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The Department of Science and Technology

By

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## List of Acronyms

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<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>ACCESS</td>
<td>Applied Centre for Climate and Earth System Science</td>
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<tr>
<td>ACEP</td>
<td>African Coelacanth Ecosystems Programme</td>
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<td>ADCP</td>
<td>Acoustic Doppler Current Profiler</td>
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<td>ASCLME</td>
<td>Agulhas Somali Currents large Marine Ecosystem Project</td>
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<tr>
<td>BEP</td>
<td>Benguela Ecology Programme</td>
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<td>BRUV</td>
<td>Baited Remote Underwater Video</td>
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<tr>
<td>CC</td>
<td>Climate Change</td>
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<tr>
<td>COE</td>
<td>Centre of Excellence</td>
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<tr>
<td>CSIR</td>
<td>Council for Scientific and Industrial Research</td>
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<tr>
<td>CTD</td>
<td>Conductivity, Temperature, Density</td>
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<tr>
<td>DACST</td>
<td>Department of Arts, Culture, Science and Technology</td>
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<tr>
<td>DAFF</td>
<td>Department of Agriculture, Forestry and Fisheries</td>
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<tr>
<td>DEA</td>
<td>Department of Environmental Affairs</td>
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<tr>
<td>DNA</td>
<td>Deoxyribonucleic Acid</td>
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<td>DOT</td>
<td>Department of Tourism</td>
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<td>DPS</td>
<td>Dynamic Positioning System</td>
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<td>DST</td>
<td>Department of Science and Technology</td>
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<td>DWA</td>
<td>Department of Water Affairs</td>
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<tr>
<td>EAF</td>
<td>Ecosystems Approach to Fisheries</td>
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<td>EEZ</td>
<td>Extended Economic Zone</td>
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<td>ENSO</td>
<td>El Niño Southern Oscillation</td>
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<td>FAO</td>
<td>Food and Agriculture Organisation</td>
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<td>GC</td>
<td>Global Change</td>
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<tr>
<td>Acronym</td>
<td>Definition</td>
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<tr>
<td>GCGC</td>
<td>Global Change Grand Challenge</td>
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<td>HBU</td>
<td>Historical Black University</td>
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<td>HEI</td>
<td>Higher Education Institution</td>
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<td>ICSU</td>
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<td>IPCC</td>
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<td>LTER</td>
<td>Long Term Environmental Research</td>
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<td>National Marine and Coastal Educators Network</td>
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<td>mRNA</td>
<td>Messenger Ribonucleic Acid</td>
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<td>MPA</td>
<td>Marine Protected Area</td>
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<td>MW</td>
<td>Mega Watt</td>
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<td>NBA</td>
<td>National Biodiversity Assessment</td>
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<td>NGO</td>
<td>Non-Government Organisation</td>
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<td>NGS</td>
<td>Next Generation Sequencing</td>
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<td>NRF</td>
<td>National Research Foundation</td>
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<td>NSI</td>
<td>National System of Innovation</td>
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<td>ORI</td>
<td>Oceanographic Research Institute</td>
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<td>RAD</td>
<td>Restriction site Associated DNA</td>
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<td>ROV</td>
<td>Remote Operated Vehicle</td>
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<td>SADCO</td>
<td>South African Data Centre for Oceanography</td>
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<td>SANCOR</td>
<td>South African Network for Coastal and Oceanic Research</td>
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<td>SAEON</td>
<td>South African Environmental Observatory Network</td>
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<td>SAIAB</td>
<td>South African Institute for Aquatic Biodiversity</td>
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<td>SARChi</td>
<td>South African Research Chairs Initiative</td>
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<td>SIBER</td>
<td>Sustained Indian Ocean Biogeochemistry and Ecosystem Research</td>
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<tr>
<td>Acronym</td>
<td>Full Form</td>
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<tr>
<td>SNP</td>
<td>Single Nucleotide Polymorphism</td>
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<td>SWIOFP</td>
<td>South Western Indian Ocean Fisheries Programme</td>
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<tr>
<td>S&amp;T</td>
<td>Science and Technology</td>
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<td>UCE</td>
<td>Ultra Conserved Elements</td>
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<td>UCT</td>
<td>University of Cape Town</td>
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<td>UKZN</td>
<td>University of KwaZulu-Natal</td>
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<td>UP</td>
<td>University of Pretoria</td>
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<td>WIOMSA</td>
<td>Western Indian Ocean Marine Science Association</td>
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<td>WIO-SAPPHIRE</td>
<td>Western Indian Ocean LMEs – Strategic Action Programme Policy Harmonization and Institutional Reforms</td>
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<td>WSSD</td>
<td>World Summit for Sustainable Development</td>
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1 Executive Summary

1.1 Introduction

This report considers a plan for scientific research into the coastal and marine sectors in South Africa. It is premised on the basis of the 2002 National Research and Development (R&D) Strategy; and the 2008 Ten-Year Innovation Plan for South Africa: “Innovation towards a knowledge-based economy 2008 – 2018”. The plan also considers the research programmes of the South African Network for Coastal and Oceanic Research (SANCOR) as well as the National Biodiversity Assessment Report, particularly the marine component.

The R&D strategy identifies priority science missions that take advantage of South Africa’s unique Geographical position. 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 Ten-Year Innovation plan identifies five Grand Challenges for the national System of Innovation (NSI) namely: Bio-economy, Space Science and Technology, Energy Security, Human and Social Dynamics, and Science and Technology for Global Change, with a focus on Climate Change, commonly known as the Global Change Grand Challenge (GCGC).

The Marine and Coastal research Plan is designed to address specific and relevant aspects of the GCGC and the Bioeconomy Grand Challenges, while also strengthening marine and Coastal research efforts of SANCOR. 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. Recognising the significant amount of work already done by the research community to identify priority areas for advancement of marine and coastal research, this research plan focuses on operationalising these efforts using currently available instruments and resources, while also providing a platform for development of new ones as informed by the gaps identified.

The plan proposes several actions for addressing the current problems. These include: 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; modelling biological climate driven changes for better spatial planning, ecosystem modelling and resource management; and adopting the appropriate regulatory tools.

1.2 Themes

The Ten-Year Global Change Research Plan for South Africa developed by the Department of Science and Technology (DST, 2009a) to address the Global Change Grand Challenge identifies 18 thematic research areas within which marine and coastal research questions are broadly covered. In Chapter 7 of the “Global Change Grand Challenge National Science Plan, South Africa” (DST, 2009b) specific priorities for marine and coastal research are highlighted under four broad priority areas namely: (i) understanding the ocean as part of a coupled regional system; (ii) sustainable coastal development: vulnerability, risks and responsibility; (iii) the response of marine ecosystems and ecosystem services to Global Change; and (iv) operational capabilities: marine science for society.

On the basis of these priorities, and bearing in mind the Terms of Reference provided by DST, the research community agreed on three principal thematic areas for the Marine and Coastal Research Plan as described below.

