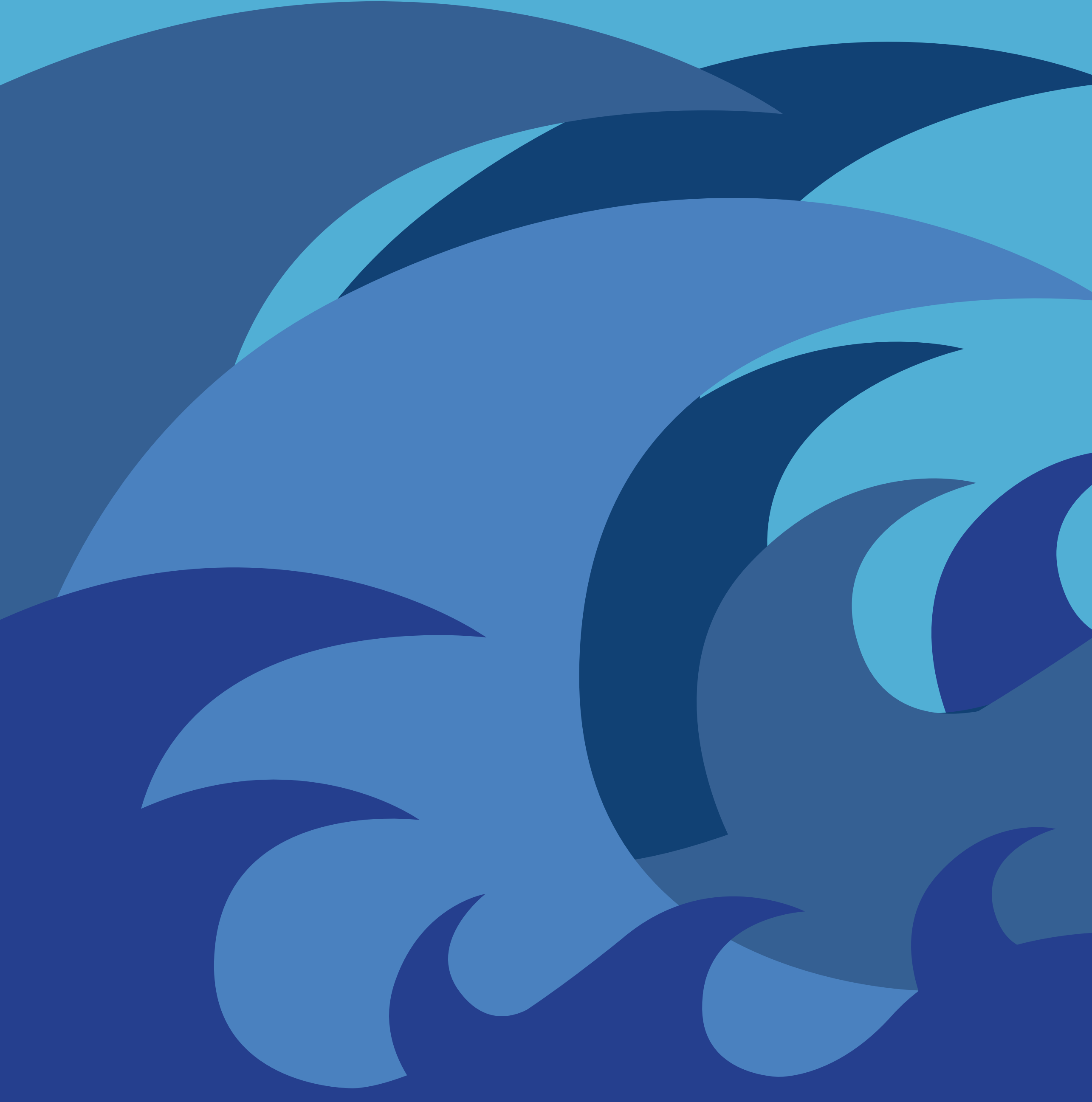

Reflections on the State of

# Research and Technology

in South Africa's

# Marine and Maritime Sectors

EDITORS: Nikki Funke • Marius Claassen • Richard Meissner • Karen Nortje

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**Disclaimer:** The views expressed by the authors are not necessarily those of the reviewers or the editors.

# Preface

In his 2014 State of the Nation Address, President Jacob Zuma highlighted the triple challenge of poverty, inequality and unemployment. Addressing this challenge, in particular through the implementation of the National Development Plan, is a key priority for the South African government. Key economic drivers that are of significance for the marine and maritime sectors are tourism, the Green Economy, infrastructure development and manufacturing. Maximising the potential of these drivers can substantially increase the ability of the marine and maritime sectors to contribute to South Africa's economy.

South Africa has not fully exploited its marine and maritime economy, which justifies the emerging emphasis on the South African ocean economy. The South African government has an important role to play in promoting the development of this economy through establishing an enabling policy environment, and ensuring effective regulation and appropriate resource allocation. Research and development (R&D) in marine and maritime industries, as well as research and academic organisations, produce marine and maritime-related knowledge and technology. This focus on R&D gives impetus to the development of the country's marine and maritime resources and has the potential to contribute to the growth of the ocean economy.

South Africa's oceans and coasts should be developed in a responsible manner to facilitate the sustainable utilisation of marine and maritime resources and secure the long-term growth of the ocean economy. Knowledge and technology play an important role in understanding the ocean, its resources and how to utilise these resources in a responsible manner to ensure their continued availability for generations to come.

The South African Maritime Safety Authority (SAMSA) has a key role to play in supporting growth in the marine and maritime sectors through ensuring safety of life and property at sea, preventing and combatting pollution from ships, and promoting the Republic's maritime interests. The Department of Science and Technology (DST) also has an important role to play in building and developing the ocean economy, for instance, through its Socio-economic Partnerships Programme, which enhances growth and development priorities through targeted science and technology interventions and the development of strategic partnerships with other government departments, industry, research institutions and communities. The DST is also involved in various marine science research initiatives that have the potential to link basic research to applied research, increase human capital, develop R&D and build closer links with industry.

This book endeavours to contribute to these objectives by presenting diverse contributions to reflect on the state of R&D and technology in South Africa's marine and maritime sectors. Its contribution lies in making the practical application of R&D and technology in the marine and maritime sectors explicit, and highlighting the ways in which this can be strengthened and improved.

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# List of acronyms

## A

**AAR:** Autonomous Acoustic Recorder
**ABACUS:** Advanced Beam-former for the Acoustic Counting of Underwater Scatterers
**ACEP:** African Coelacanth Ecosystem Programme
**ADCP:** Acoustic Doppler Current Profiling
**AED:** Aquaculture and Economic Development
**AFMA:** Australian Fisheries Management Authority
**AIMS:** Africa Integrated Maritime Strategy
**AIMURE:** African Institute for Marine and Underwater Research, Exploration and Education
**AMD:** African Maritime Domain
**API:** Application Programming Interface
**ASAPA:** Association of Southern African Professional Archaeologists
**ASCA:** Agulhas System Climate Array
**ASCLME:** Agulhas and Somali Currents Large Marine Ecosystem
**AS/NZS:** Australian/New Zealand Standards
**ASP:** Amnesic Shellfish Poisoning
**ATAP:** Acoustic Tracking Array Platform
**ATW:** Acoustic Trends Working Group
**AU:** African Union
**AUV:** Autonomous Underwater Vehicle
**AWSS:** Above-water Sensors and Signatures
**AZFP:** Acoustic Zooplankton and Fish Profiler

## B

**BCC:** Benguela Current Commission
**BENEFIT:** Benguela Environment, Fisheries, Interaction and Training
**BIOMASS:** Biological Investigation of Antarctic Systems and Stocks
**BRIC:** Brazil, Russia, India and China
**BRUV:** Baited Remote Underwater Video

## C

**CEMZA:** Combined Exclusive Maritime Zone of Africa
**CIE:** Centre for International Heritage Activities
**CLIVAR:** Climate Variability and Predictability of the Ocean Atmosphere System
**CM:** Current Meter
**CMP:** Continuous Monitoring Platform
**$CO_2$:** Carbon Dioxide
**CPIES:** Current- and Pressure-recording Inverted Echo Sounder
**CPUT:** Cape Peninsula University of Technology
**CPUE:** Catch Per Unit Effort
**CSIR:** Council for Scientific and Industrial Research
**CT:** Conductivity/Temperature
**CTD:** Conductivity/Temperature/Depth

## D

**DACST:** Department of Arts, Culture, Science and Technology
**DAFF:** Department of Agriculture, Forestry and Fisheries
**dB:** Decibel
**DB:** Database
**DDL:** Dynamic Data-logger
**DDM:** Dynamic Data Management
**DEA:** Department of Environmental Affairs
**DEAT:** Department of Environmental Affairs and Tourism
**DEFRA:** Department for Environment, Food and Rural Affairs
**DIFAR:** Differential Frequency Analysis and Ranging
**DOI:** Digital Object Identifier
**DOM:** Dissolved Organic Matter
**DoT:** Department of Transport
**DSM:** Direct Survey Method
**DSP:** Diarrhetic Shellfish Poisoning
**DST:** Department of Science and Technology
**DTAG:** Digital Acoustic Recording Tag
**DWA:** Department of Water Affairs

## E

**EEZ:** Exclusive Economic Zone
**ENCH:** Environmental Characterisation
**ENSO:** El Nino Southern Oscillation
**EPR:** Electron Paramagnetic Resonance

**EU:** European Union
**EW:** Electronic Warfare

## F

**FCO:** Fishery Control Officer
**FISH:** Fluorescent *In Situ* Hybridisation
**FMB:** Fisheries Management Branch
**FMA:** Fisheries Management Authority
**FPE:** Fish Processing Establishment
**FRD:** Fisheries Research and Development
**FRS:** Fisheries Research Ship

## G

**GEOSS:** Global Earth Observation System of Systems
**GIS:** Geographic Information System
**GOOS:** Global Ocean Observation System
**GPS:** Global Positioning System
**GSDI:** Geospatial Data Infrastructure
**GTP:** Gully Temperature Probe

## H

**HAB:** Harmful Algal Bloom
**HAT:** Highest Astronomical Tide
**HEI:** Higher Education Institution
**HF:** High Frequency
**HWM:** High-water Mark
**Hz:** Hertz

## I

**ICOMOS:** International Council on Monuments and Sites
**ICT:** Information and Communications Technology
**IDCR:** International Decade of Cetacean Research
**IFM:** Inshore Fisheries Management
**IMP:** Integrated Maritime Picture
**IMT:** Institute for Maritime Technology
**IOD:** Indian Ocean Dipole
**IOP:** Indian Ocean Panel
**IOTC:** Indian Ocean Tuna Commission
**IPCC:** Intergovernmental Panel on Climate Change
**IRD:** Institut de Recherche pour le Développement
**IT:** Information Technology
**IUCN:** International Union for the Conservation of Nature
**IUU:** Illegal, Unreported And Unregulated
**IWC:** International Whaling Commission

## K

**kU:** Kilo Unit

## L

**LAT:** Lowest Astronomic Tide
**LDES:** Littoral Detection Evaluation System
**LIDAR:** Light Detection and Ranging
**LIDO:** Listening to the Deep Ocean Environment
**LNG:** Liquefied Natural Gas
**LPG:** Liquefied Petroleum Gas
**LTER:** Long-term Ecological Research
**LWOST:** Low-water Ordinary Spring Tide

