by the sea. Its geographical position at the southern tip of Africa has been a major factor determining its natural and human history as much as its climate past, present and future.

The coast, from the border of Mozambique in the east, to the border with Namibia in the west, spans some 2800 km. The eastern Indian Ocean seaboard, warmed by the southern drift of tropical waters, is rich in biodiversity. By contrast the cold western South Atlantic seaboard, cooled by the coastal upwelling within the Benguela Current, is comparatively poor in biodiversity but productive and rich in biomass.

The exploration and exploitation of South African maritime resources is rooted in the earliest human occupation of the region (e.g. Whitelaw, 2009). Such endeavours received immediate attention with the arrival of European settlers in the 17th century and have continued unabated and with increasing intensity ever since. Scientific investigation of the sea surrounding South Africa and its physical, chemical and biological nature emerged in the late 19th century, slowly at first but picking up momentum throughout the 20th century. For much of this time the more intense focus was on the resource-rich western seaboard where academic and state resources were concentrated (Scott, 2013). East coast research has ranged broadly between continental coastal systems and inshore marine environments, largely determined by independent institutional or individual interests (Scott, 2013).

Since 1994 the South African Government has established a national scientific policy and strategy (DACST 2002) that focuses on innovation, human capital development and the building of an effective government system for science and technology. Based on this strategy a ten-year innovation plan (DST 2008) identifies five 'Grand Challenges' as priority research areas for science and technology (S&T) programmes. These five 'Grand Challenges' are Farmer to Pharma, Space S&T, Energy security, Global Change with a focus on Climate Change and Human and Social Dynamics. Of these the Global Change Grand Challenge (GCGC) has particular relevance for setting the agenda for marine research within the 10 year timeframe (2008-2018) (DST 2009). South Africa has comparative advantages when considering research into Global Change. It has an established science system, including state, private and higher educational resources, and a unique geographical advantage of a broad range of ocean systems (from cold temperate to warm tropical) for both inshore and oceanic environments.

1.2 Geographic Advantage

The geographical advantage derives from the peninsular position of South Africa (Figure 1) separating the northerly deflected, cold South Atlantic waters via the Benguela Current on the West Coast, from the southerly directed warm Indian Ocean Agulhas Current along the East Coast. The relatively sharp interface and contrast between the two systems provides its own dynamic for research, but each system will be subject to different spectral changes due to Global Change dynamics, and all can be observed and researched ideally from South Africa.

The country is situated at a globally important climate site, where warm, salty Agulhas eddies transport heat and salt from the Indian Ocean to the Atlantic Ocean, forming an important link in the thermo-haline circulation 'Global Ocean Conveyer Belt' (Beal *et al*., 2010). Furthermore, this combination of physical, chemical and biological oceanographic processes and provinces in the waters bordering and surrounding South Africa provides unique advantages for science in advancing the understanding of the regional marine environment, which is influenced by global scales of variability and change and provides feedbacks into the Earth System.

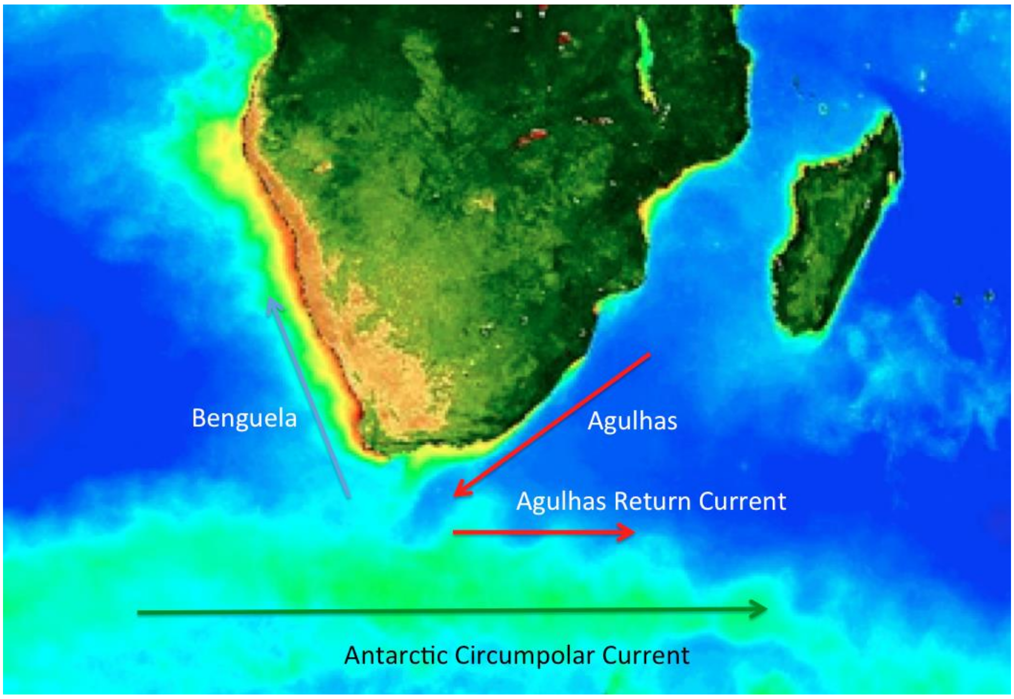

Figure 1. South African Geographical Advantage for coastal and marine research – a crossroads of ocean dynamics, with a rich ecological diversity within easy reach of the major centres where research capacity is present. Image depicts Chlorophyll concentration on a scale from low to high through the colour spectrum blue-light blue-green-yellow-red. Current systems are depicted by arrows as: red – Agulhas and Agulhas Return current; blue – Benguela Current; green – Antarctic Circumpolar Current. (Source: http://oceancolor.gsfc.nasa.gov/SeaWiFS).

1.3 International trends

Borja (2014) reviewed recent literature on marine ecosystems ecology and identified eight 'grand challenges' for research in this field. These grand challenges provide a good sense of where global research in the marine environment is currently focused. Borja's 'Grand Challenges' are:

(1) Understanding the role of biodiversity in maintaining ecosystems functionality;

(2) Understanding relationships between human pressures and ecosystems;

(3) Understanding the impact of Global Change on marine ecosystems;

(4) Assessing marine ecosystems health in an integrative way;

(5) Delivering ecosystems services by conserving and protecting our seas;

(6) Recovering ecosystem structure and functioning through restoration;

(7) Managing the seas using the ecosystems approach and spatial planning; and

(8) Modeling ecosystems for better management.

At the United Nations Conference on Sustainable Development (Rio+20) in 2012, Member States stressed the importance of

> *"the conservation and sustainable use of the oceans and seas and of their resources for sustainable development, including through their contributions to poverty eradication, sustained economic growth, food security and creation of sustainable livelihoods and decent work, while at the same time protecting biodiversity and the marine environment and addressing the impacts of climate change"* (www.sustainabledevelopment.un.org/ index.html).