1.2.1 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. However, coastal oceanography is still at its infancy in many areas of the world, including South Africa. 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. Mesoscale processes are particularly important in the coastal zone. However, majority of the studies have not focused on the coastal (<200m depth) oceans and therefore the current understanding of these processes in coastal oceans remains poor.

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 to incorporate such knowledge into policy regulations, and to design management systems that are reasonably robust to unresolvable uncertainties. This would require 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.

The major sources of pressure on marine and coastal ecosystems include climate change; sea-level rise and increase in wave heights; and the impact of these changes on coastal ecosystems, towns and cities. Of particular concern is the biological impacts of sea surface temperature rise and ocean acidification. Increasing water pollution within the coastal zone and reduced river flow into estuaries and the coastal zone are also of concern. Coastal bio-invasions, particularly by alien plant and invertebrate species, require attention. Management of coastal ecosystems under various global change scenarios requires scientific and socio-economic information as well as an appropriate regulatory environment for wise management decision making.

Recent evidence and discussions suggest that existing oceanographic models and satellite data do not resolve the coastal waters around South Africa. The research questions would therefore aim, among others, at improving the understanding of the linkages in the coupled earth system. The emphasis would be on the development of knowledge within relevant disciplines as well as at the interface of the different disciplines. Given the direct coupled effect of in-shore waters on the coastal areas of South Africa in terms of connectivity for biodiversity and the effects on coastal marine resources, a key research question would focus on understanding the physics in the coastal waters.

1.2.2 Theme 2: Ecosystems, Biodiversity & Biodiscovery

1.2.2.1 Biodiversity and Ecosystem responses to global and climate change.

This sub-theme is developed around three focal areas:

**Focal Area 1: Understanding scales of biodiversity from molecular to ecosystem.**

Whereas there seem to be a broad understanding of ecosystem functioning, weaknesses are noted in several specific areas such as modeling; microbial ecology; sub-tidal and offshore pelagic areas; ecosystem classification; mapping, assessment and systematic planning; soft sediment biota and smaller taxa/marine invertebrate and microbial taxonomy; and the genetic diversity of marine organisms. 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 (river/estuary/coastal interactions) is required. For example, the impact of changing river input into the coastal zone is still relatively unexplored. Also, additional work to understand the importance of fresh water ecosystems in the marine environment is needed. The biological and ecological importance of connectivity between marine, estuarine and freshwater ecosystems also requires further research in terms of the drivers of biodiversity and productivity along this continuum.

**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 and marine ecosystems. Coastal fisheries have received some attention, particularly the application of an Ecosystem Approach to Fisheries for the west coast fisheries. There is little or 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. Assessments of ecosystem condition should be ground-trothed.

### 1.2.2.2 Biodiscovery and Biotechnology

Marine bioprospecting or biodiscovery and Marine biotechnology have significant potential for the Bio-economy Grand Challenge and are therefore given particular attention in this research plan. Both biodiversity research and bio-discovery are relatively at their infancy. While some capacity as well as established international collaborative networks do exist in marine natural products chemistry, there is a significant lack of capacity in taxonomy, particularly in the area of molecular taxonomy of marine organisms. There is also a need to ensure that the legislative environment adequately regulates marine bio-prospecting and biotechnology activities while providing the necessary protection for the intellectual property and other rights generated or affected by those activities.

### 1.2.3 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 to support marine spatial planning in line with South Africa’s emerging ocean policy is a national 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 Exclusive Economic Zone (EEZ) and extensive petroleum and other mineral exploration concessions have been granted for large parts of South Africa’s EEZ marine sectors. Further developments in terms of the National development Plan and the development of EEZ will impact on coastal systems. Therefore development planning that is socio-ecologically resilient and sustainable would need to be given considerable attention.

The development of ocean energy is inherent with diversifying the supply of renewable energy. Ocean energy resources offer an opportunity for potentially reducing carbon emissions but this is unlikely to make any significant short-term impact due to the infancy of its development. This research plan proposes to address the priority issues of resource management and societal development under two broad headings:

1.2.3.1 **Sustainable coastal and ocean development: vulnerability, risks and responsibility.**

Research under this theme will, among others, address 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. It is estimated that runoff from rivers on the west and south coasts would decline, and that the percentage runoff change in southern Africa would be among the highest in the world. Changing temperatures and acidity (pH) are important drivers that significantly influence the sustainability of coastal resources. It is important to have a good scientific understanding of all these changes in order for policy makers and managers to be able to develop informed response strategies. Other important considerations include operational management plans, stock assessment, and policy frameworks encompassing risk assessment. Important research questions would therefore include:

- Response of Coupled Human-Natural Systems to Climate and Environmental Changes;
- Understanding of dynamics and causal flows in coupled human and natural coastal systems at various spatial, temporal, and organizational scales;
- Models to predict the responses of coastal coupled natural-human systems to endogenous and exogenous transformations including impacts, trade-off of ecosystem services, and estimates of system uncertainty under different climate change scenarios; and
• Understanding the economic impact of climate change on society

1.2.3.2 Marine Technology.
Many scientific projects and programmes are actively developing and using ‘marine technologies’. This important sphere of activity is currently underdeveloped and poorly coordinated in South Africa, and therefore requires keen attention.

Research in marine technology could embrace issues such as: compact and robust sensors and loggers, ship board measurement systems solutions to bio-fouling, mooring and material solutions to bio-fouling, remotely operated and autonomous vehicles, ocean drifters, harnessing ocean energy, swarm technologies, nano-technology exploration, as well as emerging technologies such as GoPro’s and linked GPS units. The above take place in a legal environment which needs to be thoroughly researched and adapted to those new developments.

1.3 Cross-Cutting Issues

1.3.1 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 challenges 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.

1.3.2 Platforms and Infrastructure
As a country South Africa has substantial infrastructure and capacity for marine research 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.
To significantly strengthen marine and coastal research further investment is required for additional National Research Infrastructure such as: Sentinel sites and Long Term Environmental Research (LTER) network; Biodiversity collections and associated laboratories; Estuarine and Coastal research platforms; Offshore research platforms and Remote sensing, data and 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; systems to collate and serve spatial biodiversity data; and a pH manipulation laboratory that would enable better understanding of the implications of ocean acidification on coastal ecosystems.

1.3.3 Public Awareness and Understanding of Science

A national strategy for public engagement in marine science should be underpinned by inter-departmental cooperation.

The public needs to understand the phenomena, both natural and anthropogenic, that disrupt marine and coastal environments and ecosystems, and the impacts of these disruptions. For example, 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.

Citizen science offers important opportunities to raise the public understanding of marine science and build the knowledge base to support marine research, assessment, planning and management.

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, that 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, and adapted for local implementation. It will be important to use a variety of media resources. The net effect should be to enhance awareness, ensuring that research is properly aligned with the issues to be addressed, and that the results of the research have a conduit to the appropriate policy, regulatory, and management systems.
2 Introduction

2.1 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 past, present and future climate.