## M

**m:** Metres
**MADP:** Maritime Archaeology Development Programme
**MARAM:** Marine Resource Assessment and Management Group
**MARMITE:** Maritime Microwave Test and Evaluation
**MARPOL:** International Convention for the Prevention of Pollution from Ships
**MAST:** Multi-axial Simulation Table
**MCM:** Marine and Coastal Management
**MCP:** Molecular and Cellular Proteomics
**MCS:** Monitoring, Control and Surveillance
**MDA:** Maritime Domain Awareness
**MDATE:** Maritime Domain Awareness Test and Evaluation
**MDR:** Multidrug-resistant
**MDS:** Maritime Decision Support
**MHWN:** Mean High-water Neaps
**MHWS:** Mean High-water Springs
**MIASA:** Marine Industry Association South Africa
**MLASA:** Maritime Law Association of South Africa
**MLRA:** Marine Living Resources Act
**MLWN:** Mean Low-water Neaps
**MLWS:** Mean Low-water Springs
**MPA:** Marine Protected Area

**MREA:** Maritime Rapid Environmental Assessment
**MRM:** Marine Resources Management
**MSA:** Merchant Shipping Act
**MSC:** Marine Stewardship Council
**MSY:** Maximum Sustainable Yield
**MUCH:** Maritime and Underwater Cultural Heritage

## N

**NAS:** Nautical Archaeology Society
**NCAGS:** Naval Cooperation and Guidance for Shipping
**NCLDV:** Nucleocytoplasmic Large dsDNA Viruses
**NGO:** Non-governmental Organisation
**NHRA:** National Heritage Resources Act
**NL:** Noise Levels
**NMC:** National Monuments Council
**NMEA:** National Marine Electronics Association
**NMMU:** Nelson Mandela Metropolitan University
**NOAA:** National Oceanic and Atmospheric Administration
**NPO:** Non-profit Organisation
**NRF:** National Research Foundation
**NSAW:** Naval Systems Above-water
**NSI:** National System of Innovation
**NSRI:** National Sea Rescue Institute
**NSS:** Naval Systems Subsurface

## O

**OAU:** Organisation of African Unity
**OECD:** Organisation for Economic Cooperation and Development
**OEM:** Original Equipment Manufacturer
**OHSFM:** Offshore and High Seas Fisheries Management
**OMP:** Operational Management Procedures
**OTN:** Ocean Tracking Network

## P

**P:** Pressure
**PAM:** Passive Acoustic Monitoring
**PCI:** Peripheral Component Interface
**PE-LTERP:** Pelagic Ecosystem Long-term Environmental Research Platform
**POM:** Particulate Organic Matter
**PSP:** Paralytic Shellfish Poisoning
**PULSE:** People Understanding and Living in a Sustained Environment

## R

**R&D:** Research and Development
**RAP:** Radio-linked Acoustic Positioning
**RF:** Radio Frequency
**RI:** Research Infrastructure
**RMIT:** Royal Melbourne Institute of Technology
**ROV:** Remotely Operated Vehicle
**RSET:** Rod Sediment Elevation Table
**RU:** Rhodes University
**R/V:** Research Vessel

## S

**s:** Second
**SABWP:** South African Blue Whale Project
**SADC:** Southern African Development Community
**SADM:** Ship Air Defence Model
**SADSTIA:** South African Demersal Trawl Industry Association
**SAEON:** South African Environmental Observation Network
**SAEOS:** South African Earth Observation System
**SAEOSS:** South African Earth Observation System of Systems
**SAHRA:** South African Heritage Resources Agency
**SAHRIS:** South African Heritage Resources Information System
**SAIAB:** South African Institute for Aquatic Biodiversity
**SAIMA:** South African Institute of Maritime Archaeology
**SAMSA:** South African Maritime Safety Authority
**SAN:** South African Navy
**SANAE:** South African National Antarctic Expedition
**SANBI:** South African National Biodiversity Institute

**SANDF:** South African National Defence Force
**SANHO:** South African Navy Hydrographic Office
**SANSA:** South African National Space Agency
**SAPS:** South African Police Service
**SARChI:** South African Research Chairs Initiative
**SARVA:** South African Risk and Vulnerability Atlas
**SAWS:** South African Weather Service
**SBI:** Sub-bottom Imager
**SCAR:** Scientific Committee on Antarctic Research
**SCOR:** Scientific Committee on Oceanic Research
**SCRL:** South Coast Rock Lobster
**SCRLIA:** South Coast Rock Lobster Industry Association
**SDP:** Social Development Programme
**SDR:** Special Drawing Rights
**SEM:** Scanning Electron Micrograph
**SFRI:** Sea Fisheries Research Institute
**SHAPES:** Shoal Analysis and Patch Estimation System
**SID:** Smart Integrated Database
**SNR:** Signal-to-noise Ratio
**SOFAR:** Sound Fixing and Ranging
**SOHN:** Southern Ocean Hydrophone Network
**SOLAS:** International Convention for the Safety of Life at Sea
**Sonar:** Sound Navigation and Ranging
**SORP:** Southern Ocean Research Partnership
**SOWER:** Southern Ocean Whale and Ecosystem Research
**SPL:** Sound Pressure Level
**SSTS:** Submarine System Technology Support
**StatsSA:** Statistics South Africa
**STCW:** Standards of Training, Certification and Watchkeeping for Seafarers
**SUA:** Suppression of Unlawful Acts against the Safety of Maritime Navigation

## T

**TAC:** Total Allowable Catch
**TEM:** Transmission Electron Microscopy
**TEU:** Twenty-foot Equivalent Unit

## U

**UCT:** University of Cape Town
**UFH:** University of Fort Hare
**UHF:** Ultra-high Frequency
**UHIA:** Underwater Heritage Impact Assessment
**UK:** United Kingdom
**UKZN:** University of KwaZulu-Natal
**UN:** United Nations
**UNCLOS:** United Nations Conference on the Law of the Sea
**UNEP:** United Nations Environment Programme
**UNESCO:** United Nations Educational, Scientific and Cultural Organization
**UNFCCC:** United Nations Framework Convention on Climate Change
**Unisa:** University of South Africa
**USEC:** Underwater Security
**USB:** Universal Serial Bus
**USBL:** Ultra-short BaseLine
**UTR:** Underwater Temperature Recorder
**UWC:** University of the Western Cape
**UWSS:** Underwater Sensors and Signatures
**UYDP:** Underwater Youth Development Programme

## V

**VHF:** Very High Frequency
**VMS:** Vessel Monitoring System
**VOC:** Dutch East India Company

## W

**WDCBHH:** World Data Centre for Biodiversity and Human Health in Africa
**WFS:** Web Feature Service
**WMS:** Web Map Service

## X

**XDR:** Extremely Drug-resistant
**XML:** Extensible Markup Language

## Y

**YTX:** Yessotoxin

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# Part 1

## Introduction

# Chapter 1 The Importance of a Book on Research and Technology for the Marine and Maritime Sectors

*Nikki Funke, Marius Claassen, Richard Meissner and Karen Nortje*

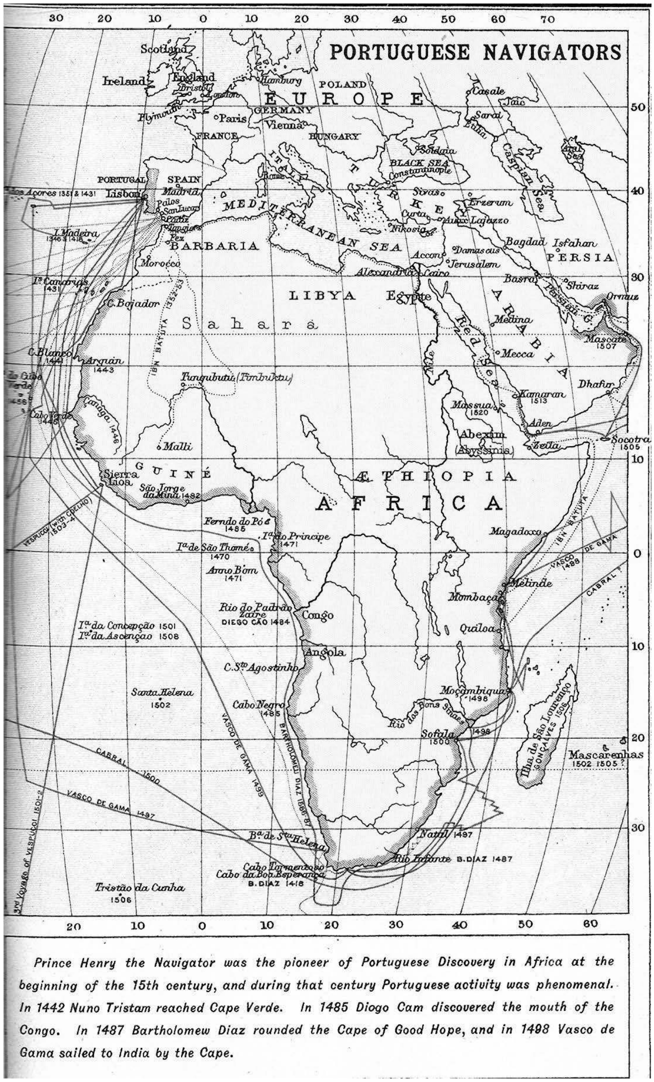


***Figure 1:*** *Navigation chart for the exploration of trade routes (Heritage History, 2012).*

Africa has a rich maritime history that dates back to the 9th century. Historical evidence indicates that, at the time, a fully-fledged commercial system existed that extended from East Africa and the Red Sea to China (Pouwels, 2002). Fifteenth century European explorers also recognised the need to discover a maritime trade route to India around the southern tip of Africa, and it was Bartolomeu Dias who did so in 1488 (see Figure 1). Muller (1969) reports his achievement as follows:

> *"The sight, during the first days of February [1488], of the African coast west of Mossel Bay must have been a moment of triumph for Dias. At last, for the first time, south of the equator, the coast ran in a new direction, which indicated that the 'southern shore' of the African continent had finally been reached, after more than seventy years, and that the passage to the India of the priest king and the glamorous riches of the East was now in sight."*

The classic work by Adam Smith, *An inquiry into the nature and causes of the wealth of nations*, states that "The discovery of America, and that of a passage to the East Indies by the Cape of Good Hope, are the two greatest and most important events recorded in the history of mankind" (Smith, 1776). Today, South Africa's marine and maritime sectors continue to build on the second of the great discoveries mentioned above. According to Statistics South Africa (StatsSA) (2004; 2006; 2012a), water transportation accounted for R4 594 million in direct income in 2002, which grew to R8 833 million in 2006 and R11 828 million in 2012. In 2012, fishing and related activities had a turnover of R7 914 million, whereas the building and repairing of ships and the building and repairing of pleasure and sporting boats had a turnover of R2 138 million over the same period (StatsSA 2012b). These figures exclude coastal and marine exploration and mining, construction, cargo handling and storage, research, tourism and social services. If well managed, South Africa's marine and maritime sectors have the potential to act as a catalyst for investment, economic growth, employment creation and enterprise development in the country (Mokhele, 2012).

The aim of this book is to present various authors' reflections on examples of current research and technology that have the potential to contribute to the growth and development of both the marine and maritime sectors. In this book, the term 'marine' refers to what is "relating to or found in the sea", whereas 'maritime' refers to "connected with the sea, especially in terms of seaborne trade or naval matters" (Oxford English Dictionary, 2014). The book therefore covers the natural inland, coastal and marine environment, as well as human activities that impact on this natural environment, with a particular focus on activities related to and impacting on the sea.

This book forms part of the initiative of the Department of Science and Technology (DST) and the South African Maritime Safety Authority (SAMSA) to develop a *Research, Innovation and Knowledge Management Road Map for the South African Maritime Sector*. This Road Map initiative aims to determine the status quo of maritime research, knowledge and innovation in South Africa, and how available knowledge in the maritime sector can best be applied. The road map also serves to indicate where the maritime sector should be heading in future, both in terms of available research, knowledge and innovation, and gaps that need to be addressed. The road map was developed in order to chart a course towards achieving maritime excellence in South Africa.

The key questions that this book, through each of its chapters, tries to address mirror the aims of the Road Map. The first question centres on what research has been done and what technologies have been developed in the marine and maritime sectors, and for what purposes this work can be applied. The second question considers the research and technology gaps that still exist in the marine and maritime sectors and how these can be addressed.