For marine science the sentiments encompassed in this broad statement are long-standing, but increasingly it is being recognised that there needs to be new approaches to achieving this vision. One such set of approaches is encapsulated in the recent International Council for Science's (ICSU) "Future Earth" research initiative (ICSU, 2013; www.icsu.org/future-earth), which emphasizes:

(i) solution-oriented research for sustainability,
(ii) effective interdisciplinary collaboration across natural and social sciences, humanities, economics, and technology development,
(iii) timely information generation for policymakers,
(iv) participation of policymakers, funders, academics, business and industry, and other sectors of civil society in co-designing and co-producing research agendas and knowledge, and
(v) increased capacity building in science, technology and innovation.

This move towards trans-disciplinary, collaborative, solution-oriented research mirrors a number of national and international initiatives, and South African marine sciences are well placed to make substantial and important contributions to such research. South Africa has a long history of inter-disciplinary and inter-institutional collaboration in marine science and is located in an area where ocean dynamics are dominated by processes at the spatial scales from tens of kilometres to metres and temporal scales from months to hours. Such systems provide dynamic natural laboratories for carrying out interdisciplinary, field-based programmes.

Globally marine and coastal science is developing rapidly in a number of key trends and directions including the following.

Inter and trans-disciplinarity: The overarching issue of these disciplines is to investigate comprehensively the interfaces and relationships between humanity, environment, economy, governance, and sustainability. The international trend is for investigation that includes systems analysis, where whole socio-environmental-economic systems, and parts thereof, are analysed. Interdisciplinary, multi-disciplinary and trans-disciplinary research are all being used as vehicles to facilitate larger questions across several hierarchies, although basic research is still required to provide base-level information for such larger questions. The new ICSU Future Earth Programme is orientated around understanding the whole socio-environmental-economic system with respect to global and climate change.

Modelling & Scenario analysis: Numerical modelling is underrepresented in South Africa. Integral investigations on processes, drivers, fore- and hindcasting are not possible without modelling. The development of modelling capacity in South Africa should include theoretical research into models and system behaviour in addition to applied research.

Operational oceanography & Longterm Environmental Research: In order to keep pace with international trends in biodiversity and ecosystem research investment needs to be made in operational oceanography and Long Term Environmental Research (LTER). Modern instrumentation such as coastal vessels, in-situ moorings, buoys, autonomous vehicles all fitted with an array of probes and instruments that measure the physical and chemical drivers (e.g. bathymetry, ocean acoustics, substrate type, temp, currents, pH, Oxygen, Carbon Dioxide etc.) and biological responses (e.g. phytoplankton and zooplankton biomass and diversity, fish, marine mammals, etc.) are now common place. These instruments are capable of generating large data sets that, when coupled with new generation biogeochemical models and used in well formulated research designs, are starting to provide answers to complex global and climate change questions with respect to ecosystem functioning and biodiversity change. Long term in-situ monitoring of ecosystems is required in conjunction with well formulated experimental science at both the species and system scale if the challenges associated with GC and CC are to be unravelled.

Data: Modern marine and coastal research requires effective data and meta-data management wrt to storage, dissemination and ethics. Investment needs to be made in expanding South Africa's data management and computational abilities. The development of a centralised and accessible metadata archive would be valuable.

Molecular studies: International trends in marine molecular biology and biotechnology involve the application of next generation sequencing (NGS) platforms, and related technologies, which allow for the high-throughput generation of genetic data on unprecedented scales in the form of the genomes of individual organisms, metagenomes (the combined genomes of all organisms in a given environment) and their transcriptomes (expressed genes in the form of mRNA transcripts). High-throughput sequencing of marine meta-genomes and meta-transcriptomes was initially aimed at biodiscovery, with the focus on mining genes and biosynthetic pathways for novel natural products. However, NGS data is now being used to map marine microbial biodiversity, genomes and metabolic activity resulting in startling discoveries of the true extent of species diversity and the complexity of marine ecosystems. In the future, the application of new technological platforms particularly in the proteomics and metabolomics fields will provide new opportunities for extending the scope of research on marine biological systems.

Other outputs of NGS platforms include SNPs, determined by RAD-sequencing, the sequencing (rather than the fragment analysis) of microsatellites, and of Ultra-Conserved Elements (UCEs), among others. With respect to molecular taxonomy and genetic diversity, these large data sets enable the study of genetic variation in more detail and on much finer-spatial scales than was previously the case using more traditional approaches. This enables the study of fine-scale genetic structure and of recruitment and self-recruitment. Moreover, these approaches enable the identification of markers that are non-neutral in terms of selection. This adaptive variation provides insight into and allows correlation with the physiology, ecology, biochemistry, and behaviour of the organisms in question and sheds light on genotype-phenotype and genotype-environment interactions. These approaches allow the screening of large parts of the genome, which, by experimental manipulation, can lead to the identification of candidate genes responsible for the expression of certain physiological, biochemical, morphological or behavioural traits. In a phylogenetic context, these approaches enable the generation of large data sets from non-model organisms, which are informative across a wide taxonomic window. Earlier approaches required the extensive and costly development of markers which would be applicable only for a limited range of taxa. Next generation sequencing approaches allow for the rapid assessment of diverse marine communities, which has varied applications, from characterising plankton or symbiotic bacterial communities (mitogenomics) through to the detection of invasive species, without targeted sampling, through environmental DNA (eDNA).

1.4 Strategic programmes required to meet national research needs

The coastal and marine environment is a very broad sector where a suite of programmes would best cater for maximum inclusion and involvement of the research community. The types of research questions and research priorities that are required to inform all types of programmes are outlined in Section 2. The following types of programmes are required to address the national research needs.

Sector specific programmes: Sector specific research would be driven by the respective line department and would be designed to meet their mandated reporting and management responsibilities e.g. DAFF – Fisheries management and stock assessment**;** DEA – State of the Environment Reporting, Coastal Zone Management, Biodiversity; and DWA – estuarine reserve determinations.

Individual or small-consortia competitively-won fundamental and applied programmes: These programmes would address fundamental and applied research from individual projects to collaborative ventures. The key characteristics would be that they would be open competitive calls aimed at meeting certain research priorities. Examples include Rated researchers, Unrated researchers, Blue sky and Thuthuka, SARChi, COE's, Belmont Forum, ACCESS, SEAKeys, etc. The SANCOR SEAChange programme (SANCOR, 2008) was a successful framework and elements could be extended (Scott, 2013).

Infrastructure linked programmes: The NSI has invested heavily in marine infrastructure such as ships, coastal craft, gliders, ROVs, oceanographic arrays, data centres, collections, and laboratories. Flagship programmes like ACEP are required to ensure that research infrastructure is made accessible on a competitive basis to researchers within the system.

Larger interdisciplinary specific issue driven programmes: There are some research needs which may require immediate attention through dedicated large scale inter- and trans-disciplinary approaches which are human capacity, and infrastructure heavy and are expensive to run. These programmes will require multiple agency input but should retain an open competitive research framework.