The coast, from the border of Moçambique 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 geographical advantage of South Africa derives from its peninsular position (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. This unique geographic position presents a crossroads of ocean dynamics, with a rich ecological diversity within easy reach of the major centres where research capacity is present. 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 Converyer Belt’ (Beal et al., 2011). 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 feed-backs into the Earth System.

The exploration and exploitation of South African maritime resources is rooted in the earliest human occupation of the region (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 the Department of Science and Technology produced a ten-year innovation plan (DST 2008) which identifies five Grand Challenges for the national System of Innovation (NSI) namely: Bio-economy, Space Science and Technology, Energy Security, Human and Social Dynamics, and Science and Technology for Global Change, with a focus on Climate Change, commonly known as the Global Change Grand Challenge (GCGC). Of these, the Global Change and the Bio economy Grand Challenges have particular relevance for setting the marine research agenda within the 10 year timeframe (2008-2018).

South Africa has comparative advantages when considering research into Global Change. It has an established science system, including state, private and higher educational resources; in addition to the unique geographical advantage of a broad range of ocean systems as discussed above.
2.2 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 ocean ecosystem processes and the drivers of human behaviour and choices;
(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 and restoring ecosystem structure as well as social economic and governance tools to incentivise sustainable development;
(7) Managing the seas using the ecosystems approach and spatial planning; and
(8) Modelling 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 the need for new approaches to achieving this vision is increasingly being recognised. One such set of approaches is encapsulated in the 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, law, humanities, economics, and technology development;
(iii) timely information generation for policy-makers as well as legislative and law enforcement bodies;
(iv) participation of policy-makers, 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.

On the globally scale marine and coastal science is developing rapidly in a number of areas which include:

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

2.2.2 Modelling & Scenario analysis
Numerical modelling is underrepresented in South Africa. Integral investigations on processes, drivers, fore- and hind-casting 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.

2.2.3 Operational oceanography and Long Term 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 global change are to be unravelled.
2.2.4 Data
Modern marine and coastal research requires effective data and meta-data management with regard to storage, dissemination and ethics. There is need for investment in expanding South Africa’s data management and computational abilities. The development of a centralised and accessible metadata archive would be valuable.

2.2.5 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 single-nucleotide polymorphisms (SNPs) determined by Restriction site associated DNA (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).

2.3 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.

2.3.1 Sector-specific programmes:

Sector-specific research would be driven by the respective line departments and would be designed to meet their mandated reporting and management responsibilities. For example the Department of Agriculture, Forestry and Fisheries (DAFF) would address Fisheries management and stock assessment; the Department of Environmental Affairs (DEA) would be responsible for the state of the Environment Reporting as well as Coastal Zone Management and Biodiversity; the Department of Mineral Resources (DMR) would drive offshore exploration and exploitation; the Department of Transport (DoT) and the South African Maritime Safety Authority (SAMSA) would drive pollution control and safety at sea; and the Department of Water Affairs (DWA) would be responsible for estuarine reserve determinations.

2.3.2 Fundamental and applied research programmes for individuals or small-consortia.

These programmes would address fundamental and applied research by individual researchers or small research consortia through a competitive funding mechanism managed according to standard NRF processes.

2.3.3 Infrastructure linked programmes

The National System of Innovation (NSI) has invested heavily in marine infrastructure such as ships, coastal craft, gliders, remote-operated vehicles
(ROVs), oceanographic arrays, data centres, collections, and laboratories. Flagship programmes using the model of the African Coelacanth Ecosystems Programme (ACEP) are required to ensure that research infrastructure is made accessible on a competitive basis to researchers within the system. The support of Transnet is also required to provide the necessary berths and work space in the ports under its control.

2.3.4 Larger programmes for specific interdisciplinary issues

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.

2.3.5 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.
3 Priority Research Themes

3.1 Rationale

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 Change, and particularly climate change on these systems and their interactions with coastal systems. The impact of Global Change on coastal and marine ecosystems has been recognized and has been given due consideration in the DST’s Ten-Year Global Change Research Plan for South Africa (DST, 2009a). In Chapter 7 of the “Global Change Grand Challenge National Science Plan, South Africa” (DST, 2009b) specific priorities for marine and coastal research are highlighted under four broad priority areas namely: (i) understanding the ocean as part of a coupled regional system; (ii) sustainable coastal development: vulnerability, risks and responsibility; (iii) the response of marine ecosystems and ecosystem services to Global Change; and (iv) operational capabilities: marine science for society. On the basis of these priorities, and guided by the Terms of Reference provided by the Department of Science and Technology for the preparation of this research plan, the following key issues emerge for consideration in the research plan:

3.1.1 The response of coastal and marine ecosystems and associated services to global 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 profound effects on human populations, both directly and indirectly through ecological impacts on the goods and services that coastal and adjacent marine ecosystems and associated biodiversity can deliver.

3.1.2 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 compromising the sustainability of the systems and the services they provide. 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, sea bed 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.

3.1.3 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/models that can be scaled down to assist in establishing regional or sub regional responses to climate change. Reliability of climate projects is fundamental for formulating scenarios of ecosystem and biodiversity responses to change, and their direct and indirect impacts on human populations. It is essential that the models creating these climate predictions are able to better resolve the key South African oceanographic features, such as the Agulhas Current.

3.1.4 Bio-discovery

Marine bio-discovery or bio-prospecting is the search for marine natural products (bioactive small molecules) and other materials with an economic benefit to society. Examples of such products include pharmaceuticals, agrochemicals, marine anti-fouling coatings etc. Associated with bio-discovery is marine biotechnology, which focuses 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, by virtue of the high levels of diversity, particularly of invertebrates (sponges and ascidians), algae and microorganisms, represent a unique and virtually yet unexplored reservoir of bio-molecular diversity.

i. The research plan considers the four major issues above into three overarching research thematic areas as discussed below. These thematic areas duel essentially on: the physical nature of the marine systems of the southern African region;

ii. the living dynamics of the marine ecosystems of the region; and

iii. human exploration, exploitation and development of southern African marine systems.
3.2 Theme 1: Oceans and marine ecosystems under global change

3.2.1 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 develops 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 that integrates the natural and social sciences is required for generating new knowledge of real relevance to policy development and management.

3.2.2 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 are all 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 the coasts of South Africa. On the west coast, where the Benguela coastal upwelling system supports the region's most important fisheries, research on this system revealed 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 amount of research towards understanding the
dynamics of the Agulhas Current system (Lutjeharms, 2006, 2010) and its marine
resources. Current oceanographic research is focusing on mesoscale through to
inter-annual variability in the Greater Agulhas Current Region, including its source
regions and the retroflection region. These include processes in the Mozambique
Channel (Marsac et al, 2014), the Agulhas retroflection and leakage of warm,
salty waters into the Atlantic Ocean (Backeberg et al, 2012), with concurrent
studies of their influences on biogeochemical cycles, biological productivity and
living marine resources. There is also some work on the Agulhas-coastal
interaction, the East Madagascar Current, variability in the Agulhas Current, etc.