This book contributes to the state of knowledge about research and technology in the marine and maritime sectors by drawing together and presenting some examples of recent intellectual and innovation-related developments. In addition, it allows for self-critical reflection by the authors on what research and technology-related gaps still exist and how they can be overcome to contribute towards the goal of DST and SAMSA of steering both sectors towards maritime excellence.

## Structure of the book

**Part 1** of the book is made up of the introduction (**Chapter 1**), which introduces the purpose and structure of this publication.

**Part 2** of the book adopts a forward-looking approach for the marine and maritime sectors, with a particular focus on regulatory and strategic views with regard to these sectors.

In **Chapter 2**, Patrick H.G. Vrancken and Andrew Pike reflect on marine and maritime law in South Africa. They argue, firstly, that the law of the sea is highly complex because the marine environment is divided into various maritime zones governed by different legal regimes. Secondly, the largely borderless nature of the marine environment and most human activities at sea results in an unusually high degree of integration between two distinct legal systems (international law and laws applied by South African organs of state). There are also conflicting interests at stake – a third factor adding to the complexity of the law of the sea. In addition, Vrancken and Pike's chapter emphasises the importance of the law of the sea in the fulfilment of any maritime ambitions for the country. The policy and regulatory landscape is a fast-changing one at the global, continental, regional and domestic levels, which has led to marine and maritime law becoming very dynamic and multi-layered. In order to keep up with research and developments in policy and legislation, and for South Africa to take its rightful place in the fast-expanding Blue Economy, the country needs to acquire the necessary resources to do so, as well as nurture a growing cadre of younger experts in the law of the seas. A final message by the authors is that South Africa needs to be able to influence any changes in the law of the seas regime beyond its immediate borders.

In **Chapter 3**, Keith P. Mackie writes about fixing the high-water mark (HWM). He argues that it becomes a matter of policy to demarcate a seashore boundary based on the constraints presented by natural physical processes that are present. The chapter identifies the two primary sources for the general concept of the HWM in the English-speaking world, a persistent error in translation from the original Latin passage in one of the references to the term, and the effect that this has had on the South African legal definitions of the HWM (and particularly on the use of the term 'flood'). The author concludes the chapter by making some recommendations for correcting the legal definition of the HWM and refers to areas where research is needed in future.

In **Chapter 4**, Marius Claassen, Nikki Funke, Meena D. Lysko and Cebile Ntombela introduce four scenarios for the South African maritime sector (the Maritime Nation scenarios) and reflect on how to best utilise these scenarios as a tool to support decision-making, future planning and action for the sector. One of the purposes of developing scenarios for the maritime sector is to identify preferred future outcomes and to assist role-players to navigate towards such outcomes through explicit decisions and actions. The authors argue that a very challenging part of any scenario development process is to disseminate them and to try to ensure that they are taken up by their intended target audiences. A potential way forward for the Maritime Nation scenarios is to present them to a wide range of stakeholders in the sector for further inputs, refinements and ultimately buy-ins. This will require a key decision-maker in the sector to take ownership of the scenarios, and the development and implementation of an adequately resourced communication strategy. The revised scenarios could then be used for strategy development, planning and management in the maritime sector.

**Part 3** of the book focuses on current research and technology advances in the marine sciences.

In **Chapter 5**, Thomas Bornman, Lara Atkinson, Anthony Bernard, Paul Cowley, Shaun Deyzel, Wayne Goschen, Albrecht Götz, Juliet Hermes, Wim Hugo, Angus Paterson and Charles von der Meden introduce the long-term marine research platforms that the National Research Foundation (NRF) provides for the broader research community in South Africa. These platforms support research areas of strategic importance and provide both researchers and research institutions with access to science equipment and infrastructure. It is as a result of these platforms that South Africa can cooperate and compete with its international counterparts. The country's current network of long-term marine research platforms is unrivalled in Africa, yet some infrastructure and research gaps remain, for example the need for a South African marine and Antarctic research facility, and shallow marine and coastal research infrastructures. The most important gap is the spatial extent of the platforms, with the least number of platforms being available on the West Coast, Wild Coast, northern KwaZulu-Natal, the sub-Antarctic Islands and offshore. The authors make a number of recommendations of what would be needed to address these gaps. These include, among others, developing real-time observatories and associated technologies, establishing a South African marine and Antarctic research facility, developing a centralised data management facility and securing dedicated funding.

In **Chapter 6**, Maya C. Pfaff, Flavia Flaviani, Gerda du Plessis, Edward P. Rybicki and Declan C. Schroeder critically reflect on the overlooked foundation of marine microbes in the oceans surrounding South Africa. These microbes play a critical role in driving large-scale earth-system processes and have profound societal impacts as a result. Developing a solid understanding of this overlooked foundation of marine ecosystems is necessary to be able to respond to the increasing threats that microbes pose as pathogens and to harness their potential for the production of renewable energies, pharmaceuticals and food sources, all of which can contribute significantly to the developing Blue Economy of South Africa. Understanding marine microbial systems therefore forms an important component of the management of oceans and coasts that are under severe pressure from human impacts. Despite the important role of microbes in marine ecosystems, there is an obvious deficiency of studies that deal with the diversity and functional roles of marine microbes. Microbes are also not currently considered in assessments of the status of marine biodiversity or when setting conservation targets in South Africa and most of the rest of the world. There is therefore a need for local and international collaboration to identify focus areas for microbial research. South Africa is in a position to take on a leading role here due to its unique geographic position and access to several research vessels.

In **Chapter 7**, Fannie W. Shabangu, Janet C. Coetzee, Ian Hampton, Sven E. Kerwath, Willem M. de Wet and Ainhoa Lezama-Ochoa look at hydro-acoustic technology and its application to marine science in South Africa. In this chapter, the authors argue that South Africa's marine ecosystem has been subjected to unfavourable anthropogenic effects brought about by mismanagement and over-exploitation. In order to manage exploited marine resources properly, knowledge is needed about their size and distribution, and how their exploitation can potentially impact on the remainder of the ecosystem. Hydro-acoustic methods can facilitate the study of aquatic animals and their environment without causing any significant environmental damage or change. The authors describe how hydro-acoustic technology can be used in fisheries research, oceanography and geomorphology in South African waters. They also highlight opportunities for how this technology can be further developed and identify needs and opportunities for further research in the South African context.

In **Chapter 8**, Fannie W. Shabangu and Ken Findlay write about passive acoustic monitoring of marine mammals in South Africa, with special reference to Antarctic blue whales. Marine mammals, and in particular Antarctic blue whales, represent an important predator component of marine ecosystems. These mammals are considered to be critically endangered due to unsustainable whaling practices in the previous century. Currently, it is also difficult to monitor the species' population recovery through the use of sighting surveys. Passive acoustic monitoring (PAM) can be used to research Antarctic blue whales because they are quite vocal and can be detected over long distances through the use of this technology. PAM also has considerable application potential to other baleen species that reside in South African waters, including fin whales *(Balaenoptera physalus)*. It is, however, still an emerging methodology in South Africa and a number of challenges need to be addressed before it reaches the same level of maturity as visual surveys in South Africa and around the world.

In **Chapter 9**, Amos Barkai and Philippe Lallemand write about e-logbook technology development in South Africa. The authors argue that one of the main obstacles to integrated knowledge management between fishers, managers and scientists is the lack of reliable and suitable fishing data and the inability to capture it. This results in a significant lack of reliable data to describe fishing operations, which has posed a considerable problem to the development of fisheries management in South Africa and around the world. In response to these problems, the authors reflect on the use of electronic logbook (e-logbook) systems, and, in particular, the Olrac Electronic Logbook Software Solution, as a way of integrating data collection and management. An e-logbook system can be an effective and useful tool for stakeholders throughout the marine and maritime sectors.

**Part 4** of the book focuses on research for the maritime sector in the humanities.

In **Chapter 10**, Richard Meissner engages in a critical analysis of research paradigms in a subset of marine and maritime scholarly thought. According to the author, the humanities and social sciences have a key role to play in the development of long-term strategies in the perceived high-tech marine and maritime environments because these environments are largely the products of human construction. By means of applying the PULSE$^3$ framework, the author shows that social science theories, such as the theory of social learning and policy paradigms, the ambiguity theory of leadership and everyday international political economy, can make an important contribution to explaining dynamics in the two sectors. These theories provide alternatives to the rational and problem-solving theories that are largely used to understand the two sectors because of their dependence on technological advancement. The author argues that it is not only regulatory authorities such as SAMSA that have the responsibility of raising the profile of the humanities and social sciences in the marine and maritime sectors, but that social scientists themselves should become involved in research to better understand and solve problems within the sectors.

In **Chapter 11**, Jonathan Sharfman, Vanessa Maitland, Sophie Winton and Robert Parthesius reflect on the state of maritime and underwater cultural heritage research, legislation and technology in South Africa. Maritime and underwater cultural heritage (MUCH) studies is the study of all underwater and maritime cultural archaeological sites, as well as intangible and living heritage related to water. It is making its mark as delivering a scientifically rigorous contribution to maritime archaeology. Despite this promising development, the authors argue that in South Africa this kind of archaeology still lags behind its terrestrial counterpart. This can partly be attributed to the popular perception that maritime archaeology is nothing more than a 'treasure hunt'. In addition, the development of a legislative framework aimed at protecting underwater heritage sites has been relatively slow. On the positive side, the South African Heritage Resources Agency (SAHRA) aims to expand its coastal network, increase dialogue around MUCH and promote initiatives through a series of projects and programmes. In conclusion, the authors argue that what is ultimately required to realise the full potential of existing projects and research is capacity-building and funding to assist MUCH to contribute to the development of South Africa as a maritime nation.

In **Chapter 12**, Bruno E.J.S. Werz introduces Southern African maritime archaeological research and the development of the African Institute for Marine and Underwater Research, Exploration and Education (AIMURE). According to Werz, AIMURE recognises the value of a more integrated intra- and interdisciplinary training model by uniting different fields of study related to the marine, maritime and underwater spheres under one interdisciplinary umbrella. One of the specific aims of this private initiative is to stimulate the effective development and management of South Africa's cultural resource by promoting scientific research, providing advice and presenting practical and theoretical courses. The chapter describes the establishment of AIMURE and the interesting projects the institute has been involved in. Yet, despite the progress made in supporting capacity-building in maritime archaeology, more funding is required to continue the work that is currently being undertaken and to capacitate researchers to explore and research the country's history as it relates to the sea.

**Part 5** of the book looks at infrastructure and technology developments for the maritime sector.

In **Chapter 13**, Kana Mutombo presents a holistic framework for adaptation to climate change in relation to port infrastructure. The changes in the global economy due to increasing trade and the globalisation of production have led to developments in international logistics, shipping technology, industry consolidation and environmental regulations, which will change the way in which ports operate in the 21st century. The role of ports is changing gradually from being perceived as a set of complex infrastructures to becoming a major player in national supply chain management. The sharp increase in the imports and exports that flow through ports has also led to a greater focus on the vulnerability of port infrastructure to climate change. Climate change-induced effects can have very adverse effects on port infrastructure, resulting in the failure of foundations, the degradation of superstructure material, increased storm and flood damage and the failure of roofs and cladding. The author introduces a three-tier model for port infrastructure adaptation to the climate change framework, with a focus on policy, management and technology.