Dedicated transformation programmes: Dedicated programmes that enhance marine research at HBUs and drive transformation are required.

There are a number of interested and affected groups that should be part of marine research planning and execution; many of these are already unified under the South African Network for Coastal and Ocean Research (SANCOR), which represents both bottom-up interests (through individual researchers) and top-down guidance and direction (through the funders; currently the NRF and DAFF: Fisheries Branch). This provides a good platform from which to develop a suite of new research programmes and projects, including flagship projects that maximise South Africa's locational advantage.

There is a clear need for strong leadership to help coordinate and strengthen South Africa's marine research and its research capacity. In moving forward, there are compelling issues that should form part of research planning, related to transformation and the development of strategic skills and capacity. These issues should be addressed at the same time that research plans are formulated, so that appropriate instruments, processes and infrastructure are developed.

2. Themes

2.1 The Challenge of Global Change

The geographic advantage that South Africa has for conducting coastal and marine research at the interface of diametrically different ecosystems, pertains directly to the impact of Global and Climate Change on these systems and their interaction with coastal systems. The impact of Global Change on coastal and marine ecosystems is a priority challenge for Science and Technology (DST 2008) and therefore an appropriate blanket theme for the marine sciences in the 2014-2018 timeframe and beyond.

The four Priority areas of focus for marine ecosystem and biodiversity studies identified within the GCGC are (i) understanding the ocean as part of a coupled regional system, (ii) the risks and responsibilities of ecologically sustainable coastal development, (iii) the response of coastal and marine ecosystems and ecosystem services to Global Change, and (iv) operational capabilities, marine science for society. Various issues within these focal areas are identified and outlined below, to be addressed variably within the Themes of the plan:

The response of coastal and marine ecosystems and associated services to global and climate change. Understanding the response and resilience of coastal and marine ecosystems to change requires an integrated approach. The coastal zone is one where climate change will have especially profound effects on human populations, both directly and indirectly through ecological effects and the goods and services that coastal and adjacent marine ecosystems and associated biodiversity can deliver.

Ecologically sustainable coastal development: vulnerability, risks and responsibilities. Coastal development implies a human impact on coastal and marine ecosystems and biodiversity. The ecological costs depend on the extent of development as well as the robustness and vulnerability of the ecosystems. Development entails the risks raised and responsibilities carried in terms of the benefits derived from the developments. The challenge lies in maximising those benefits without impairing the ability of the system to provide ecosystem services sustainably. Ecosystem services in the form of fisheries and tourism already support many coastal communities. Current and future developments in a variety of emerging industrial sectors such as oil and gas, seabed mining etc will require a sound scientific base if they are to be sustainably managed. The opportunity for research is to provide solutions that maximise benefits and ensure sustainability whilst minimising the environmental costs.

Reducing uncertainty of seasonal, inter-annual and decadal climate projections in southern Africa. The most immediate societal benefit associated with this theme is the development of reliable climate projections. Reliable climate projections (models) that can be scaled down to assist in establishing regional or sub regional responses to climate change are urgently required to formulate projections of ecosystem and biodiversity responses to change, and their direct and indirect impacts on the human population.

Biodiscovery. Marine biodiscovery - or bioprospecting - is defined as searching for marine natural products (bioactive small molecules) and other materials with an economic benefit to society, including pharmaceuticals, agrochemicals, marine anti-fouling coatings etc. Coupled with biodiscovery is marine biotechnology, which focusses on developing processes to exploit the unique properties of marine organisms and their products, for economic benefit. Marine biota and in particular those endemic to South African waters, represent a unique and as yet virtually unexplored reservoir of biomolecular diversity, due to high levels of diversity, in particular invertebrates (sponges and ascidians), algae and microorganisms.

According to these needs, three Themes are considered for this plan, embracing in the first instance the physical nature of the marine systems of the southern African region, secondly the living dynamics of the marine ecosystems of the region, and thirdly human exploration, exploitation and development of southern African marine systems.

2.2 Theme 1: Oceans and marine ecosystems under global change

Introduction

Regional and large-scale oceanographic processes underpin aspects of South Africa's marine environment that link research directly to significant societal benefits. These include environmental monitoring and maritime safety linked to extreme weather events, employment and food security linked to fisheries and aquaculture, bioprospecting linked to marine biodiversity, oil, gas and other exploration and mining linked to non-renewable marine resources, and ecotourism linked to the country's beaches and coastal waters and the biodiversity they support.

Under the current situation of rapid global change, including climate change (IPCC 2007, 2013), it is important that South Africa further develop the capacity for understanding and predicting the state of the ocean and its ecosystems, and the capacity and systems to incorporate such knowledge into policy and management. To do this requires multi-, inter- and cross-disciplinary approaches to marine science with explicit links to stakeholder requirements. Research needs to span the natural and social disciplines, generating new knowledge of real relevance to policy development and management. Such research should provide information to support decision-makers and local industries, which in turn provide jobs and food security and generate tourism.

State of the knowledge

The circulation, hydrography and marine ecosystems around southern Africa are influenced by global and synoptic scale variability of the oceans and atmosphere. Large-scale natural variability, such as the El Niño Southern Oscillation (ENSO), has been shown to influence local climate and ocean conditions. The ocean environment is also influenced by anthropogenic climate change, affecting global temperatures and sea levels. Other human activities also influence marine environments, with resulting ocean acidification, marine pollution, marine habitat alteration and destruction, eutrophication of coastal waters, the spread of invasive species, and the exploitation of commercial and non-commercial species. These large-scale impacts all are occurring concurrently, increasing the vulnerability of natural systems and making it difficult to predict the response of marine ecosystems as well as regional and global climate.

Over the past few decades there have been a number of large research projects that focused on aspects of change in the marine environment off South Africa. On the west coast, where the Benguela coastal upwelling system supports the region's most important fisheries, the results of research on this system highlighted observed variability in the marine environment and the living organisms it supports (Shannon *et al*., 2006; Checkley *et al*., 2009). On the east coast of South Africa, there has been considerable progress in understanding the dynamics of the Agulhas Current system (Lutjeharms, 2006, 2010) and its marine resources. Current oceanographic research is focusing on mesoscale processes in the Mozambique Channel, the Agulhas retroflection and leakage of warm, salty waters into the Atlantic Ocean, with concurrent studies of their influences on biogeochemical cycles, biological productivity and living marine resources.

Recent changes have been observed in South African marine ecosystems (Mead *et al*., 2013; Moloney *et al*., 2013). There are indications of cooling on the west and south coasts and warming on the east coast over the last 20–30 years. Oxygen concentrations on the west coast have also decreased over this period. Observed changes in marine communities include south-, west- and eastward changes in species distributions, changes in abundance of some species, and probable alterations in foodweb dynamics. Moloney *et al*., 2013 reviewed the evidence of ecosystem change off South Africa and concluded that whilst changes in various sectors and components have been reported, the data time series are generally too limited or short to distinguish long-term trends from shorter-term variability.