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 food web dynamics. Moloney et al., 2013 reviewed the
evidence of ecosystem change off the coast of South Africa and concluded that
while 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 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 Agulhas-Somali Current Large Marine Ecosystem
(ASCLME), the South-West Indian Ocean Fisheries Project (SWIOFP) and the
Western Indian Ocean Large Marine Ecosystems – Strategic Action Programme
Policy Harmonization and Institutional Reforms (WIO-SAPPHIRE) project
(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. Hind-cast simulations, data assimilation and the calibration of complex models to observed time series require sophisticated algorithms to be developed.

3.2.3 Major Gaps

One of the major gaps confronted in marine ecosystem research is the absence of long-term data sets. Marine ecosystems off the coasts of South Africa are naturally variable on inter-annual and decadal time-scales, 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 a 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 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. 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 institutions.
3.2.4 Key research needs and research questions

Global change pressures include climate change; sea-level rise and increase in wave heights; and the impact that these changes will have on coastal ecosystems, towns and cities. Increasing water pollution within the coastal zone and the reduction in river flow to estuaries and the coastal zone constitute threatening challenges that need urgent attention. Knowledge and understanding of the impacts of these challenges is crucial for sustainable management of the coastal fisheries. Coastal bio-invasions, particularly by alien plant and invertebrate species, constitute another threat. Urgent remediation efforts are required to reverse the direct and indirect adverse effects of these invasions. Management of coastal ecosystems under various global change scenarios requires that knowledge and information generated through fundamental and applied scientific research be integrated with socio-economic knowledge in order to be able to make 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 create secondary opportunities for jobs in construction and service industries especially where there are numerous recreational nodes for holidays and for retirement settlements. The fishing industry is vital to the coastal economy, particularly in the cool temperate region of the Western Cape.

Coastal systems, especially estuaries, are at the interface between inland freshwater sources and the marine environment, and represent the central part of a continuum that extends from the catchment to the sea. Future research in this area needs to be focused on the contributions of each of the component ecosystems to the well-being of the entire coastal environment. In particular, actions which result in a breaking down of that connectivity are likely to have serious consequences for the biodiversity and productivity of all the component ecosystems, especially estuaries and the coastal marine environment.

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.

Recent evidence and discussions suggest that existing oceanographic models and satellite data do not resolve the coastal waters around South Africa. 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.

In view of the foregoing discussion, research questions under this theme would aim, among others, at improving the understanding of the linkages in the coupled earth system. The emphasis would be on the development of knowledge within relevant disciplines as well as at the interface of the different disciplines. Given the direct coupled effect of in-shore waters on the coastal areas of South Africa in terms of connectivity for biodiversity and the effects on coastal marine resources, some research questions would seek to improve understanding of the physics in the coastal waters.

Specific research and development priorities may include, but not limited to:

- Understanding modes of ocean variability across temporal and spatial scales, and their feedbacks and linkages to marine ecosystems;
- Developing a regional observations network to link with other countries of the region, in emulation of initiatives such as the observatory for the
marine environment of the Western Indian Ocean which 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, including 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 the state of knowledge obtained from observations and models to guide policies and decision-making processes across disciplines;

- Reconstructing past climate changes, particularly across major climate transitions from glacial to interglacial periods over the last one million years.

### 3.3 Theme 2: Ecosystems, Biodiversity & Biodiscovery

#### 3.3.1 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. It also identified gaps, threats, human skills and 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. Similarly, very small systems such as coastal inlets or micro-estuaries are poorly studied, despite there being more than 100 such systems around our coast. 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),
The National Biodiversity Assessment (Driver et al., 2012), and the SANCOR proposed research programme – Making Marine Science Effective (SANCOR, 2013). All of these processes involved significant input from a wide range of scientists and managers in the South African marine sector. In addition to this collective community-wide input two principal line departments (DEA and DAFF) each have specifically mandated research priorities. It emerges from all these processes that the main challenges of the South African Marine environment are linked to global change. It is against this background that this theme is developed to focus on the responses of biodiversity to the forces of global change. Alongside this, issues of biodiscovery and biotechnology are also considered. These issues are discussed under two sub themes as presented below.

### 3.3.2 sub-theme A: Biodiversity and Ecosystem responses to global change (including climate change)

The research focus for this sub theme will dwell on three key aspects:

#### 3.3.2.1 Understanding Biodiversity across scales from molecular to ecosystem levels.

While there may be a broad understanding of ecosystem functioning, there are still several specific areas where knowledge is weak and for which research efforts need to be strengthened. The following issues are of particular concern:

- The linked physical, chemical and biological numerical models required to understand global change impacts under various scenarios do not yet exist, or are not sufficiently 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 near-shore and estuarine ecosystems;
- Developing an understanding of physiological changes in order to reliably project the effects of climate change on marine life, e.g. fishes;
- The marine environment is several generations behind terrestrial habitat mapping and conservation planning while sub-tidal mapping is still in its infancy;
- Macro-faunal taxonomy (e.g. fish) is generally well known but soft sediment biota and smaller taxa, including micro-biota, 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 applied and theoretical biodiversity knowledge to ecosystem functioning is largely non-existent.

Research questions that arise include, among others:

• 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 adaptable are these attributes?
• How can genetic and adaptive diversity be maintained in the face of global change?
• What properties of ecosystems make them resilient or vulnerable to biological invasions?
• How do we optimise the siting and functionality of Marine Protected Areas?

Some priority research areas may include:

• Systematic conservation planning and identification of priority conservation areas;
• Modelling frameworks for projections of change and sustainable functioning of ecosystems, and for projections of range shifts and productivity of coastal species;
• Physiological research to determine the environmental limits of coastal species;
• Taxonomy and systematics of priority groups identified in the National Biodiversity Assessment;
• Benthic continental shelf ecosystems;
• Sub-tidal habitat mapping;
• Development of comprehensive species databases;
• Invasion biology;
• Microbial ecology;
• Molecular ecology.

3.3.2.2 Connectivity between terrestrial, coastal and marine systems

An overview of existing knowledge shows that 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. However, further work is required to scale up from individual systems to regional impacts, and for understanding the connectivity of systems.

The estuary-marine interactions are 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. Bearing in mind the impacts of climate change, it is critical to understand the influence of fresh water flow on the coastal zone in order to properly predict biological production and coastal fisheries. Some work off the Thukela catchment has shown the importance of understanding these relationships in managing coastal fisheries, e.g. that for prawns and linefish.

Important research questions would include:

• How would global change or climate change influence productivity and exchanges of biomass between terrestrial, coastal and marine systems?
• What is the role of interconnectivity between estuaries with respect to biodiversity and how will this interconnectivity be influenced by climate or global change?
• How would global change or climate change impact on the complex onshore-offshore biochemical and biophysical processes and their feedback effects?
• 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 would these be influenced by the forces of global change?
• What is the connectivity between catchment, estuaries, inshore and offshore areas?
• What are the linkages between hydrology and coastal biodiversity and ecosystem change and what are the hydro-geographical links?
• Are there any Aeolian and non-estuarine impacts?
• What are the terrestrial nutrient drivers (natural and anthropogenic) of harmful algal blooms?