In **Chapter 14**, Carl K. Wainman, Jörg Schmid, Hannes van Wyk, Andrew Cothill, Willie Gunter, Philip la Grange and Geertien Venter focus on maritime technology support to the South African Navy (SAN). This technology is developed by the Institute for Maritime Technology (IMT), and is a unique and home-grown capability that assists SAN to patrol, watch and care for South Africa's sea routes and Exclusive Economic Zone (EEZ) in terms of its current operational and future requirements. In the chapter, the authors introduce seven areas of technological support:

Underwater Security (USEC), Naval Systems Subsurface (NSS), Naval Systems Above-water (NSAW), Underwater Sensors and Signatures (UWSS), Above-water Sensors and Signatures (AWSS), Environmental Characterisation (ENCH) and Maritime Decision Support (MDS). IMT provides technical guidance and support to SAN and also aims to conduct research in support of the maritime operational requirements of the South African National Defence Force (SANDF). As naval and geopolitical trends and priorities change, IMT starts new projects and realigns existing ones. The institute also collaborates with other similar international organisations and has a close working relationship with formal academia.

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# Part 2

## The Way Forward for the Maritime Sector: Regulatory and Strategic Views

# Chapter 2 Marine and Maritime Law in South Africa

*Patrick H.G. Vrancken[1] and Andrew Pike*

## 1. Introduction

The reach of the law extends beyond the land territory of South Africa into the oceans surrounding it. In that environment, the legal regime presents a level of complexity not altogether different from the interaction between the various bodies of water that make the southern tip of Africa such a prime area for marine and maritime research.

One of the reasons for that complexity is that the sea is divided into a number of maritime zones that are governed by different legal regimes. A country's internal waters[2] and the territorial sea are nearest to the coast and stretch up to 12 nautical miles[3] from the baselines. Those waters are part of the South African territory and therefore the whole corpus of South African law applies. The Exclusive Economic Zone (EEZ)[4] is beyond the territorial sea and extends to 200 nautical miles from the baselines. Although the EEZ is not part of the South African territory, South Africa has within it exclusive rights to explore, exploit, conserve and manage the living and non-living natural resources. South Africa also has exclusive rights with regard to other activities for the economic exploration and exploitation of the EEZ, such as the production of energy from the water, currents and winds. Along most of the EEZ's outer limit, those rights extend even further out on and within the continental shelf. It is only beyond the outer edge of the South African continental shelf that the international seabed area starts, the non-living resources of which are the common heritage of humankind. The waters beyond the EEZ constitute the high seas, where all states enjoy a wide range of freedom.

A second reason for the complexity of marine and maritime law in South Africa is that the largely borderless nature of the marine environment and most of the activities humans engage in at sea result in an unusually high degree of integration between two usually quite distinct legal systems. On the one hand, international law includes the contractual and customary rules governing the interaction between states at sea (Tanaka, 2012). On the other hand, the rules the South African organs of state apply to the natural and juristic persons over whom they have authority are part of South African domestic law. The latter distinguishes between maritime law, with a largely business and procedural focus, and marine law, with a public interest approach.

A third factor compounding the complexity of marine and maritime law is the wide variety of conflicting interests at stake. On the one hand, the law takes into account the often opposing claims of coastal states, while on the other, it considers other states that also want to use the maritime zones under the jurisdiction of the coastal states. The law also attempts to find a balance between the demands made by various kinds of users in the same waters. For instance, how does one reconcile the need for marine scientific research with both security concerns and exclusive rights to the resources located in the area where the research is taking place?

1 This work is based on research supported by the South African Research Chairs Initiative (SARChI) of the Department of Science and Technology (DST) and the National Research Foundation (NRF) of South Africa.

2 Landward of the baselines.

3 One nautical mile equals 1 852 metres.

4 The EEZ overlaps the Contiguous Zone and the Maritime Cultural Zone between 12 and 24 nautical miles from the baselines.

This chapter first stresses the importance of marine and maritime law in any strategy to fulfil the country's maritime ambitions by outlining the fast-changing policy and regulatory landscape at the global, continental, regional and domestic levels. This also makes it possible to contextualise the synopsis of the state of current knowledge in the field in South Africa. Subsequently, the chapter identifies a number of knowledge gaps and concludes by suggesting a way forward.

## 2. The policy and regulatory landscape

### 2.1 Global level

After the age of Western exploration, the seas were largely subject to a laissez-faire regime. This laissez-faire regime was adequate for the two main uses of the sea – navigation and fishing – that prevailed during this period, since ships were small and relatively few compared with today, and fish stocks were thought to be inexhaustible (Churchill and Lowe, 1999).

The political, economic and technological developments associated with the industrial revolution slowly put pressure on both the natural resources and the regularisation of navigation. A first attempt at codification of the body of rules, which had slowly developed during the previous centuries, failed in 1930 because, according to Churchill and Lowe (1999), "it was not possible to reach agreement on the crucial question of the breadth of the territorial sea". After the Second World War, a second attempt was made during the first United Nations Conference on the Law of the Sea (UNCLOS I), which was held in Geneva in 1958. The event resulted in the adoption of four conventions: the Convention on the Territorial Sea and the Contiguous Zone (UN, 1958d), the Convention on the High Seas (UN, 1958c), the Convention on the Continental Shelf (UN, 1958a) and the Convention on Fishing and Conservation of the Living Resources of the High Seas (UN, 1958b). According to Churchill and Lowe (1999), "the first three of these international instruments were ratified by substantial numbers of States, and were also based in large measure upon customary international law". For those reasons, the conventions constituted the core of the generally accepted rules of the law of the sea concerning maritime zones. The fourth convention, the Convention on Fishing and Conservation of the Living Resources of the High Seas, was less popular, perhaps partly because it went further than the existing obligations which customary law had imposed on States (Churchill and Lowe, 1999).

In 1963, South Africa became a party to the four 1958 conventions. However, the newly independent states in the UN that had had no say in the formulation of the 1958 conventions were in favour of reviewing the earlier law. Many states were increasingly concerned about the problems of over-fishing and marine pollution off their coasts, neither of which could satisfactorily be controlled in the narrow jurisdictional limits on which the 1958 regime was based. These factors, and the recognition that the various parts of the law of the sea were inextricably interrelated, led to widespread support for a review of the whole of the law of the sea (Churchill and Lowe, 1999).

After the failure of the second conference (UNCLOS II), once again because of the absence of agreement on the breadth of the territorial sea, the third conference (UNCLOS III) was convened in 1973. It concluded its work in 1982 with the adoption of the UN Convention on the Law of the

Sea (UNCLOS) (UN, 1982).[5] The Convention, which supersedes the 1958 conventions, represents a finely balanced package deal (Devine, 1986c).[6] It is referred to often, but inaccurately, as 'the Constitution of the Seas' because it sets the framework into which other related and more subject-specific international instruments are expected to fit.

Some of these instruments were adopted long before 1982. For instance, a Convention for the Protection of Submarine Cables[7] was adopted in 1884 and an International Convention for the Unification of Certain Rules Relating to Assistance and Salvage at Sea (Comité Maritime International, 1910) was adopted in 1910. The International Convention for the Unification of Certain Rules of Law relating to Bills of Lading (also known as the Hague Rules) was adopted in 1924 (Comité Maritime International, 1924). However, as a reflection of the high level of interstate relations in the field, the great majority were adopted during the last half a century and include instruments as varied as the following:

- The 1966 International Convention on Load Lines (IMO, 1966)[8]
- The 1968 Protocol to Amend the International Convention for the Unification of Certain Rules of Law Relating to Bills of Lading (also known as the Hague-Visby Rules) (Comité Maritime International, 1968) together with an amendment made in the Special Drawing Rights (SDR) Protocol of 1979 (Comité Maritime International, 1979)[9]
- The 1969 International Convention Relating to Intervention on the High Seas in Cases of Oil Pollution Casualties (IMO, 1969)[10] and its 1973 Protocol (IMO, 1973b)[11]
- The 1971 Treaty on the Prohibition of the Emplacement of Nuclear Weapons and Other Weapons of Mass Destruction on the Seabed and the Ocean Floor and in the Subsoil Thereof (UN, 1971)[12]
- The 1972 Convention on the International Regulations for Preventing Collisions at Sea (IMO, 1972)[13]
- The 1973 International Convention for the Prevention of Pollution from Ships (MARPOL) (IMO, 1973a) as amended by its 1978 Protocol (IMO, 1978b)[14]
- The 1974 International Convention for the Safety of Life at Sea (SOLAS) (IMO, 1974) as amended by its 1978 Protocol (IMO, 1978c)[15]
- The 1976 Convention on Limitation of Liability for Maritime Claims (IMO, 1976), as amended by the 1996 Protocol thereto (IMO, 1996)[16]

5 South Africa ratified the Convention in 1997.

6 The package is completed by the 1994 Agreement Relating to the Implementation of Part XI of the UNCLOS (1836 "United Nations Treaty Series 3", (1994) 33 "International Legal Materials", 1309) and the 1995 Agreement for the Implementation of the Provisions of LOSC Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (2167 "United Nations Treaty Series 88", (1995) 34 "International Legal Materials", 1542), which South Africa also ratified in 1997.

7 163 "Consolidated Treaty Series", 391.

8 South Africa accepted the Convention in 1966.

9 The Hague-Visby Rules were incorporated into South African domestic law by virtue of the Carriage of Goods by Sea Act, 1986.

10 South Africa acceded to the Convention in 1986.

11 South Africa acceded to the Protocol in 1997.

12 South Africa ratified the Treaty in 1973.

13 South Africa acceded to the Convention in 1976.

14 South Africa acceded to the Protocol in 1984.

15 The text of SOLAS and the 1978 Protocol are reproduced in the second schedule to the Merchant Shipping Act, Act 57 of 1951. South Africa acceded to the Convention in 1980 and to the Protocol in 1982.

16 The Convention replaced the International Convention Relating to the Limitation of the Liability of Owners of Seagoing Ships, which was signed in Brussels in 1957 and came into force in 1968. South Africa acceded to neither, but adopted the 1957 Convention's tonnage limits in section 261 of the Merchant Shipping Act of 1951.

- The 1978 International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) (IMO, 1978a)[17]
- The 1988 Convention for the Suppression of Unlawful Acts against the Safety of Maritime Navigation (SUA) (IMO, 1988)[18]
- The 1990 International Convention on Oil Pollution Preparedness, Response and Cooperation (IMO, 1990)[19]
- The 2001 Agreement on the Conservation of Albatrosses and Petrels[20]
- The 2001 Convention on the Protection of the Underwater Cultural Heritage (UNESCO, 2001)
- The 2004 International Convention for the Control and Management of Ships' Ballast Water and Sediments (IMO, 2004)[21]
- The 2006 Maritime Labour Convention (ILO, 2006)[22]

At present, issues that are high on the global agenda include the maritime boundary delimitations, the claims to extended continental shelves, the military activities in the EEZ, criminal activities at sea, the genetic resources of the high seas (e.g. Van Dyke et al., 2013) and, more generally, the impact the rise in the sea level has on international law.[23] They are discussed in international fora, such as the annual meetings of the states' parties to the UNCLOS,[24] the UN Open-ended Informal Consultative Process on Oceans and the Law of the Sea,[25] the meetings and conferences of the International Maritime Organisation[26] and the Comité Maritime International.[27]

## 2.2 Continental level

At the continental level, Article II(1) of the 1963 Charter of the Organisation of African Unity (OAU), which states the purposes of the organisation, made no reference to maritime matters. This is not to say that African states were entirely unconcerned by such matters during the first four decades of independence. On the contrary, African states were very involved in the negotiations leading to the adoption of the UNCLOS (e.g. OAU, 1972) and made by far the greatest contribution to the coming into effect of UNCLOS at the end of 1994.[28] Even so, the continent's progress was relatively slow and "closely related to the pace of economic and democratic change" on the continent (Kwiatkowska, 1993). Nevertheless, the 1991 Treaty Establishing the African Economic Community acknowledges maritime matters in three instances when, in a short chapter covering the broad scope of transport, communications and tourism, it mandates member states to do the following:

17 South Africa acceded to the Convention in 1983.

18 South Africa acceded to the Convention in 2005.

19 South Africa acceded to the Convention in 2008.

20 2258 "United Nations Treaty Series" 257. South Africa ratified the Agreement in 2003.