The long history of marine ecosystem research in South Africa has provided a solid knowledge base for the implementation of an ecosystem approach to fisheries management, through the Fisheries Branch of the Department of Agriculture, Forestry and Fisheries (DAFF). South Africa is currently regarded as a leading state in terms of developing ecosystem-based fisheries management (www.nda.agric.za/doaDev/fisheries/), and future research activities should aim to maintain and further develop this capacity. South Africa also plays an important role internationally in regional fisheries management organisations and in regional and international research programmes such as the ASCLME, SWIOFP and WIO-SAPPHIRE (Vousden, 2013).

Observational monitoring activities and numerical modeling together play key roles in consolidating and advancing the state of knowledge of marine systems. In the last decades, much effort has been dedicated to the development of modeling strategies to better understand and predict changes in marine ecosystems under combined effects of climate change and fishing. Climate change affects the structure and functioning of marine ecosystems through several processes, and fishing impacts the species and size composition of marine communities by targeting specific components of the ecosystem. Less is understood about the impacts and effects of other pressures (such as ocean acidification, mining and pollution) in South African marine ecosystems, but these pressures need to be measured and incorporated into models using a multiplicity of approaches.

Building end-to-end models of the ecosystem from the physics to the biotic and their exploitation requires the coupling of disciplinary models, with potential discrepancies in spatio-temporal scale. Hindcast simulations, data assimilation and the calibration of complex models to observed time series require sophisticated algorithms to be developed.

<u>A Vital Gap - Long-term data sets</u>

Marine ecosystems off South Africa are naturally variable on inter-annual and decadal timescales, making it difficult to separate long-term trends from large-amplitude, short-term variability that result in strong environmental signals. Unequivocal, unidirectional change cannot be identified from short time-series and changes cannot be detected without having an historical baseline against which to compare modern observations. In reviewing the evidence for long-term changes in South Africa's marine ecosystems, Moloney *et al.* (2013) concluded there are <u>insufficient baseline data to disentangle short- and medium-term variability from long-term change</u>. Where large-scale ecosystem changes have been observed, it was generally not possible to attribute these changes to specific pressures. The current state of understanding mainly involves untested hypotheses based on incomplete data.

The situation can be improved by strengthening and enriching current data sets and improving model-assisted interpretations of the complex interactions. This requires a multi-pronged approach that includes enhancing observational programmes to provide routine environmental data to monitor key variables; strengthening data management capabilities to assure data quality and to enable improved access for researchers and improved data mining capabilities; and establishing structures for collaborative and consultative planning for research cruises to provide strong leadership and better integrate field experiments and process studies across disciplines and institutes.

Coastal systems under pressure - research needs

Global change pressures include climate change, increases in sea-level rise and wave heights, and the impact that these changes will have on coastal ecosystems, towns and cities. Increasing water pollution within the coastal zone is a reality that needs to be addressed, as well as the reduction in river flow to estuaries and the coastal zone. Knowledge and understanding of the impacts of both aspects are vital to the sustainability of the coastal recreational and subsistence fisheries. Coastal bio-invasions, particularly by alien plant and invertebrate species, necessitate urgent attention being given to the implementation of remediation efforts to reverse the direct and indirect adverse effects of these invasions. Management of coastal ecosystems under global change scenarios requires information from fundamental and applied scientific studies in association with socio-economic knowledge, that can inform the taking of wise management decisions.

A large proportion (40%) of South Africa's population lives within 100 km of the coast and four major cities are located within this zone. The coast and its resources not only provide direct employment opportunities (e.g. in the shipping and tourism businesses), but is also where there are numerous nodes of holiday and retirement settlements that also create job opportunities in construction and service industries. The fishing industry is vital to the coastal economy economy, particularly in the cool temperate region of the Western Cape.

The Benguela Ecology Programme (BEP) has been globally acknowledged as an outstanding achievement and brought wide recognition for South African marine research excellence. The advantages provided by a location across three major marine biogeographic zones suggests that similar research opportunities can be created going forward. In this context, southern Africa is a global biodiversity hotspot with more than 12900 described species of marine biota, of which a third are endemic to the region. South Africa has a diverse coastline, with ecosystems ranging from coral reefs in the northeast to kelp beds in the south-west. There are approximately 280 functional estuaries along the coast, comprising a range of types that have relevance to other African countries and the globe. Thus, there are many opportunities for international scientific collaboration in coastal ecosystem research.

From an ecotourism perspective, South Africa is a growing international destination, with its coastal World Heritage Sites and Marine Protected Areas

(MPAs) showing all the signs of being key factors in attracting tourists to the region. These visitors are demanding ever more detailed information on the biology and ecology of local species – a demand that can only be met by dedicated and informed research that can be relayed to an ever more informed public. The role of MPAs in sustaining coastal biological resources is a global issue and South Africa is a research leader within this field.

Full understanding of marine ecosystems under global change requires ongoing and effective data collection, management and archiving, and coordination in carrying out ecosystem research. In taking South African marine science forward to understand, quantify and address the pressures on the marine environment and to ensure sustainable use of marine resources, there is a need for baseline data, continuous monitoring and modeling efforts, hypothesis-driven process studies and experiments under coherent, well-designed ecosystem programmes. Such an approach should include all disciplines involved in marine global change research, including interactions between the atmosphere and oceans, regional impacts and global feedbacks, the responses of ecosystems to change, and the reciprocal effects on biodiversity, marine resources and human societies.

A Priority Focus Area is: <u>The southern African ocean in the coupled earth system.</u> The aims are to attain an understanding of the linkages in the coupled earth system, from climate tele-connections to regional impacts and ecosystem responses under global change. The emphasis is on the development of disciplinary knowledge and knowledge at the interface of different disciplines.

Research and development priorities include:

- Understanding modes of ocean variability across temporal and spatial scales their feedbacks and linkages to marine ecosystems;
- Developing a regional observations network. (Note, it is essential to link with other countries of the region. For instance, an observatory for the marine environment of the Western Indian Ocean will soon be opened in the Reunion Islands);
- Developing end-to-end modelling and operational prediction capabilities towards guiding observational programmes based on model-based hypotheses. (Note, this includes models across disciplines and scales, coupling of these models and their integration with observations);
- Establishing global, regional and coastal system indicators and linkages, including ecosystem state and fish stock status and their response to climate change;

- Deliver robust and useful information to society by synthesising state of knowledge obtained from observations and models to guide policies and decisionmaking processes across disciplines (this is e.g. included in finding indicators for fish stock status, however it is of course broader than fish stocks to include carbon guidelines, or using model outcomes with some confidence in decision making);
- Reconstructing past climate changes, particularly across major climate transitions from glacial to interglacial periods over the last one million years.