3.3.2.3 Understanding natural and anthropogenic drivers of change

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, as is the case for freshwater inflow into estuaries, physical drivers of sandy beaches and for coastal fisheries. Coastal fisheries have received some attention, in particular the application of an Ecosystem Approach to Fisheries (EAF) for the west coast 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. There is little or 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.

Some key research priorities would include:

• Investigating the absolute limits to the natural resources and eco-system services that our socio-economic systems can extract and how far we are from breaching these limits;
• Identifying the indicators of limits and tipping points in coastal and marine ecosystems;
• Understanding cycles in natural drivers and differentiating them from interacting anthropogenic ones;
• Determining the current adaptive capacity to change;
• 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.

3.3.3 sub-theme B: Biodiscovery and 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 the Bio-economy Grand Challenge and are therefore accorded particular attention in this research plan. Both biodiversity research and bio-discovery are relatively at their infancy. While some capacity as well as established international collaborative networks do exist in marine natural products chemistry, there is a significant lack of capacity in taxonomy, particularly in the area of molecular taxonomy of marine organisms. There is also a need to ensure that the legislative environment adequately regulates marine bio-prospecting and biotechnology activities while providing the necessary protection for the intellectual property and other rights generated or affected by those activities.

3.3.3.1: Biodiversity and Biodiscovery

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 is poor or non-existent. Bolton et al. (2013) reviewed the situation regarding biodiscovery and biotechnology in the marine environment off the coast of 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.

The key research priorities would include:

- 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 adaptability to changing environments;
- 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;
- Development of adequate regulatory regime both within the maritime zones under South Africa’s jurisdiction and beyond.
In addition to the above non-exhaustive list of research priorities, molecular taxonomy, molecular microbial ecology, metagenomics, proteomics and metabolomics, and chemical taxonomy are among specialised disciplines that would need to be developed.

3.3.3.2 **Innovative marine processes and products**

The emphasis here would be on Bio-mineralization; biomaterials; Nanobiotechnology; and drug discovery. Priority research areas would include:

- Developing innovative technologies for aquaculture of indigenous species;
- Developing Algal and microbial biotechnology to discover new products and processes involving indigenous organisms;
- Developing innovative products and processes in mariculture in order to find new indigenous species for commercial production. This would include using marine biotechnological techniques to improve the existing mariculture industries and to bio-remediate waste from commercial enterprises;
- Innovative research in Biofouling to solve problems involving the fouling of marine structures;
- Innovative technologies in biodiversity research to enable the discovery of novel indigenous species for marine biotechnological applications, and to enhance the investigation of relationships and diversity of commercial and potentially commercial marine organisms using molecular techniques, as well as carry out strain selection and genetic testing of commercially important organisms for existing and new products.
- Development of adequate regulatory frameworks to protect intellectual property and other rights generated or affected by new marine processes and products.

3.4 **Theme 3: Coastal and marine resources, society and development**

3.4.1 **Introduction**

This section of the marine research plan presents the research needs associated with the use of both extractive and non-extractive living and non-living coastal and marine resources. These resources are the basis for our close relationship with the ocean. Not only do we need to understand the limits of resources use, i.e. the difference between sustainability and over-exploitation, but we also need to acknowledge and comprehend the growing concern of accelerated environmental change and understand our precarious exposure and vulnerability to increasing hazards, and risks.
While there is an obvious need to understand the impact of resource exploitation, it is even more important to recognize the impact of societal existence on the coast. It is often remarked that natural systems do not require management, only human activities do. This section of the research plan will none the less also consider the scientific research that underpins the management of anthropogenic impacts of a transforming and developing society.

The national imperative for growth and development has never been more clearly articulated (NPC, 2012) as is the need to use available resources to enable the vision of a developed South Africa. This vision incorporates an agreement on the requirement for environmental, social and economic sustainability that is expressed as the development of a Green Economy. Such a strategy compels the use of science to be integrated in all aspects of human society. The following areas are therefore recognized and prioritized for research in this plan:

- Living and non-living extractive coastal and marine resources, both;
- Coastal and marine-based renewable energy;
- Land-based sources of marine pollution; and
- Coastal and marine development planning, including port development

3.4.1.1 State of the knowledge

3.4.1.1.1 Extractive living marine resources –

The South African fishing sector and the resources upon which it is based is arguably most developed in terms of supporting science (DAFF, 2010; 2010b; 2012). The fishing sector is a complex mixture of sub-sectors that include; commercial fishing and harvesting; recreational fishing; subsistence harvesting and aquaculture. All fisheries sectors are managed through an equally complex legal and policy framework that includes: the Marine Living Resources Act; the Policy for Small Scale Fisheries Sector in South Africa; and the National Aquaculture Policy Framework for South Africa 2013. Mariculture illegal harvesting and poaching is another important activity that forms part of the national fishery sector.

Fisheries are a national competence delegated to the Department of Agriculture, Forestry and Fisheries (DAFF). Fishery resources are a major contributor to GDP and as such it has relative large supporting government processes, infrastructure and research. The state of knowledge of fisheries is well-developed although aspects of aquaculture, as a new sub-set of a resource-based industry still needs research development (DAFF, 2011). 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 hakes. 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). It is expected that much of the scientific research related to fisheries will either originate from DAFF, or be facilitated through a national research agenda developed by that line department.
3.4.1.1.2 **Extractive non-living marine resources**

The South African coastal and marine environment is rich in mineral resources, and is predominantly mined for mineral sands and aggregates (UNOPS 2011), and increasingly for oil and gas. Ocean mining has huge economic impacts and as such it remains a national competency of governed, managed by the Department of Mineral Resources (DMR) through the *Mineral and Petroleum Resources Development Act*, 2008.

Despite the rather dismal mineral market conditions, the world will become more dependent on the oceans as a mineral resource reservoir in the future. Similarly, the future for the oil and gas industry has changed. For over 100 years the story was one of growth in production to supply a largely Western-driven market, and of competition between private companies for access to reserves. Since 2005, oil prices have moved to a permanently high level.

Heavy minerals sand-mining in KwaZulu-Natal are estimated to be worth about R1.5 billion (UNOPS 2011). A recent estimate (SANBI, 2009), suggests that 554 km² of land in coastal districts in South Africa is used for mining. At a national scale, most mining activities take place in the Namaqua District of the Northern Cape. All coastal mining activities have significant adverse social and biophysical impacts on the environment, including the denial of access to certain areas due to mining concessions and restrictions. On-shore and off-shore petroleum and gas exploitation are also potential causes of pollution of the coastal environment. At a much smaller scale, sand mining in estuaries is contributing to a much bigger issue of sand-starvation of urban beaches. The research needs relating to large-scale disruption of the coastal and marine environment is understandably important.