21 South Africa acceded to the Convention in 2008.

22 South Africa ratified the Convention in 2013.

23 One of the co-authors of this chapter is one of only two members, who are based in a developing country, of the Committee on International Law and Sea Level Rise established by the International Law Association in 2013.

24 URL: http://www.un.org/Depts/los/meeting_states_parties/meeting_states_parties.htm. Accessed: 26 March 2014.

25 URL: http://www.un.org/Depts/los/consultative_process/consultative_process.htm. Accessed: 26 March 2014.

26 URL: http://www.imo.org/Pages/home.aspx. Accessed: 26 March 2014.

27 URL: http://comitemaritime.org/Home/0,271,1132,00.html. Accessed: 26 March 2014.

28 In November 1993, when the 60th instrument of ratification or accession required for the UNCLOS to come into effect was deposited, 45% of the 60 states were African states.

- Harmonise their policies on maritime transport
- Undertake to progressively harmonise their rules and regulations relating to maritime transport
- Encourage the establishment of community and African multinational enterprises in that field[29]

By the end of its existence, the OAU had placed coastal and maritime issues higher on its agenda. This is illustrated by the Organisation's decision to adopt an African process for the development and protection of the marine and coastal environment in Africa in 2001 (OAU, 2001), as well as the 1999 Convention on the Prevention and Combating of Terrorism (OAU, 1999).[30] In terms of the latter, the states' parties undertake to consider, as a matter of priority, if they have not already done so, also becoming parties to the UNCLOS and the 1988 Convention for the Suppression of Unlawful Acts against Maritime Navigation.[31]

Since its succession to the OAU and inception in 2002, coastal and maritime issues have been high on the agenda of the African Union (AU). The results include the 2009 Durban Resolution on Maritime Safety, Maritime Security and Protection of the Marine Environment in Africa (AU, 2009) and the 2010 African Maritime Transport Charter (AU, 2010). Nevertheless, the main development is the adoption in January 2014 by the Assembly of Heads of State and Government, the highest AU organ, of the 2050 Africa Integrated Maritime Strategy (AIMS) (AU, 2014). The latter is based on the premise that the development of the African Maritime Domain (AMD) "requires innovative solutions and careful management systems to ensure its long-term sustainability, as well as the implementation of national and international regulations and instruments to address current challenges amidst new, shifting global dynamics (e.g. shifting geographic trade patterns, emerging economic powers, environmental dynamics, etc.)".[32] AIMS also acknowledges that the AMD is affected by threats and vulnerabilities, including transnational organised crime, environmental crime and illegal, unreported and unregulated (IUU) fishing, natural disasters and marine environmental degradation, as well as legal frameworks[33] that are often weak.

On the above basis, AIMS is meant to provide a "comprehensive, concerted, coherent and coordinated approach that improves maritime conditions with respect to environmental and socio-economic development, as well as the capacity to generate wealth from the sustainable governance of Africa's seas and oceans".[34] Among the strategic objectives of AIMS, those most relevant to lawyers are the prevention of hostile and criminal acts at sea, together with the successful prosecution of offenders, improved integrated coastal zone management, the promotion of the ratification, domestication and implementation of relevant international legal instruments, as well as the establishment of a Combined Exclusive Maritime Zone of Africa (CEMZA).[35] The latter is envisaged as a common African maritime space without barriers, which aims at 'boosting intra-African trade', eliminating or simplifying administrative procedures in

29 Articles 61(2)(c)(i), 61(1)(c) and 62(1).

30 South Africa ratified the Convention in 2002.

31 Article 2(b) read with paragraphs (d), (f), (h) and (i) of the Annex.

32 AIMS Paragraph 4.

33 AIMS Paragraph 16.

34 AIMS Paragraph 19(ii).

35 Paragraph 21(vii), (ix), (x) and (i) respectively.

intra-AU maritime transport. The aim is to make it more attractive, more efficient and more competitive, and doing more to protect the environment. It should allow the convergence of existing and future monitoring and tracking systems used for maritime safety and security, the protection of the marine environment, fisheries control, trade and economic interests, border control and other law enforcement and defence activities.[36]

## 2.3 Regional level

As a member of the Southern African Development Community (SADC), South Africa is a party to the 1996 SADC Protocol on Transport, Communication and Meteorology (SADC, 1996),[37] which requires that states' parties collectively investigate and develop a common understanding with regard to the following:

- The net benefits of a common ports policy and, in particular, the economic benefits of such a policy
- The existing diversity in economic policy between member states and its impact on the development and implementation of a common ports policy
- The provisions of their existing ports legislation and the need to review it in order to provide an appropriate legal framework for the implementation of a common ports policy
- Efficiency in maritime transport along their individual coastlines, inland waterways and ports, and optimisation of shipping services
- The promotion of the role of the private sector in providing cargo-handling services and the application of commercial criteria by public sector undertakings providing such services[38]

The Protocol also expects SADC member states to "promote the economic and social development of the region by developing and implementing harmonised international and regional transport policies in respect of the high seas",[39] as well as to facilitate the integration of regional maritime transport by the implementation of compatible policies, legislation, rules, standards and procedures.[40] The Southern African Transport and Communication Commission is the SADC body that was constituted to guide and coordinate cooperation and integration policies and programmes in the transport sectoral area.[41] South Africa is also a party to the 2001 SADC Protocol on Fisheries (SADC, 2001).[42] This Protocol's objective is to promote the responsible and sustainable use of the living aquatic resources and aquatic ecosystems of interest to states' parties in order to do the following:

- Promote and enhance food security and human health
- Safeguard the livelihood of fishing communities
- Generate economic opportunities for nationals in the region
- Ensure that future generations benefit from these renewable resources

36 AIMS Paragraph 30.

37 South Africa ratified the Protocol in 1997.

38 Article 8.2(1).

39 Article 8.1.

40 Article 2.4(a).

41 Article 13.3(1). See further articles 13.14 and 13.17-13.19 PTCM.

42 South Africa ratified the Protocol in 2003.

- Alleviate poverty with the ultimate objective of its eradication[43]

The above should be achieved within the scope of the Protocol's application, which includes the following:

- Living aquatic resources and aquatic ecosystems within the jurisdiction of a state party
- Living aquatic resources of states' parties, the ranges of which extend outside the areas under their jurisdiction, or high seas resources, as may be considered to be of interest to states' parties
- Fishing, by nationals of states' parties, and activities directly related to it
- International activities outside SADC that promote the objectives of the Protocol[44]

The Protocol requires South Africa to endeavour "to establish common positions and undertake coordinated and complementary actions with regard to [specific] international fora, conventions and agreements", as well as certain international fisheries bodies.[45] The Protocol also creates obligations for South Africa with regard to, inter alia, the management of shared resources, harmonisation of legislation, foreign fishing access agreements, human resources development, as well as trade and investment.[46]

As far as its western seaboard is concerned, South Africa is a party to a number of international instruments. This includes the 2013 Benguela Current Convention,[47] which applies to "all human activities, aircraft and vessels under the jurisdiction or control of a party to the extent that these activities, or the operation of such aircraft or vessels result, or are likely to result in adverse impacts" in the internal waters, territorial seas, EEZs and continental shelves of Angola, Namibia and South Africa.[48] That area overlaps with the area of application of the 1981 Abidjan Convention for Cooperation in the Protection and Development of the Marine and Coastal Environment of the Central and West African Region (UNEP, 1981).[49] Beyond the areas of national jurisdiction in all the waters of the South-East Atlantic Ocean and the extreme South-West Indian Ocean, the 2001 Convention on the Conservation and Management of Fishery Resources in the South-East Atlantic Ocean[50] applies. The Convention established the South-East Atlantic Fisheries Organisation.[51] The latter includes a Commission[52] that:

- identifies conservation and management needs;
- formulates and adopts conservation and management measures applying the precautionary approach;
- determines total allowable catches (TACs) and/or levels of fishing effort;
- determines the nature and extent of participation in fishing considering, inter alia, the interests of developing states' parties, among other things;

43 Article 3. See further the 2008 SADC Declaration on Poverty Eradication and Sustainable Development.

44 Article 2.

45 Article 6(1).

46 Articles 7, 8, 10, 15 and 16 respectively.

47 URL: http://d2zmx6mlqh7g3a.cloudfront.net/cdn/farfuture/vZa0MjbjJq_Zrlw1pMGhAnP1UR-U3INJ63e9ZrSdSKI/mtime:1381765443/files/131008benguela.pdf. Accessed: 26 March 2014. The Convention, which Angola and Namibia have also signed, is the permanent legal instrument replacing the 2007 Interim Agreement on the Establishment of the Benguela Current Commission.

48 Article 3.

49 South Africa ratified the Convention in 2002.

50 2221 "United Nations Treaty Series" 189, (2002) 41 "International Legal Materials" 257. South Africa has been a party since 2008.

51 Article 5(1).

52 Article 5(2)(a).

- establishes appropriate cooperative mechanisms for effective monitoring, control, surveillance and enforcement; and
- adopts measures concerning control and enforcement[53]

South Africa is also a party to the 1966 International Convention for the Conservation of Atlantic Tunas,[54] since it came into force in 1969. At the bilateral level, South Africa concluded an Agreement Relating to Mutual Assistance in Curbing and Preventing Illegal Fishing with Namibia in 1991.

South Africa is involved in several international instruments and bodies with regard to its eastern seaboard.[55] For instance, South Africa is a member of the South-West Indian Ocean Fisheries Commission. The Commission's area of competence corresponds to the Agulhas and Somali Large Current Marine Ecosystem and includes all living marine resources in all the waters under the national jurisdiction of the South-West Indian Ocean coastal states within latitude 10°00 N, longitude 65°00 E, the equator, longitude 80°00 E, latitude 45°00 S and longitude 30°00 E.[56] South Africa is not a signatory of the 2006 Southern Indian Ocean Fisheries Agreement (FAO, 2006), but it is a cooperating non-contracting party to the 1993 Agreement for the Establishment of the Indian Ocean Tuna Commission (IOTC) (FAO, 1993).[57] The IOTC's area of competence is "the Indian Ocean … and adjacent seas, north of the Antarctic Convergence, insofar as it is necessary to cover such seas for the purpose of conserving and managing stocks that migrate into or out of the Indian Ocean".[58] Also at the bilateral level, South Africa concluded an Agreement on Cooperation in Respect of Fisheries and Integrated Marine and Coastal Management and Development with Mozambique in 2008. This Agreement states that both states must, inter alia, develop and implement an action programme regarding fisheries, and harmonise their fisheries rules and procedures[59]. The Agreement also contains provisions relating to fisheries research and management, aquaculture development and economic cooperation.[60]

As far as Antarctica and the Southern Ocean are concerned, South Africa is one of the 12 original signatories of the 1959 Antarctic Treaty[61] and is a party to the 1972 Convention for the Conservation of Antarctic Seals (Antarctic Treaty System, 1972)[62] and the 1980 Convention on the Conservation of Antarctic Marine Living Resources (Antarctic Treaty System, 1980).[63] South Africa is also party to the 1991 Protocol on Environmental Protection to the Antarctic Treaty

53 Article 6(3).

54 673 "United Nations Treaty Series" 63.

55 South Africa is not a member of the Indian Ocean Fisheries Commission. The 2001 Memorandum of Understanding on the Conservation and Management of Marine Turtles and their Habitats of the Indian Ocean and South-East Asia entered into force with regard to South Africa in 2005. In contrast, South Africa did not sign the 2006 Southern Indian Ocean Fisheries Agreement. South Africa has also not signed the 1991 Western Indian Ocean Tuna Organisation Convention. However, South Africa is a member of the South-West Indian Ocean Fisheries Project, a collaborative project that embraces the fishery-related needs and expectations of the states in the region in a regional and transboundary context.

56 Paragraph 1 of the Statutes of the Commission.

57 The Agreement came into force in 1996.

58 Article II of the Agreement.

59 Articles 1 and 3 of Annexure 1 of the Agreement.

60 Articles 4 and 5 of Annexure 1 of the Agreement.

61 402 "United Nations Treaty Series" 71, "South African Treaty Series" 10/1959.