2.3 Theme 2: Ecosystems, Biodiversity & Biodiscovery

Introduction

Over the past decade, the South African marine community has reviewed the state of marine science through a series of interactive consultative exercises, starting with a Status Report of Marine Biodiversity (Duhram & Pauw, 2000). This review dealt with a suite of functional ecosystems such as rocky shores, sandy beaches, estuaries, etc., and a few selected taxonomic categories and provided a specific status report for each, also identifying gaps, threats, human skills capacity and the link between the functioning ecosystem and management. For most areas basic knowledge was good, often with decades of research input. In some areas (e.g. pelagic and deep sea ecosystems) the knowledge base was comparatively weak, as research was restricted by limited access to large-scale logistical infrastructure (ships and ships time) needed to conduct the research. Taxonomically most macrofaunal taxa are comparatively well known but flora and microbial biodiversity was poorly explored in general. With exceptions where there are commercial or cultural interests knowledge of biodiversity beyond taxonomy is generally very poor.

In the past decade further considerations of the needs of marine science were made, in particular through the Global Change Grand Challenge (DST, 2009), National Biodiversity Assessment (Driver *et al*., 2012), and the SANCOR programme – Making Marine Science Effective (SANCOR, 2013) initiatives. All of these processes involved significant input from a wide range of specialist scientists and managers in the South African marine sector. In addition to this collective community-wide input the two main line departments (DEA and DAFF) each have specifically mandated research priorities. Documentation describing these initiatives (referenced above) has guided the development of this theme. All the processes highlighted global change and climate change as key areas of concern if the South African marine environment is to continue to provide sustainable societal benefits.

This theme has two sub-themes, (A) biodiversity responses to global and climate change, and (B) Biodiscovery and biotechnology.

A. Biodiversity and Ecosystem responses to global and climate change.

Focal Area 1: <u>Understanding scales of biodiversity from molecular to ecosystem</u>

Overview of existing knowledge: Whilst a broad understanding of ecosystem functioning is known, there are several specific areas where knowledge is weak and needs input at this stage, in particular the following:

- Models: The linked physical, chemical and biological numerical models required to understand GC and CC impacts under various scenarios are as yet not existent or not very robust;
- Microbial ecology and the contribution of the microbial loop to ecosystem functioning is still understudied;
- Sub-tidal (in particular sub 30m) and offshore pelagic ecosystems are less well understood in comparison to coastal and estuarine ecosystems;
- The marine environment is a number of generations behind terrestrial habitat mapping and conservation planning. Subtidal mapping is still in its infancy;
- The macro-faunal taxonomy e.g. fish, is generally well known. Soft sediment biota and smaller taxa/microbial taxonomy are still poorly known or described;
- Investigations into the genetic diversity of marine organisms is in its infancy;
- The development of a reference barcode library is still at an early stage;
- Linking biodiversity knowledge to ecosystem functioning (in both applied and theoretical fields) is largely non-existent.

Research questions that arise are:

- What are the relationships between ecosystem productivity, ecosystem stability and biodiversity?

- What is the contribution of the microbial loop to ecosystem productivity and ecosystem sustainability?
- What are the changes in the processes driving/maintaining patterns of genetic diversity?
- How can resilience be maintained and enhanced, through for instance, maintaining degrees of redundancy?
- What characteristics of ecosystems promote systems-level stability in the face of climate change?
- What elements of biodiversity are functionally resilient to Global Change impacts?
- What are the physiological attributes underpinning species resilience to global change?
- How to maintain genetic diversity and adaptive diversity in the face of CC?
- What properties of ecosystems make them resilient or vulnerable to biological invasions?
- How do we optimise the siting and functionality of Marine Protected Areas?

Priority areas for research include:

- Systematic conservation planning and identification of priority conservation areas;
- Modelling frameworks for projections of change and sustainable functioning of ecosystems;
- Taxonomy and systematics of priority groups identified in NBA;
- Benthic continental shelf ecosystems;
- Sub-tidal habitat mapping;
- Development of comprehensive species databases;
- Invasion biology;
- Microbial ecology;
- Molecular ecology.

Focal Area 2: Connectivity between terrestrial, coastal and marine systems

Overview of existing knowledge: Good progress has been made over the last 15 years in understanding river-estuary interactions. This research has been translated into management and scientific decision-making protocols. Further work scaling up from individual systems to regional impacts and understanding the connectivity of systems, is required.

The understanding of estuary-marine interactions is relatively well-understood at the conceptual level, but robust quantitative scenario analysis of changes in freshwater input into the marine environment, and impacts on the biodiversity and ecosystem functioning, are not available. Some work off the Thukela catchment has shown the importance of understanding these relationships in managing offshore fisheries, e.g. that for prawns and line fish.

Research questions & research priorities:

- How will GC/CC influence productivity of and biomass exchanges between terrestrial, coastal and marine systems?
- What is the role of interconnectivity between estuaries wrt to biodiversity and how will this interconnectivity be influenced by climate and global change?
- Onshore-offshore biochemical and biophysical influences and feedbacks are complex. How will GC and CC impact on these processes?
- What are the appropriate coastal and marine ecosystem bio-physical indicators?
- What are the drivers and cues for recruitment of estuarine-dependent organisms (in particular fishery species) and how will they change to GC and CC?
- Connectivity between catchment, estuaries, inshore and offshore areas.
- Understanding linkages between hydrology and coastal biodiversity and ecosystem change inclusive of hydro-geographical links.
- Are there any aeolian and non-estuarine impacts?

Focal Area 3: Understanding natural and anthropogenic drivers of change

Overview of existing knowledge: Habitat classification and mapping has been conducted for some stretches of coast, e.g. in conjunction with SeaPlan. Selected natural drivers have been investigated on selected ecosystems, e.g. freshwater inflow into estuaries, physical drivers of sandy beaches and for coastal fisheries. However, the broader understanding of both natural and anthropogenic drivers on natural and transformed ecosystems, especially in terms of predictive capacity, is largely lacking for coastal ecosystems. Coastal fisheries have received some attention, in particular the application of an Ecosystem Approach to Fisheries (EAF) for the west coast fisheries. There is little to no knowledge on drivers for whole ecosystem functioning on other South African ecosystems in terms of modeling frameworks and scenario building.

Questions of limits to system transformation and tipping points of ecosystems have not been addressed for South African marine systems.

Research questions & priorities:

- Are there absolute limits to the natural resources and eco-system services that our socio-economic systems can extract and how far are we from breaching these limits?
- What are the indicators of limits and tipping points in coastal and marine ecosystems?
- Understanding cycles in natural drivers and differentiating them from interacting anthropogenic ones.
- What adaptive capacity to change exists?
- Understanding the human dimensions of ocean and coastal change (as driver and recipient).
- Understanding natural and anthropogenic drivers on marine organisms and ecosystems?
- Habitat classification, mapping and research to support ecological understanding and impact assessment.
- Advancing palaeo-ocean data, linked to terrestrial data sets of comparable time scales.

B. Biodiscovery & Biotechnology

Marine bioprospecting or biodiscovery is 'the search for marine products that may have potential economic value' (Bolton *et al*., 2013). Marine biotechnology is 'the commercial exploitation of organisms that originate from the marine environment' (Bolton, *et al*.,2013). These disciplines have significant potential for achievement of the Grand Challenge 'Farmer to Pharma' and therefore are a relevant subtheme in this plan.