3.4.1.1.3 **Renewable energy**

South Africa has developed a White Paper on Renewable Energy in 2003 subsequent to the World Summit on Sustainable Development (WSSD): Johannesburg Plan of Action (CSD-11, 2002), which calls for nations to “Diversify energy supply by developing advanced, cleaner, more efficient, affordable and cost-effective energy technologies, including fossil fuel technologies and renewable energy technologies. With a sense of urgency, substantially increase the global share of renewable energy sources with the objective of increasing its contribution to total energy supply, recognizing the role of national and voluntary regional targets”. The development of ocean energy is thus inherent with renewable energy as outlined in the White Paper. The potential environmental issues relating to new and renewable sources of energy is not well understood in the South African context.

3.4.1.1.4 **Land-based source of marine pollution**

Land-based sources of marine pollution in the South Africa are primarily associated with urban areas and river discharges from larger catchments into the sea (UNEP, 2009). Industry, agriculture, mining, shipping and ports all contribute

Most industrial development along the coast of South Africa is related to port development such as at Richards Bay, Coega and Durban. South Africa has diverse industrial activities that account for about a third of the national Gross Domestic Product (GDP), including energy production, automobile assemblies, machineries, textile, paper, iron and steel, tyre manufacture, chemicals, fertilizer and foodstuffs. Agricultural production in South Africa is well developed, providing not only most of the nation’s food requirements but also major exported products. As expected, agriculture, including forestry, is the most significant agent for the transformation of land and the degradation of catchments.

The environmental cost of, and the need for management actions relating to land-based sources of pollution provides a compelling argument for research investment. This includes understanding the impacts of oil pollution, coastal and offshore waste water discharge and other sources of pollution and waste.

3.4.1.1.5 Coastal and marine development planning

Terrestrial development planning is enabled by a complex set of legal instruments that include the Municipal Systems Act, Spatial Planning and Land-use Management Act, and a diverse range of planning and management tools at local level, that include the Spatial Development Framework, Strategic Environmental Assessment, and the Integrated Development Plan. The Integrated Coastal Management Act (ICM Act) establishes a system of integrated coastal and estuarine management in South Africa. The integration of a diverse range of scientific and other knowledge systems requires a different tactic to achieve the pro-poor, people-centered vision of the ICM Act.

The coastal and marine space is a valuable resource by virtue of its existence and the planning of the entire spectrum of human activities area paramount for the achievement of national growth and development objectives. Recent estimates indicate that approximately 30 per cent of South Africa’s population lives within 60 km of the coast (UNOPS 2011). Currently, there is no seamless planning system that incorporates both coastal and marine spatial planning.

Large socio-political change has occurred in South African coastal communities since the onset of democracy in 1994. Far-reaching changes have been made to many of the country's policies and laws that regulate use of the marine and coastal environments (Sowman et al. 2013). The ways in which human systems inform and are informed by research undertaken on natural systems remain important challenges for future research activities. The interface between marine research and societal needs has to be managed effectively.
3.4.1.2 The Big Issues

3.4.1.2.1 Marine fisheries

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, in particular 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. Landings from the region are dominated by small pelagic fishes such as herring, sardine and anchovies; midwater pelagic species such as horse mackerel; and demersal fish such as hakes. The most important stocks within these groups 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. It is only in the recent past years that the importance of looking at entire ecosystems has become largely accepted as means of holistic management of fisheries (Reykjavik 2001). As a result, limited interactions between competing species or predators and prey were formally taken into account when modelling the stock dynamics and providing management advice to the authorities (Hutchings et al. 2009).

3.4.1.2.2 Mineral Resources

The value of mineral resources including oil and gas, and the national interest in its continued contribution to GDP often creates conflict with the socio-ecological environment in which prospecting or mining takes place. Oil and gas exploration is likely to increase within and out of the South African EEZ, and on-land coastal mining will continue to be a major disturbance in the landscape. The increasing demand for mineral resources will remain a big research issue as there is an urgent need to reconcile the real impact and cost of the mining with the apparent benefits. While it is certain that prospecting and mining will continue over the next decades, the socio-ecological effects, mitigation and rehabilitation must be given priority for research. The ecological value and irreplaceability of coastal and marine landscapes must be understood in order that intelligent trade-offs can be negotiated.

3.4.1.2.3 Ocean energy

Ocean energy offers the potential for long-term reduction of carbon emissions but is unlikely to make a significant short-term contribution before 2020 due to its early stage of development. By 2009, less than 10 MW of capacity worldwide was installed that yielded about 300 MW. All ocean energy technologies, except tidal barrages are in conceptual phase, thus undergoing research and development, or in pre-commercial prototype and demonstration stages. 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).

3.4.1.2.4 Land-based sources of marine pollution

Land-based sources of marine pollution (DEAT, 2008) will remain one of the major anthropogenic impacts that will require a very specific research strategy over the next decades as the world transitions to a low-carbon economy. There are many opportunities for improved technologies for cleaner production, and for monitoring and treatment of pollution. Understanding point-source and cumulative impacts remain important. It is increasingly becoming important to understand how these impacts will limit future growth and development, and the trade-offs that will decide on where best to locate and mitigate impacts. All the challenges relating to resource use and the impacts of society are increasingly complex and our understanding needs to incorporate the complexity. Part of the requirement of understanding the impacts must also be to recognize the greater uncertainty of the impacts of land-based sources of pollution in a rapidly changing environment. Similarly, our planning and development responses should also be responsive to the dynamic nature of the environment and the multiple impacts.

3.4.1.2.5 Coastal and marine development planning

Terrestrial development planning in South Africa has traditionally not included the complexities of the dynamic coastal and marine processes. Unlike fisheries, mineral resources and energy, the management of the physical coastal space and the associated activities are not centrally governed. Legislation such as the MSA and ICM Act assigns management responsibility to local government. Coastal space is a valuable resource that is often not consistently managed. This multi-use and multi-stakeholder space is where there are interactions between ecosystems (and their components) and societal processes, including human activities and development in the coastal environment, such as tourism and marine aquaculture, governance and compliance etc. These interactions can be positive and negative but almost always have serious consequences for some component of the socio-ecological system. It is this space, where the environment, society and its economy collide.

A number of relevant issues require further understanding through directed research efforts:

- Urbanisation (SANBI, 2009) and its impact on coastal resources and society;
- Port development and the port-city interface;
- Coastal and infrastructure development;
- Tourism interactions with the ecosystem and society;
- Social vulnerability and risks of exposure to coastal and marine hazards;
• Coastal and marine special planning processes;
• Access to coastal and marine resources;
• Poverty, coastal livelihoods and health;
• Coastal knowledge systems;
• Cohesion, livelihoods and sensitivity of coastal communities;
• Coastal and marine resource governance and institutions; and
• Coastal management and monitoring systems.