62 South Africa ratified the Convention in 1972.

63 In 1981, South Africa ratified the Convention, which complements the 1946 International Convention for the Regulation of Whaling (161 "United Nations Treaty Series" 72, "South African Treaty Series" 6/1949), which South Africa ratified in 1948.

(Antarctic Treaty System, 1991),[64] together with its annexes, including the Annex on Liability Arising from Environmental Emergencies adopted in 2005 (Antarctic Treaty System, 2005).

### 2.4 National level

Between 1910, when South Africa came into being as a legal entity, and the Second World War, regulatory developments were limited and confined to coastal, harbour and shipping matters.[65] After the war, Parliament enacted the Merchant Shipping Act, 1951 (Act 57 of 1951) (MSA), which is still in force today in a somewhat amended form.[66] The MSA is the basis of a vast and extremely complex body of subordinate legislation. Thirty years later, maritime jurisdiction came of age in South Africa when an innovative piece of legislation, the Admiralty Jurisdiction Regulation Act, 1983 (Act 105 of 1983), came into effect. This was during a decade where the legislature focused on the regulation of navigation in the country's waters with the passing of the Marine Traffic Act, 1981 (Act 2 of 1981). During the same decade, the legislature also focused on pollution matters with the passing of pieces of legislation such as the Marine Pollution (Control and Civil Liability) Act, 1981 (Act 6 of 1981), the Marine Pollution (Prevention of Pollution from Ships) Act, 1986 (Act 2 of 1986), and the Marine Pollution (Intervention) Act, 1987 (Act 64 of 1987).

Both the Constitution of the Republic of South Africa (1996) presently in force and its predecessor, the Constitution of the Republic of South Africa (1993), were silent on the maritime component of the South African territory (Vrancken, 2011). Nevertheless, one of the first steps taken by the first fully democratically elected legislature was to update the country's maritime zones claims with the passing of the Maritime Zones Act, 1994 (Act 15 of 1994). That marked the beginning of a period of almost frenetic legislative activity aimed at filling the many gaps in the South African legal regime caused by decades of inadequate focus on the marine and maritime environment. At first, the legislature focused mainly on shipping matters, with pieces of primary legislation such as the following:

- The Transport General Amendment Act, 1995 (Act 16 of 1995)
- The Transport (Second General Amendment) Act, 1995 (Act 82 of 1995)
- The Wreck and Salvage Act, 1996 (Act 94 of 1996)
- The Shipping General Amendment Act, 1997 (Act 23 of 1997)
- The South African Maritime Safety Authority Act, 1998 (Act 5 of 1998)
- The Ship Registration Act, 1998 (Act 58 of 1998)
- The Sea Transport Documents Act, 2000 (Act 65 of 2000)
- The South African Maritime and Aeronautical Search and Rescue Act, 2002 (Act 44 of 2002)

(Vrancken, 2004a)

64 South Africa ratified the Protocol in 1995.

65 The Seashore Act, 1935 (Act 21 of 1935) is still in force. The title of this Act is now incorrect (it no longer corresponds to that chosen by the legislature). The proposed amendment is therefore not supported for that reason.

66 The Merchant Shipping Act has had significant sections excised over the years and was converted into more comprehensive "free-standing" legislation. Many of the MSA's provisions are outdated (for instance, the section 261 tonnage limitation regime). The MSA requires a complete revision.

The abovementioned legislation was implemented over and above a wide range of subordinate legislation.[67] The focus then shifted to port regulation with the passing of the National Ports Act, 2005 (Act 12 of 2005).[68] A decade earlier, Parliament had passed the Antarctic Treaties Act, 1996 (Act 60 of 1996), to enable South Africa to fulfil its obligations in terms of the relevant international instruments to which it is a party. The legislature then overhauled its fisheries legislation with the passing of the Marine Living Resources Act, 1998 (Act 18 of 1998), while adopting the National Environmental Management Act, 1998 (Act 107 of 1998). Within the framework provided by the National Environmental Management Act of 1998, the National Environmental Management: Protected Areas Act, 2003 (Act 57 of 2003), the National Environmental Management: Biodiversity Act, 2004 (Act 10 of 2004), and the National Environmental Management: Integrated Coastal Management Act, 2008 (Act 24 of 2008), were adopted. Parliament also passed the Mineral and Petroleum Resources Development Act, 2002 (Act 28 of 2002), with regard to the non-living resources of the sea, as well as a number of instruments that strengthened the state's legislative arsenal against criminal activities at sea. These instruments include the Defence Act, 2002 (Act 42 of 2002), which incorporated UNCLOS's definition of piracy into South African law, and the Protection of Constitutional Democracy against Terrorist and Related Activities Act, 2004 (Act 33 of 2004). More recently, the legislature filled a very serious gap when it passed the Merchant Shipping (International Oil Pollution Compensation Fund) Act, 2013 (Act 24 of 2013), together with the Merchant Shipping (International Oil Pollution Compensation Fund) Administration Act, 2013 (Act 35 of 2013), and the Merchant Shipping (International Oil Pollution Compensation Fund) Contributions Act, 2013 (Act 36 of 2013). All these pieces of legislation finally came into force in May 2014.

A large number of policy instruments must be added to the legislative environment outlined above. Among the policy documents that should be added are the following:

- The Draft National Coastal Management Programme of South Africa (DEA, 2014)
- The Draft South African Maritime Transport Policy (DoT, 2008)
- The National Aquaculture Policy Framework for South Africa (DAFF, 2013)
- The Policy for the Small-scale Fisheries Sector in South Africa (DAFF, 2012)
- The Policy on the Management of Seals, Seabirds and Shorebirds (DEAT, 2007)
- The White Paper on Marine Fisheries Policy for South Africa (DEAT, 1997)
- The White Paper on National Commercial Ports Policy (DoT, 2002)
- The White Paper on National Management of the Ocean (DEA, 2014)

67 For instance, the Merchant Shipping (Carriage of Cargoes) Regulations, 2004, the Merchant Shipping (Carriage of Charts and Nautical Publications) Regulations, 2002, the Merchant Shipping (Collision and Distress Signals) Regulations, 2005, the Merchant Shipping (EPIRB Registration) Regulations, 2002, the Merchant Shipping (Eyesight and Medical Examination) Regulations, 2004, the Merchant Shipping (INF Code) Regulations, 2003, the Merchant Shipping (Maritime Security) Regulations, 2004, the Merchant Shipping (National Small Vessel Safety) Regulations, 2007, the Merchant Shipping (Radio Installations) Regulations, 2002, the Merchant Shipping (Safety Management) Regulations, 2003, the Merchant Shipping (Safe Manning) Regulations, 1999, the Merchant Shipping (Training and Certification) Regulations, 1999, and the Merchant Shipping Long-range Identification and Tracking of Ships Regulations, 2009.

68 This legislation was followed by the making of the National Ports Regulations, 2007, the Port Limits Regulations, 2009, and the Port Rules, 2009. The Act was passed after the enactment of the Port of Ngqura Establishment Act, 1998 (Act 77 of 1998). Aspects of this Act are arguably inconsistent with the National Ports Act. The latter contains a number of provisions that have brought about results that legislation could never have intended. For example, section 10 arguably does not permit the promulgation of a new port, the provisions of Chapter 5 pertaining to the Ports Regulator are restrictive and tend to give the Ports Regulator inadequate powers and resources, and requires revision.

## 3. State of current knowledge

South African maritime law and its practitioners are part of a long and internationally highly respected tradition. The Maritime Law Association of South Africa (MLASA) was established in February 1974. Maritime lawyers, who were practising in South Africa back then, were concerned that the evolution of maritime law in South Africa was not keeping pace with international developments. Therefore, the MLASA was formed primarily "to promote the study, research, administration and advancement of the maritime laws of the Republic…".[69] Since its inception, the MLASA has been at the forefront of the drafting of and contribution to new laws or amending laws in the sphere of maritime law, and has a number of standing committees charged with reviewing all pertinent laws periodically, as well as monitoring international developments.

The South African Maritime Safety Authority (SAMSA) administers the MSA,[70] among other things. SAMSA's mandate is "to promote the Republic's maritime interests",[71] which must be interpreted to include the promotion of the maritime legislation that supports South Africa's interests. As an agency of the Department of Transport (DoT), SAMSA is in fact very active in this sphere, but requires the cooperation and support of the Department in order to see draft legislation, which SAMSA promotes, come to fruition.

In 1992, a Shipping Law Unit was established at the University of Cape Town (UCT) with Prof J. Hare as its head. A few years earlier, at the erstwhile University of Natal, Prof H. Staniland had established an Institute for Maritime Law, which became the Unit for Maritime Law and Studies of the University of KwaZulu-Natal (UKZN) in 2012. In addition to a substantial number of journal articles and Prof Staniland's chapters on admiralty law that have been published in the *Annual survey of South African law* since 1993, there were a few substantial contributions to the field. These contributions include the following:

- B.R. Bamford's *The law of shipping in South Africa*, first published in 1961 (Bamford, 1961) with a second edition in 1973 (Bamford, 1973) and a third edition in 1983 (Bamford, 1983)
- C. Dillon and J.P. van Niekerk's *South African maritime law and marine insurance*, published in 1983 (Dillon and Van Niekerk, 1983)
- D.J. Shaw's *Admiralty jurisdiction and practice in South Africa,* published in 1987 (Shaw, 1987)
- G. Hofmeyr's *Admiralty jurisdiction law and practice in South Africa,* published in 2006 (Hofmeyr, 2006), with a second edition in 2012 (Hofmeyr, 2012)
- M. Wallis's *The associated ship and South African admiralty jurisdiction,* published in 2010 (Wallis, 2010)
- J. Hare's *Shipping law and admiralty jurisdiction in South Africa,* published in 1999 (Hare, 1999), with a second edition in 2009 (Hare, 2009).

In addition, the encyclopaedia *Law of South Africa* (LAWSA) carries a number of chapters in the sphere of marine and maritime law. Each chapter is written by an expert in the field. The encyclopaedia includes admiralty actions, admiralty courts, admiralty jurisdiction, cargo,

69 http://www.mlasa.co.za/about/.

70 S.4(a) of Act 5 of 1998.

71 S.3(c) of Act 5 of 1998.

carriage by sea, marine insurance, marine living resources, marine pollution, maritime claims, seashore and sea transport documents. Adv M. Stranex has published a loose-leaf anthology, *Shipping cases of South Africa,* which is updated periodically (Stranex, 1995). A.J. Pike also contributed chapters to Prof W. Tetley's books *Maritime liens and claims* (Tetley, 1998) and *Marine cargo claims* (Tetley, 2008).