Focal Area 1: Biodiversity and Biodiscovery

Overview of existing knowledge: Current knowledge on the extent of marine protist and vertebrate diversity is considered to be sound (Durham & Pauw, 2000), but, in general, knowledge of the species diversity of invertebrates and microbial species ranges is poor to non-existent. Bolton *et al*. (2013) reviewed the situation regarding biodiscovery and biotechnology in the marine environment off South Africa and concluded that, with the possible exception of mariculture, both sectors are in relative infancy. Some capacity exists in marine natural products chemistry, vested within a few research groups and there are established international collaborative networks in this area. There is a significant lack of capacity in taxonomy and in particular the molecular taxonomy of marine organisms.

Research questions & priorities:

- Systematic assessment of the extent of biodiversity endemic to South African estuarine and coastal systems, including invertebrates, algae and microbial (algae, fungi, bacterial and viruses) diversity;
- Identifying areas of high genetic diversity and assessing these for potential adaptatbility in the face of GC/CC;
- Characterising marine metagenomes and assessing the potential for the discovery of novel organisms, their genomes, biosynthetic pathways and metabolites;
- Identification and protection of biodiversity hotspots with importance to biodiscovery;
- Searching for new indigenous species for marine biotechnological use.

Priority Areas of research are molecular taxonomy, molecular microbial ecology, metagenomics, proteomics and metabolomics, and chemical taxonomy.

Focal Area 2: Innovative marine processes and products

Research priorities:

- Algal and microbial biotechnology: to discover new products and processes involving indigenous organisms.

- Innovative products and processes in mariculture: To find new indigenous species for commercial production, to use marine biotechnological techniques to improve existing mariculture industries and to bioremediate waste from commercial enterprises;

- Biofouling: To solve problems involving the fouling of marine structures using innovative research;

- Biodiversity: To discover novel indigenous species for marine biotechnological use, to study relationships and diversity of commercial and potentially commercial marine organisms using molecular techniques, and to carry out strain selection and genetic testing of commercially important organisms for existing and new product production.

Key Priority Areas for research are: Biomineralization; biomaterials; nanobiotechnology; drug discovery.

2.4 Theme 3: Coastal and marine resources, society and development

Introduction

This Theme is in tune with the reality that coastal and inshore environments are not only ecologically dynamic and sensitive systems, but also are areas where humans congregate in large concentrations both annually and seasonally. Coastal ecosystems are highly vulnerable to human-mediated drivers of global change because they are located at the land–ocean interface and host many centres of urbanisation and development (Mead *et al*. (2013).. The natural resources of coastal and inshore environments are heavily utilized and exploited by people, and the impacts of humans on them are therefore both direct and indirect.. At present the physical development of coastal areas is intense and this intensity varies in places, frequently consequent on the discovery and existence of exploitable resources as much as it is on habitation. Pressures on coastal and marine environments are rising rapidly at the present time as resource exploration is intensified. Research that focuses on the interface between resources, society and development is of high priority in the coastal and marine environments.

State of the knowledge: Marine resources include biological (fisheries) as well as geological in the form of minerals and fossil fuels (oil and gas). South Africa has a long-standing fishery sector and fisheries catch landings in the country are dominated by small pelagic fishes such as herring, sardine and anchovies, midwater pelagic species such as horse mackerel and demersal fish such as hake. Many of these stocks have been fully exploited, with deep-sea stocks showing signs of overexploitation, while the small pelagic fish are subject to inter-annual and decadal variability (FAO, 2011).

Marine fisheries are very important to the economy and well-being of coastal communities. Maintaining the long-term prosperity and sustainability of marine fisheries is not only of political and social significance but also of economic and ecological importance (FAO, 2011).

This part of the Southeast Atlantic, particularly South Africa, is a very variable and dynamic region from the point of view of oceanography. This variability significantly influences the marine living resources (Hutchings *et al*., 2009). The last three decades have been characterized by several major oceanographic events that have influenced the dynamics of several important fish stocks. The most important fishery stocks were all subjected to heavy fishing pressure at different periods between the 1960s and the 1980s. Data for management purposes have been collected by means of fishery-dependent and fishery-independent survey techniques appropriate to each particular stock and analysed using traditional single species stock assessment techniques. Only in the recent past years has the importance of looking at entire ecosystems become largely accepted as means of holistic management of fisheries (e.g. Pikitch *et al.*, 2004). Thus limited interactions between competing species or predators and prey being formally taken into account when modeling the stock dynamics and providing management advice to the authorities (Hutchings *et al.*, 2009).

South Africa is a world leader in off-shore mining for diamonds off the west coast. Gas and oil exploration has taken place for several decades and there is commercial exploitation involving a state refinery for the Bredasdorp Basin off-shore gas fields near Mossel Bay in the Western Cape. Since the promulgation and enactment of the Mineral and Petroleum Resources Development Act in 2002 there has been an upsurge in offshore exploration within the South African EEZ (e.g. www.impactoilandgas.co.uk) and extensive mineral exploration concessions have been granted for large parts of South Africa's EEZ marine sectors. Mining of ocean mineral resources (including construction materials, industrial materials, metallic minerals, and metallic oxides and sulphides) has major economic potential.

The development of ocean energy is in accordance with diversifying the supply of renewable energy as outlined in the White Paper on Renewable Energy (2003). Ocean energy offers the potential for long-term carbon emissions reduction but is unlikely to a significant short-term contribution before 2020 due to its early stage of development. All ocean energy technologies, except tidal barrages are in conceptual phase, are undergoing research and development, or are in a pre-commercial prototype and demonstration stage. Some national and regional governments are supporting ocean energy development through a range of initiatives, including R&D and capital grants to device developers; performance incentives for produced electricity; marine infrastructure development; standards; protocols and regulatory interventions for permitting; and space and resource allocation (Lewis *et al.*, 2011).

The theme has two sub-themes (A) Sustainable coastal and ocean development: vulnerability, risks and responsibility; and (B) Marine technology.

A. Sustainable coastal and ocean development: vulnerability, risks and responsibility

Focal Area 1: Physical coastal processes (including extreme events)

Overview of existing knowledge: South Africa is likely to experience substantial climate change in the next decades leading to a dramatic decline in biodiversity (Van Jaarsveld & Chown 2001). The predicted changes in the rate of sea-level rise, as a result of global warming, will have important impacts on the coastal zone, displacing ecosystems, altering geomorphological configurations and their associated sediment dynamics, and increasing the vulnerability of social infrastructure. Coastal wetlands (collectively comprising salt marshes, mangroves, intertidal and supratidal areas) could experience substantial losses as a result of sea-level rise. These economically valuable ecosystems are highly productive and provide a number of important functions such as flood and storm protection, waste assimilation, nursery areas for fisheries, supply of organic matter to estuarine and marine environments and nature conservation (Nicholls *et al*. 1999).