3.4.1.3 Vision (where are we going?)

UNEP (2012) recognizes that a global transition to a low-carbon, resource-efficient green economy is unlikely unless the seas and the oceans are a key part of the urgently needed transformations. In this context, the 'Blue-Green Economy', results in a reduction in ecological impacts, while promoting the economic and social sustainability of traditional and emerging ocean-oriented economies. The blue-green economy relates to a number of interrelated sectors, including:

• Fisheries;
• Tourism;
• Maritime Transport;
• Energy Generation;
• Aquaculture;
• Mining; and
• Nutrient Economy.

The Monaco Workshop on the sustainable use of oceans in the context of a green economy and poverty eradication, focused on three particular themes (i.e. food security, energy and tourism) which are critical to consider when promoting a blue-green economy.

The emerging concept of the blue-green economy has not previously been used in the South African context, even though the coastal and marine domain has been identified as a driver of national growth and development (NPC, 2012). There is an increasing need to employ science and scientific research in order to more directly benefit the transforming and developing South African society.

The need to explore new approaches in achieving this vision is increasingly gaining recognition. One such set of approaches is encapsulated in the recently-launched Future Earth research initiative (www.icsu.org/future-earth), which emphasizes

(i) solution-oriented research for sustainability;

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1 Sustainable Use of Oceans in the Context of the Green Economy and Poverty Eradication, 28-30 November 2011 Principauté de Monaco
(ii) effective interdisciplinary collaboration across natural and social sciences, humanities, economics, and technology development;

(iii) timely information generation for policy-makers;

(iv) participation of policy-makers, 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 science is well placed to make substantial and important contributions to such research. For example, South Africa has a long history of inter-disciplinary and inter-institutional collaboration in marine science. This is a solid foundation that needs to be further strengthened. South Africa’s geographical advantage by virtue of its location in an area where ocean dynamics are dominated by processes at the mesoscale and sub-mesoscale provides a dynamic natural laboratory for carrying out interdisciplinary research.

3.4.1.4 Framework of how (type of projects that may achieve this)

Human impacts on the marine and coastal environment are an integral part of development benefits. The challenge lies in maximising those development benefits without impairing the ability of the system to provide them sustainably. This applies to the exploitation limits of fisheries as much as it applies, for example, to urban and port impacts on coastal erosion.

To have a full understanding of the dynamics, the potential and the use of marine resources and how these are affected by global change it is essential to have continuous and effective data collection, management and archiving; and well-coordinated research. Well-designed coherent ecosystem programs would enable proper understanding, quantifying and addressing the pressures on, and opportunities for the South African marine environment in order to ensure sustainable use of the marine resources. Such programmes should focus on hypothesis-driven transdisciplinary research characterized by baseline data collection, continuous monitoring and modelling. The research programmes should cover 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.

There are a number of interested and affected groups that should be part of coastal and marine research planning and execution; many of these already are 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). In addition, since the research is all encompassing, including a range of resources exploited from the marine environment, it is imperative to engage with those role players or interested parties that are not traditionally engaged, e.g. non-living resources such as minerals, etc. This provides a good platform for
developing 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.

3.4.2 Research themes

3.4.2.1 Sustainable coastal and ocean development: vulnerability, risks and responsibility

Research under this theme will, among others, address Physical coastal processes (including extreme events); coupled urban coasts and estuarine systems; and environmental security and coping capacity.

3.4.2.1.1 Physical coastal processes (including extreme events)

South Africa is likely to experience substantial climate change in the next decades leading to a dramatic decline in biodiversity (Van Jaarsveld & Chown 2001). 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).

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 possibly 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.

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).

Changing temperatures and acidity (pH) are other important drivers that significantly influence the sustainability of coastal resources. It is important to have a good scientific understanding of all these changes in order for policy makers and managers to be able to develop informed response strategies. Other important considerations include operational management plans, stock assessment, and policy frameworks encompassing risk assessment. Priority research areas would therefore include:

- **Response of Coupled Human-Natural Systems to Climate and Environmental Changes;**
- **Understanding of dynamics and causal flows in coupled human and natural coastal systems at various spatial, temporal, and organizational scales;**
- **Models to predict the responses of coastal coupled natural-human systems to endogenous and exogenous transformations including impacts, trade-off of ecosystem services, and estimates of system uncertainty under different climate change scenarios; and**
- **Understanding the economic impact of climate change on society**

Typical research questions may include:

- **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 climate change scenarios?
• Can extreme events and their potential impacts be forecast; and, can this information be disseminated with adequate lead-times and contingency implementation?
• How accurately are coastal vulnerability maps linked to future climate change scenarios?
• What would the changes in rainfall and freshwater runoff patterns and what would be the impact of altered freshwater supply to the marine and estuarine environment?
• What would be the appropriate mix of mitigation and adaptation measures, for example in relation to setback lines, coastal protection, and coastal infrastructure protection for vulnerable areas along the coast?
• What are the obstacles to the full implementation of the National Environmental Management: Integrated Coastal Management Act, 2008 (Act 24 of 2008), and how can those obstacles be overcome?
• How will changes in physical processes such as erosion, deposition and long-shore drift impact estuarine, coastal and marine ecosystems?

3.4.2.1.2 Coupled urban coasts and estuarine systems

There are some efforts in monitoring the potential impacts of outfalls on estuarine and marine biota but on a broad scale, nor on an ecosystem or modelling scale. Research on ecotoxicology is on a small scale, as is pollution monitoring with respect to physical, chemical, biological and ecosystem responses.

The priority issues for research would include:

• The extent to which coastal development is impacting, influencing or extending into marine processes and ecosystems;
• The carrying capacity limitations to the development of urban bay, and how these can be measured;
• How altered river flows, sea-levels and storm events arising from global change would affect the structure and functioning of estuarine and coastal ecosystems; and
• The urgent priorities in respect of coastal zone management and urban bay management, that would enable mitigating the risks associated with global change.
3.4.2.1.3 Environmental security and coping capacity

This is a new, open field for research. It requires interactions between environmental scientists, ecologists, sociologists, lawyers and modelers. The priority areas for research would include:

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

3.4.2.2 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, examples of which include Cowley (2013); and Roberts & Morris (2013). This important sphere of activity is at present largely in the hands of industry and international academia but in South Africa it is still unfocused and un-coordinated, and therefore requires further attention.

Research in marine technology could embrace issues such as: compact and robust sensors and loggers, ship board measurement systems solutions to bio-fouling, mooring and material solutions to bio-fouling, remotely operated and autonomous vehicles, ocean drifters, harnessing ocean energy, swarm technologies, nano-technology exploration, as well as emerging technologies such as GoPro’s and linked GPS units. The above take place in a legal environment which needs to be thoroughly researched and adapted to those new developments.

4 Cross-cutting issues

4.1 Human Capital Development

One of the pillars of South Africa’s National Research and Development Strategy (DACST 2002) is human capital development. 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 Higher Education Institutions (HEIs).
However, this is not the case in Government Departments and institutions such as the CSIR and the National Research Facilities, as well as in non-government institutions like the Oceanographic Research Institute (ORI) where training and development of a new demographically representative cohort of researchers 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 provide a cost-effective means of developing science-based solutions to the marine and coastal challenges facing the country and the region as a whole.