In contrast, the law of the sea lacked any noteworthy scholarly attention until the early 1970s, when an interest in the field was generated mainly by the convening of UNCLOS III (e.g. Barrie, 1973; Reese, 1973; White, 1974; Oelofsen, 1975a; Oelofsen, 1975b; Oelofsen, 1976; Stassen, 1977). This came as no surprise as the Conference provided fertile ground for academic debate on almost all aspects of the international regime of the seas (Bennett et al., 1986). However, a decade would pass before Prof D.J. Devine was appointed as the second director of the newly established Institute of Marine Law at UCT in 1985. This exceptional scholar played a central role in laying the foundations of the South African law of the sea during the following 15 years, lecturing and writing prolifically while being the editor of a new South African marine law journal, *Sea changes*.[72] He was also the supervisor of a substantial number of research students, including the senior academic experts currently practising in the field. Scholarly work in the field continued after Prof Devine's retirement, but on a much smaller scale until *South Africa and the law of the sea* made it possible to produce a systematic account of the law of the sea from a South African perspective in 2011 (Vrancken, 2011). The work builds on a sizeable amount of scholarly notes and articles that were devoted to the following specific topics:

- Problems created by the apartheid legal regime and the transition to the new constitutional dispensation (e.g. Devine, 1986c; Devine, 1990a; Devine, 1992/1993b; Devine, 1993c; Devine, 1995a)
- Part XI of UNCLOS devoted to the International Seabed Area (e.g. Barrie, 1983; Bennett, 1986; Devine, 1986/1987; Vrancken, 1993)
- The country's maritime zones and the jurisdiction of the organs of state at sea (e.g. Booysen, 1977; Botha, 1978; Soni, 1979; Devine, 1985; Booysen, 1987/1988; Devine, 1989b; Devine, 1989/1990b; Devine, 1992; Devine, 1993b; Hare, 1994; Ehrenbeck, 1995; Hare, 1996; Devine, 2000b; Schlemmer, 2002; Vrancken, 2002a; Vrancken, 2002b; Vrancken, 2004b; Vrancken and Van der Berg, 2005; Fouché, 2006; Du Plessis, 2008; Surbun, 2010; Vrancken and Hoctor, 2010)
- The Prince Edward Islands (e.g. Schaffer, 1978; Monteiro, 1987)
- Maritime boundary delimitations (e.g. Erasmus and Hamman, 1987/1988; Devine, 1989/1990a; Hamman, 1991; Hamman, 1992; Hamman, 1995; Hamman, 2000; Devine, 2001; Hamman, 2007)
- Navigation in South African waters (e.g. Van Niekerk, 1981; Devine, 1986a; Devine, 1990/1991b; Van Eeden, 1992; Glazewski, 1994; Wardley, 1995/1996; Devine, 1996)
- Marine resources both in South Africa and Namibia (e.g. Bartlett and Van Rensburg, 1986; Devine, 1986b; Gertenbach, 1986; Grindley et al., 1986; Cole, 1988a; Cole, 1988b; Devine, 1988a; Devine, 1989a; Devine, 1989c; Devine, 1989d; Devine, 1990/1991a; Glazewski, 1990/1991; Hamman, 1992/1993; Vrancken and Glazewski, 1993; Devine, 1993a; Devine, 1994a; Devine, 1994b; Devine, 1994c; Martin, 1994; Devine, 1995b; Devine, 1995c Hauck and Sowman, 2001; Witbooi, 2002; Wright, 2004;

72 Seventeen volumes were produced between 1985 and 1996.

Vrancken, 2005; Witbooi, 2005; Clark, 2006; Crosoer et al., 2006; Hauck and Kroese, 2006; Nielsen and Hara, 2006; Witbooi, 2006; Tladi, 2007; Purves, 2009)
- Marine pollution (e.g. Rabie and Lusher, 1986; Steward, 1986; Devine, 1988b; Devine, 1992/1993a; Murungi and Kotzé, 2005)
- Coastal zone regulation (e.g. Gasson and Glazewski, 1988; Wroe-Street, 1989; Devine, 1990b; Devine, 1990c; Glazewski and Haward, 2005; Gibson, 2007)
- Marine research and the underwater cultural heritage (e.g. Staniland, 1983; Van Meurs, 1984; Van Meurs, 1986; Scheepers, 1989; Staniland, 1999; Beukes, 2001; Beukes, 2004; Forrest, 2005)
- Maritime security (e.g. Forrest, 2008; Gibson, 2009; Potgieter, 2009)
- Landlocked states (e.g. Sulaiman, 1984; Sizani, 1991; Van Zyl, 1991; Maluwa, 1995)
- Dispute settlement (e.g. Erasmus, 1986; Hamman, 1997; Devine, 1998a; Devine, 1998b; Devine, 1999a; Devine, 1999b; Devine, 2000a; Devine, 2000c; Devine, 2002; Devine, 2003a; Devine, 2003b)
- Antarctica (e.g. Barrie, 1975; Siegfried, 1986; Devine, 1988/1989; Botha, 1992/1993; Vrancken, 1995; Barrie, 1999; Vrancken, 2003)

That is over and above a number of chapters on marine matters in environmental law books (e.g. Glazewski, 2005; Bosman and Kidd, 2009; McLean and Glazewski, 2009).

## 4. Knowledge gaps and the way forward

The above investigation of the fast-changing policy and regulatory landscape at the global, continental, regional and domestic levels highlights how dynamic and multi-layered marine and maritime law have become. The fields have, in fact, reached such a level of complexity that it is increasingly difficult, if not already impossible, to claim scientific authority over the whole range of issues involved. Indeed, the amount and nature of interstate and judicial activity, as well as the volume of scholarly writing globally, are such that one individual can no longer seriously claim to be at the same time an expert in the legal regimes of coastal zone management, fisheries, maritime safety, maritime security and the polar regions, for instance. By contrast, the above synopsis of the state of current knowledge in the field in South Africa reveals a substantial body of scientific work, the bigger part of which is, as far as marine law is concerned, unfortunately becoming, if it is not already, outdated as a result of the change in the constitutional dispensation in the mid-1990s and the major legislative developments that ensued. Moreover, individuals in the small community of experts in the field have aged and an adequate new generation has not been nurtured. This situation is aggravated by exceptionally slow lead times to the enactment of new or amending pieces of legislation, resulting in a number of laws in the field being outdated and out of step with the rest of the world. That is a highly unsatisfactory state of affairs for a state that is not only the leading maritime nation in Africa, but also finds itself in a unique strategic position at the confluence of three oceans.

The establishment by the DST of the South African Research Chair in the Law of the Sea and Development in Africa at the Nelson Mandela Metropolitan University (NMMU) was a crucial initiative that attempted to address the situation. However, that can only be a first step in a wider strategy aimed at ensuring that South Africa is able to take its rightful place in the fast-expanding Blue Economy. In order to do so, the country needs to build the human capacity and resources necessary to critically review all domestic legal developments affecting the marine and maritime environment and find solutions to the legal problems that arise. This needs to be done in such a way that the most coherent and effective domestic law of the sea is developed.

However, South Africa must not only have in place, implement and enforce the law of the sea regime best suited to its present developmental needs, it must also be in a position in the years ahead to keep up with and influence legal developments beyond its borders, not only regionally, but globally as well. That requires having the human capacity and resources to critically review legal developments affecting the marine and maritime environment, not only in the United Nations (UN) itself, but also in the wide range of specialised global institutions and organisations that have an impact on human activities at sea. At the regional level, South Africa must be able to critically review legal developments not only in SADC, but also in the framework of the various specialised organisations and instruments in place in the South Atlantic Ocean, the Indian Ocean and the Southern Ocean, together with Antarctica. At the continental level, South Africa must further ensure that it has the human capacity and resources necessary to critically review developments in the legal order of the AU. In this regard, the adoption of the African Maritime Transport Charter and the 2050 AIMS has also made it necessary for the country to have the human capacity and resources to play a leading role in the harmonisation of the domestic marine and maritime legal orders of its fellow African coastal states, which is required for the establishment of the CEMZA. That will necessitate developing a new generation of South African marine lawyers who are able to engage with colleagues who are trained and practising in different legal regimes and traditions on the continent. Moreover, proper and effective staffing, training, funding and procedures must be in place at intra- and intergovernmental levels to ensure that evolving legislation is promptly reviewed and passed into law.

South Africa requires a research chair in maritime law over and above the newly established South African Research Chair in the Law of the Sea and Development in Africa. Both chairs need the funding required to ensure that world-class research material is available in the country and to support a greater number of full-time and part-time research master's and doctoral students. In order to harness the full potential of the presently limited and uncoordinated research capacity mainly at NMMU, UCT and UKZN, a medium- to long-term multi-institutional South African marine and maritime law research project should be established. The project would draw on areas of existing strengths and target a number of issues that require a systematic and comprehensive research focus. It should include the establishment of a common electronic database, the publication of a new peer-reviewed electronic journal dedicated to marine and maritime law, regular research workshops and conferences, as well as a detailed and well-funded strategy for research capacity-building in the field. Funding and expertise constraints in the country and the inherently international nature of the field, as well as the continent-wide strategy to successfully manage the AMD, militate in favour of the project becoming continental. This would make it possible to harness the full potential, not only of the presently limited and uncoordinated research capacity within the country, but also research capacity in other jurisdictions on the continent. Some of the benefits of such an arrangement would include avoiding the duplication of global, continental and regional resources and expertise, creating more room for specialisation in the field, and expanding a largely non-existent African community of research scholars who are required to tackle the legal challenges involved in the establishment and sustainable development of the CEMZA.

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# Chapter 3 Fixing the High-water Mark

*Keith P. Mackie*

## 1. Introduction

The seashore marks a phase change in the nature of the surface of the earth from solid to liquid. Since the liquid phase (the surface of the sea) is in a constant state of agitation, the physical boundary is in constant motion, but within a defined fuzzy zone. There are two independent drivers: the tides (equinoctial spring tides in the extreme), which are deterministic, and wind waves (storm waves in the extreme), which are probabilistic. The magnitudes of each vary enormously, from negligible to extreme in different parts of the world, and each does so independently of the other, although there is some tendency for coastal morphology to induce inverse correlation.

Assessing, selecting from and combining these two becomes a matter of policy, within the constraints of these natural physical processes, when demarcating a seashore boundary.

This chapter identifies the two primary sources for the general concept of the high-water mark (HWM) in the English-speaking world. It goes on to discuss a persistent error in translation of the original Latin passage by leading British jurists throughout the 19th and 20th centuries. This has had a corrupting effect on the South African legal definitions of the HWM, specifically the use of the word 'flood'. The chapter concludes with a suggestion for correcting the current legal definition of the HWM and some suggestions for further research.

## 2. The two primary sources for the concept of the HWM in the English-speaking world

The concept of the HWM from Anglo-Saxon decent has two primary sources:

The first source is Lord Chief Justice Matthew Hale in *De Jure Maris* (1666) (Graber, 1980). He gives a clear description of the basic parameters of the tides:

- The high spring tides, which are the fluxes of the sea at those tides that happen at the two equinoxials.
- The spring tides, which happen twice every month at full and change of the moon.
- The ordinary tides or neap tides, which happen between the full and change of the moon (new moon).

The British Isles lie in a region of mega tides (> 4 m), a condition often amplified to extreme tides in the estuaries that account for a significant portion of the coastline. Under these conditions, there is a wide variation in the tides between neaps and springs. Hale held that for most of the time, land that was only flooded by exceptional tides could be (and was) used as any other land and should be judged to be above the HWM. Hence, he held that Crown land extended landward only so far as it could be covered by "the ordinary flux of the sea" (Graber, 1980). Although his intent was clear, there has been some dissension over the meaning of 'the ordinary flux of the sea'. Did he mean neap high water or average high water, averaged across the neaps between two successive spring tides?