Tide gauge measurements from South Africa indicate that sea-levels have risen by approximately 1.2 mm/year over the last three decades, similar to international estimates (Brundrit, 1995). The current trend of rising sea-level is expected to accelerate in the future, with recent estimates indicating a 12.3 cm rise by 2020, 24.5 cm rise by 2050 and 40.7 cm rise by 2080 (Nicholls *et al*., 1999). In addition to sea-level rise, Clarke *et al*. (2000) estimated that runoff from rivers on the west and south coasts would decline by 11– 84%, while those on the east coast would change by anything from -21% to +10%, making the percentage runoff change in southern Africa amongst the highest in the world (Arnell, 1999). Changes in freshwater runoff are of significance for the marine environment in that any reduction in flow will be translated directly to estuaries with concomitant effects on marine biota that utilise these systems (Clarke, 2006).

Lutjeharms *et al*. (2001) are of the opinion that the impact of sea-level rise on the ecological functioning of the marine environment in southern Africa is likely to be insignificant, except in estuaries where most of the marine production is linked to salt marsh ecosystems. Marginal and emergent vegetation such as salt marshes and mangroves contribute significantly to estuarine productivity and any negative effects on these communities could thus feed through to estuarine associated fish and fisheries. If coastal wetlands in general and salt marsh in particular, are to persist in the face of rising water levels, they must be able to accrete sediments at a rate such that surface elevation gain is sufficient to offset sea level rise. In the face of a global rise in sea-level, a critical scientific goal is to understand the response of the shoreline, the change in productivity of coastal wetlands and its impacts on faunal populations and other coastal ecosystems, so as to inform policy makers and managers.

The combined effects of sea-level rise and possible increased sea storms will lead to an increased occurrence and magnitude of extreme inshore seawater levels and consequently flooding/inundation impacts that could breach existing storm protection measures if these are not reinforced or enhanced. The increased wave energy, current and wind velocity will probably increase sediment transport and could possibly lead to the erosion of beaches.

Research questions & priorities:

- Which coastal areas are at risk to storm surge flooding?
- Which coastal ecosystems are impacted by increased storm surge flooding?
- How will storm surge frequency and intensity change under future CC scenarios?
- Can extreme events and their potential impacts be forecast and can this information be disseminated with adequate lead-times and contingency implementation?
- Accurate coastal vulnerability maps linked to future climate change scenarios?
- How will the rainfall and freshwater runoff patterns change and what will the impact be of altered freshwater supply to the marine and estuarine environment?
- Establishing the appropriate mix of mitigation and adaptation measures e.g. setback lines, coastal protection, coastal infrastructure protection for vulnerable areas along the coast;
- How will changes in physical processes such as erosion, deposition and long-shore drift impact estuarine, coastal and marine ecosystems?

Focal Area 2**:** Coupled urban coasts and estuarine systems

Overview of existing knowledge: Selected monitoring efforts of potential impacts of outfalls on estuarine and marine biota exist, however not on a broad scale, nor on a ecosystem or modelling scale. Research on ecotoxicology is small scale, as is pollution monitoring with respect to physical, chemical, biological and ecosystem responses.

Research questions & priorities include:

- To what extent are coastal developments impacting, influencing or extending into marine processes and ecosystems?
- What are the carrying capacity limitations to the development of urban bay, and how can these be measured?
- How will altered river flows, sea-levels and storm events arising from global and climate change affect the structure and functioning of estuarine and coastal ecosystems?
- What are the urgent priorities in respect of coastal zone management and urban bay management in order to mitigate the risks associated with global and climate change?

Focal Area 3: Environmental security and coping capacity

Overview of existing knowledge: This is a new, open field for research. It requires interactions between environmental scientists, ecologists, sociologists and modelers.

Research Questions & priorities include:

- Understanding how global change impacts on coastal and marine biodiversity and ecosystems, and how these changes will in turn impact on coastal economies.
- What are the threats to coastal environmental security in Southern Africa?
- What scientifically based management tools are appropriate for application in an integrated approach to mitigate and limit threats to environmental security?

B. Marine Technology

There is a large and ever-increasing area of operations under the sphere of 'marine technology' (defined in Wikipedia as 'technologies for the safe use, exploitation, protection of, and intervention in, the marine environment'). Many scientific projects and programmes are actively developing and using 'marine technologies' e.g. Cowley (2013), and Roberts & Morris (2013). This important sphere of activity is at present largely in the hands of industry and international academia, and in South Africa is unfocused and un-coordinated at present, and therefore requires further attention.

Research in marine technology could embrace issues such as: compact and robust sensors and loggers, shipboard measurement systems solutions to biofouling, mooring and material solutions to biofouling, remotely operated and autonomous vehicles, ocean drifters, harnessing ocean energy, swarm technologies, and nano-technology exploration.

3. Human Capital Development

One of the pillars of South Africa's National Research and Development Strategy (DACST 2002) is human capital development. Whilst there has been a good deal of marine research over a long period in South Africa that ensures a complement of skilled and proficient researchers at several HEIs, Government Departments and institutions, the CSIR, National Research Facilities, and non-government institutions like the Oceanographic Research Institute (ORI), like other science and technology sectors the training and development of a new cohort of researchers representative of society is in an early phase. The need is well acknowledged and is beginning to be addressed through Flagship projects like ACEP (ACEP, 2013), and, in a regional context, ASCLME (Vousden, 2013). It is evident that special interventions such as the ACEP Phuhlisa Programme are needed to ensure the induction of a transformative cohort of new demographically representative researchers (Paterson, 2013). A focused development programme similarly fashioned will further address both the skills shortage and transformation in the marine sector.

Considering the need to strengthen marine science in order to deal with the challenges outlined in this document, it is important that such strengthening is not confined to government institutions. The development of partnerships with South African non-government research organisations such as ORI will increase this capacity and broaden the base of marine science in South Africa, as well as providing a cost-effective means of developing science-based solutions to the marine and coastal challenges facing this region.

The skills spectrum that is required in the sector is broad and has been identified in the Global Change Grand Challenge (DST 2009) as particularly the need for having interdisciplinary and trans-disciplinary competencies as well as skills in modeling, scenario development and communication, advanced statistics, sustainability science, policy and governance, and taxonomy, especially of invertebrates and microalgae.

One of the difficulties faced by marine researchers is the lack of suitable career paths, and the problem of studying for higher degrees with limited bursary funding. Strategies are required to promote the acquisition and retention of suitably trained post-graduates. These strategies could include internship programmes, enhanced bursaries, and more opportunities for soft-funded, salaried, postdoctoral positions in marine research (as is commonplace, for example, in medical disciplines).