Collaborative ventures with international institutions, such as the French International Centre for Education, Marine and Atmospheric Sciences over Africa (ICEMASA) and the Norwegian Nansen Tutu Centre, have enabled setting up an international student exchange scheme with European universities and research agencies. Erasmus Mundus initiatives and Innovative Training Networks are other European programmes offering training opportunities for young South African scientists.

The skills spectrum that is required in the marine sector is broad and as expressed in the Global Change Research Plan (DST 2009), trans- and interdisciplinary skills and competencies are required in several areas. In general, South Africa has to address both a skills shortage in the country and transformation of the marine research community. Expertise is particularly required in the following areas:

- numerical modelling;
- technical support for developing, maintaining and using marine instrumentation;
- high-performance computing;
- marine engineering;
- scenario development and communication;
- advanced statistics;
• sustainability science;
• policy and governance; and
• taxonomy, especially of invertebrates and microalgae.

There are also gaps in expertise in marine-related chemistry and biology disciplines. Current options to address these skills shortages include technology and knowledge transfer via international research partnerships, and continued strategic linkages for future bilateral research funding.

The transitioning of science to policy and management is also an important component of Human Capacity Development. Not only should there be development of science and scientists, but also much greater emphasis on the development of managers and decision-makers to engage with the science that is produced. One of the difficulties faced by marine researchers is the lack of suitable career paths, and the limited access to funding to support the pursuit of higher academic degrees. Strategies are required to promote the training and retention of post-graduates. These may include internship programmes, enhanced bursaries, and other opportunities for soft-funded, salaried, postdoctoral positions in marine research as is commonly done in other disciplines, (for example, in medical disciplines).

4.2 Platforms and Infrastructure

South Africa already has significant research infrastructure and capacity that if properly managed and coordinated, would allow the country to continue contributing to national needs and to lead international research in the marine sector. The available research infrastructure in the country is dispersed across several government departments, institutions and laboratories. Given the interdependence of research in the sector, proper management of the available infrastructure is essential for ensuring equitable access by researchers through open competitive processes. Agreements are needed between government departments and the key institutions to ensure that this interdependence is upheld and facilitated.

The funding instruments for marine research in South Africa require some rethinking 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 trans- and interdisciplinary 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 modelling studies that advance knowledge.
Some suggested general infrastructure needs at the national level are listed below.

4.2.1.1 **Sentinel sites and Long Term Environmental Research (LTER) network**

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

4.2.1.2 **Biodiversity collections and associated laboratories**

South Africa’s biodiversity collections (wet, dry and frozen) need to be properly resourced. The data needs to be properly curated and safely kept in a good database. The collections must be linked to well-equipped genetic (including metagenomic and biotechnology), isotope, fatty acid and x-ray laboratories.

4.2.1.3 **Operational Oceanography**

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, given that operational oceanographic modelling is currently an academic pursuit with very limited technical support.

4.2.1.4 **Estuarine and Coastal research platforms**

National estuarine and coastal research infrastructure which is beyond the technical or operating capability of Higher Education Institutions, Non-Governmental Organisations and state institutions needs to be made available to researchers within the NSI. Access to such platforms should be equitable and through a fair competitive process. Examples of desired platforms for marine and coastal research include:

- Specialised in-situ instrumentation and moorings such as Acoustic Doppler Current Profilers (ADCPs), Conductivity, Temperature, and Depth Sondes (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 such as Gliders, Remotely Operated Vehicles (ROVs), Baited Remote Underwater videos (BRUVs), ski-monkeys etc.).
4.2.1.5 Offshore research platforms

Offshore research requires equitable access to well-resourced and equipped ships and deep water research infrastructure such as moored and ship borne ADCPs; deep water moorings; moored and ship borne deep water CTDs and dynamic positioning sensors (DPSs); ROVs and gliders; deep water grabs, corers and sediment traps.

4.2.1.6 Remote sensing, data and computing facilities

Marine research requires:

- Centres or a National Centre for integrative modelling, data collection and data archiving (at minimum metadata);
- Access to remotely sensed Earth Observation data;
- Advanced measurement and analytical capability;
- Bandwidth and High Performance Computing;
- Systems to collate and serve spatial biodiversity data; and
- a pH manipulation laboratory that would enable better understanding of the implications of ocean acidification on coastal ecosystems.

4.2.1.7 Service Platforms

The following general service platforms would be required to strengthen marine research in South Africa:

- A centralised operational coastal monitoring system that will provide monitoring services at a national scale relating to the utilization and state of the coastal land resources, and would advise all spheres of government on spatial planning and development decisions and trade-offs;
- National computing facilities and data servers for testing model developments and archiving data (e.g. the Centre for High Performance Computing);
- Improved and integrated data management and archiving system for marine data, with ring-fenced funding for national data facilities such as the South African Data Centre for Oceanography (SADCO) and the proposed Oceans and Coastal Information Management System of DEA;
- A national co-ordinating facility for marine research, with a science mandate (and managers), funded through different government departments;
- A platform for the facilitation of long-term environmental data relating to the coastal and marine environment (SAEON); and
- A facility or centre of excellence focused on research relating to society and sustainability of the coastal and marine environment.
4.3 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 in the coastal zones, there is growing pressure on the marine and coastal environment. This, combined with other global pressures such as pollution and over-fishing, means
that our seas and coastal environments are under threat. Education is the key in raising awareness to protect these 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. Efforts in marine and coastal education need to be extended inland to increase awareness about the oceans and to support environmental and other educators working in the aquatic environment. This can be done through a catchment-to-coast approach that includes the importance of rivers to the health of marine and coastal ecosystems.

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. However, these networks are limited in the scope of their activities by funding constraints. 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 should be central to an effective education and outreach/public engagement strategy for marine science in South Africa. The efforts of SANCOR and MCEN can further be strengthened by engagement with the South African Agency for Science Advancement (SAASTA) for the development of a comprehensive Marine and Coastal Public Engagement Programme.

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. The key areas where such communication needs to be improved would include:

- between science and policy;
- between the research community and government
- between government and the public;
- between the research community and the public;
- among institutions and across disciplines engaged in marine and coastal research; and
- within and across communities affected by, and/or interested in the marine and coastal environment.
A communication strategy should be developed, based on best practice and experience from elsewhere, and adapted to local needs. It will be important to use a variety of media resources including social media, peer-reviewed research publications, popular articles, radio, television, public talks, etc. The net effect should be to enhance awareness, ensuring that research is properly aligned with the issues to be addressed, and that the results of the research have a conduit to the appropriate policy and management systems.

The improvement of communication is part of only one main challenge to improve the science to policy pathway. Another challenge is that of engaging stakeholders in the actual scientific process. Scientific knowledge is only one form of knowledge that is required to make informed decisions on how resources are allocated and used. Incorporation of all knowledge types, i.e. tacit, embedded and technical; and from a variety of sources, i.e. ecology, sociology, economy and political, is required for efficient management of a rapidly changing environment.
5 References