4. Platforms and Infrastructure

In South Africa there already is significant research infrastructure and capacity in the marine sector that, if properly managed and coordinated, should allow the country to continue to contribute to national needs in the national and the international research arenas. In the marine sector, where interdependence of researchers and the availability (access and co-ordination) and management of infrastructure is essential, research infrastructure is dispersed across several government departments, institutions and laboratories. The principle of equal, open but competitive access is a strategic fundamental for such research to take place. Agreements are needed between government departments as well as the key institutions to ensure this interdependence is upheld and facilitated.

National Research Infrastructure

Required national strategic infrastructure for marine research is as follows:

<u>Sentinel sites & LTER network</u>

Representative sentinel sites and LTER sites need to be set up in all major bioregions and habitat types (Estuaries, bays, beaches, pelagic, deep-water etc.). These sites need to be managed in the long term and be appropriately equipped with research infrastructure. Data from these sites need to be made accessible to researchers.

<u>Biodiversity collections and associated labs</u>

South Africa's biodiversity collections (wet, dry and frozen) need to be properly resourced, curated and databased. The collections must be linked to well-equipped genetic (including metagenomic and biotechnology), isotope, fatty acid and x-ray laboratories.

<u>Operational Oceanography</u>

An end-to-end operational oceanography system (in-situ instrumentation, data assimilation, modeling, data products, hind casting and forecasting) needs to be established. This will embody a centralised operational oceanographic 'agency' to provide operational and *in situ* infrastructure and services. For example, operational oceanographic modeling is currently an academic pursuit with very limited technical support.

Estuarine & Coastal research platforms

National estuarine and coastal research infrastructure which is beyond the technical or operating capability of HEIs, NGOs and state institutions needs to be made available on a competitive bases to researchers within the NSI. Examples include:

- Specialised in-situ instrumentation and moorings (e.g. ADCPs, CTDs, sediment traps, tide gauges, flow gauging stations, coastal radar, passive acoustic monitoring etc.);
- Coastal craft (<9m and >9m) with associated instrumentation;
- National acoustic telemetry curtains;
- Specialised remotely operated or autonomous research vehicles or instruments (Gliders, ROVs, BRUVs, ski-monkeys etc.).

Offshore research platforms

Offshore research requires competitive access to well-resourced and equipped ships and deep-water research infrastructure e.g.: moored and ship borne ADCPs; deep-water moorings; moored and ship borne deep-water CTDs;

ROVs and gliders; deep-water ROVs and a ships with DPSs; deep-water grabs, corers and sediment traps.

Remote sensing, data & computing facilities

Marine research requires:

- Centres or a National Centre for integrative modelling, data collection and data archiving (at minimum metadata);
- Access to Earth Observation remotely sensed data;
- Advanced measurement and analytical capability;
- Bandwidth and High Performance Computing;
- Systems to collate and serve spatial biodiversity data.

There is a need to rethink the funding instruments for marine research in South Africa in order to align these with any new marine research agendas and to ensure that research funds are used optimally and efficiently in meeting the country's research needs. Funding structures should facilitate cross- and inter-disciplinary research, with opportunities for sound logistical and financial support for long-term data collection platforms, for data management and distribution, and for fundamental field-, process- and modeling studies that advance knowledge. An envisioned Oceanographic 'agency' will ensure improved and integrated data management and archiving for marine data and metadata such as currently at SADCO as well as providing a national coordinating facility for marine research, with a science mandate (and managers), funded through different government departments.

5. Public Awareness and Understanding of Science

The coast is the dynamic interface where land and sea meet and it supports unique ecosystems in its estuaries, salt marshes and dunes. Coastal and marine resources provide opportunities for economic and social activities that include fisheries, agriculture, mineral resource exploitation and a range of development opportunities. The coast and its many estuaries are also highly valued for recreation. The sustainability of these resources is important since they constitute a rich and diverse national asset that is sensitive to human induced and environmental pressures.

A national strategy for public engagement in marine science should be underpinned by inter-departmental cooperation. Traditionally this has been vested in the DEA which has a legacy of excellent resource provision for marine and coastal education (Marine Week, Coastal Clean-up days, Blue flag beaches, Coast Care Fact Sheets, posters, etc.). The Department of Tourism has a long-term vested interest in the coast and the wide range of tourism opportunities it offers. As the South African economy grows and the interface with other African countries develops, attention is being focused on the cooperative benefits of developing an African Network of Maritime Clusters. These maritime clusters are seen as incubators of small business enterprises and an African maritime economy. National departments such as the Department of Economic Affairs, Department of Trade and Industry and the Department of Transport, as well as Transnet and other industry players are focusing more attention on our ports in their strategic planning. Marine research platforms, such as those supported by the DST through the NRF contribute towards the protection and preservation of coastal and marine environments in support of sustainable economic and social growth in South Africa.

Phenomena such as global warming and sea-level rise disrupt normal weather patterns. Cyclones bring torrential rain and flooding to our eastern shores. Gale-force winds, strong currents and giant waves make many parts of South Africa's coast hazardous to both land-based and seas-based users. Periodic red tides experienced under particular conditions can cause massive loss of marine life and the poisoning of filter-feeders such as mussels and oysters. The public needs to understand such phenomena to avoid the dangers, but also to interact in sympathy with the environment.

Currently, marine education is under-represented in environmental education in South Africa. With increasing numbers of South Africans living by the coast, there is growing pressure on the marine and coastal environment. This combined with other global pressures, including pollution and over-fishing, means that our seas and coastal environments are under threat. Education is the key in raising awareness to protect our coasts and oceans.

Marine and coastal education has been traditionally concentrated in coastal areas. A strategic, integrated, coordinated, well-funded national effort is required that focuses public attention on sustainable development of the marine and coastal environment through an ecosystems-based approach. Through taking a catchment-to-coast approach to the aquatic environment, which includes the importance of our rivers to the health of marine and coastal ecosystems, efforts should be extended inland to increase awareness about the oceans and to support environmental and other educators working in the aquatic environment.

The South African Network for Coastal and Oceanic Research (SANCOR), with the National Marine and Coastal Educators Network (MCEN) are established bodies that can drive a unified approach to marine education and outreach. Lack of designated funding limits the reach of these agents. The provision of sustained funding and human capacity to support the essential cross-cutting functions performed by SANCOR and MCEN and to enable the development of national public engagement programmes for marine science should be central to an effective education and outreach/ public engagement strategy for marine science in South Africa.

Under a research paradigm that emphasizes solutions-oriented research, one of the main challenges is to develop effective mechanisms of communication among stakeholders, researchers, decision-makers and affected communities. This will require extended funding cycles for some research projects, perhaps by allowing for research development and planning phases to allow effective communication. There are many areas where such communication needs to be improved, e.g. between science and policy; research to government communication; government to public communication and researcher to public communication.

A communication strategy should be developed based on best practice and experience from elsewhere, modified for local implementation. It will be important to use a variety of media resources (e.g. Twitter, Facebook, blogs, peer-reviewed research publications, popular articles, radio, television, public talks, etc.). The net effect should be to enhance awareness, ensuring the research is properly aligned with the issues to be addressed, and that the results of the research have a conduit to the appropriate policy or management systems.

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