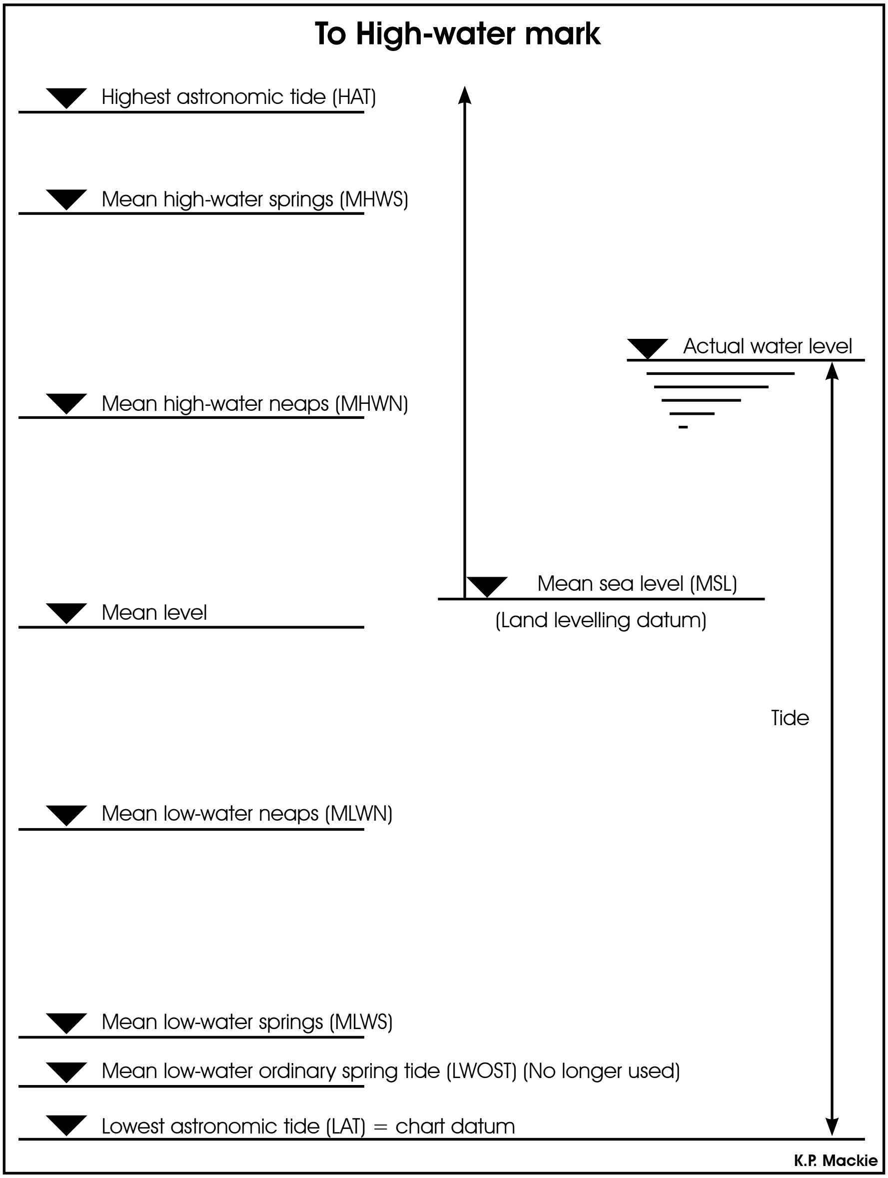


**Figure 1:** *Tide parameters on the South African coast: a typical open, oceanic, high energy, microtidal shore (Mackie, 2002).*

To the extent that nothing much of principle depends on this, it can be easily clarified in legislation. What is clear is that it reflects the normal condition of deep estuaries that are completely protected from oceanic waves. It is explicitly limited to the tides and excludes any form of wave action.

Compare Hale's parameters to an illustration of modern tide stage categories recognised in South Africa in Figure 1.

The second source is the Institutes of Justinian (533 AD) (Thomas, 1975). The relevant section is *Book II, Title 1, Clause 3 – Of the Different Kinds of Things*, where the boundary between land and sea is described. The primary intent of this section is to catalogue various classes of ownership of things. The important issue is ownership, not the precise physical nature of the object, in this case, the location of a boundary.

# 3. Translation of the key passage in the Institutes of Justinian

## 3.1 Assessment

The key sentence in the Institutes of Justinian reads:

"*Est autem litus maris, quatenus hibernus fluctus maximus excurrit*."

I have translated this as:

"The seashore, however, is as far as the greatest run-up of the winter waves."

The two key words are: *excurrit* and *fluctus*.

*Excurrit*: This generally means to dash out or sally (Marchant and Charles, 1952). I have chosen to convert the original Latin verb to a noun and translate it into the modern term 'run-up'. I have avoided the term 'swash', since it describes the manner of the terminal excursion of the waves on the seashore, not the extent of that excursion, which is covered by 'run-up'. Both words are terms recently adopted by oceanography and coastal engineering. They cover the explicit meanings of these two aspects of the maximum landwards excursion of the sea due to wave action.

*Fluctus:* Normally this means 'waves' and I have translated it as such (Marchant and Charles, 1952). As in its English derivative, 'fluctuate', the verb means 'undulate' and derives from '*fluer'* – to flow. As a result, *fluctus* is sometimes used to mean 'flood'.

The key phrase is the one that I have translated as "… is as far as the greatest run-up of the winter waves".

The following translations of the key passage over the past 200 years, except those by Cooper (1812) and Halsall (1998), are all by leading English jurists:

- Cooper (1812) (USA): over which the greatest winter flood extends itself
- Grapel (1855) (UK): over which the highest winter's tide extends itself
- Abdy (1876) (UK): the line reached by the highest winter tide
- Moyle (1913) (UK): the limit of the highest tide in time of storm or winter
- Thomas (1975) (UK): as far as the winter tide reaches its furthest extent
- Halsall (1998) (USA): as far as the greatest winter flood runs up

This is staggering! Every one of them is incorrect!

Each of these translations poses a specific problem in its interpretation of the concept of the term '*fluctus*', and its subsequent use of the words 'flood' and 'tide'.

The Institutes of Justinian is straightforward and clear, yet Grapel, Abdy, Moyle and Thomas all persist in translating '*fluctus*' as 'tide'. There may have been some sort of collaboration in the sense that one copied from another. Cooper states that his rendering is based on that of a prior translation by a Dr Harris, and Thomas claims to have followed Moyle.

The substitution of 'tide' for 'wave' may owe something to a cross-contamination to the basis of Hale's approach strengthened by the process of copying. The most likely explanation, however, is that all the translations are focused on the main subject of the work and not on an apparently minor detail of physical exactitude. They have allowed themselves to drop into a common, albeit normally poetic, English usage of referring to the 'sea' as 'tide'.

In its entry for the word 'tide', under II/12, the Oxford English Dictionary (1971) describes 'tide' as "waters of the sea". It lists this usage as poetic and gives the following as examples:

- Shakespeare: "swelling tide"
- Cowper: "Ocean's restless tide"
- Byron: "Bounding o'er yon blue tide"
- Eliza Cook: "afloat on the fierce rolling tide"

The straightforward nature of the description of the seashore in the Institutes of Justinian conforms exceptionally well with the typical Mediterranean shore, particularly on the North African and Levantine coasts. These are open, high-energy shores with a micro (virtually zero) tide. I once walked along the seashore at Tel Aviv with two professors of coastal engineering. One remarked that he thought the wave regime on that coast was all fetch limited. The other replied that it was actually duration limited. Even in the great oceans of the world where fetch is virtually unlimited, duration is the usual constraint on oceanic swell. Much of the shoreline of the Mediterranean can be exposed to very severe waves with large shoreward excursions of the waters of the sea (Minikin, 1963). It is therefore incorrect to use 'tide' for '*fluctus*' when translating the key passage in the Institutes of Justinian.

Similarly, the translations of Cooper (1812) and Halsall (1998) are also defective in their use of 'flood' instead of 'waves'. This could be the consequence of translating '*fluctus*' into its minor meaning of 'flood' (Marchant and Charles, 1952). But this might only have had a subliminal influence on the translators. The context suggests that it is merely a variation of the use of 'tide' – an abbreviation of 'flood tide'.

The primary meaning of the terms 'flood' and 'ebb' in a tidal context refer to the rising and falling of the tide, but it would be quite natural to associate high water with the rising tide and low water with the falling tide. Oxford English Dictionary (1971) lists two uses that bear out this supposition: 'top-of-the-flood' and 'flood-mark'. It then follows that 'flood' could simply be a word used loosely for high water and that this was the intended meaning of 'flood' in the translations of Cooper (1812) and Halsall (1998). When considering the term 'flood tide', the translations from the aforementioned translators are cognate with the term 'tide' in the translations by Grapel (1855), Abdy (1876), Moyle (1913) and Thomas (1975). The term 'flood' is thus not an appropriate translation in the Institutes of Justinian either. Both errors introduce into the translation an idea that is not present in the original passage.

**To summarise:**

*Hale treats tides without any concern for waves.*
*The Institutes of Justinian treats waves without any concern for tides*

### 3.2 Qualifications in each of the opinions in Hale and in the Institutes of Justinian

Hale is quite explicit. He requires the boundary of the seashore, the HWM, to be delineated by the water line of a prespecified tide and that this tide should be less than the highest tides on that shore. Additionally, by his exposition of the characteristics of the tides, he makes it clear that he only implies the astronomic tides and, by default, by making no mention of them, excludes all other tsunami-like fluctuations of the sea surface and the concomitant extreme run-up.

The Institutes of Justinian is also explicit in its qualification: "the greatest run-up of the winter waves". By and large, the greatest run-up will be caused by the greatest waves and these, in turn, will be the storm waves. In the Mediterranean and any other temperate and high-latitude region, these storms are extratropical cyclones. Although they can occur at any time of the year, the greatest energy transferred onto the sea surface occurs during the winter months. Winter therefore characterises these storms and the great waves they generate – as prescribed by the Institutes of Justinian.

Tropical cyclones (known in some parts of the world as 'hurricanes' or 'typhoons') have very different characteristics to the temperate, extratropical cyclones. Where the temperate cyclone tends to be widespread and diffuse, the tropical cyclone is commonly localised and intense. Whereas a particular temperate shore will experience the full impact of many storms each year, the full impact of a tropical cyclone on a particular piece of tropical shore will be very infrequent. They are extreme events to be treated as such. Since they are typically a summer phenomenon, they are, by default, excluded by the opinion of the Institutes of Justinian. Hale's opinion is sympathetic to this interpretation.

While these two opinions are independent of each other, they are valid representations of reality and are capable of superposition: i.e. they can be applied together where appropriate to local circumstances. In other words, on coasts where both tides and waves are significant, a definition of the HWM, based on a combination of the two approaches by addition of the two excursions, one riding on the other, would be fully appropriate and in keeping with the intent of each, taken independently. Viewed in this way, these opinions are beautifully cognisant, as far as they go, of the modern understanding of the sea and the seashore.

## 4. The South African usage of the term HWM

The net result of these errors in translation of the key passage in the Institutes of Justinian in South African law, with Hale lurking in the background, has been definitions of the HWM in two pieces of legislation that are both garble.

The Seashore Act, Act 21 of 1935, gives the following definition of the HWM based on case law:

*"High-water mark means the highest line reached by the water of the sea during ordinary storms occurring during the most stormy period of the year, excluding exceptional or abnormal floods."*

Here, the problem is the use of the word 'floods' – the same error described in the translations of Cooper (1812) and Halsall (1998). In the English megatidal estuaries, the use of the terms 'flood' and 'ebb' serve to describe the very real fast-flowing currents of the rising and falling tides.

On the open, high-energy, microtidal (< 2 m) South African coasts, a vestige of these tidal flows exists in some of the estuaries, but are relatively insignificant and, in practice, the terms are not used on this coast. Hence, the use of the term 'flood' leads to confusion, and can be confused with riverine floods that occasionally pass through an estuary. Here it should be kept in mind that these riverine floods have no effect whatsoever on sea level. The only residual effect is on the backwater curve from the sea.

On open, high-energy, microtidal shores, the seashore is generally quite steep and the difference in altitude between the highest astronomical tide (HAT) and the mean high-water springs (MHWS) is quite small. Hence the difference in landward excursion between these two tides is generally too small to be significant. In fact, compared to the wave effects, it is probably unmeasurable.

On open, high-energy, microtidal oceanic shores, the maximum excursion of the sea onto land is dominated by wave effects. It will be the maximum run-up of the swash of the sea that depends on both the weather and the breaking of the waves. Both have the effect of raising the sea level at the shoreline. Under storm conditions, it is the breaking of the waves that has the dominant effect and the final altitude of the run-up can be many times the incident wave height. This, in turn, is dependent on the nature of the shore and can vary widely on different shores. Overall, the contribution of storm attack will be much greater than that of the tides. In practice, there is no need to specify a cut-off to the tides as in Hale's opinion. On the South African coast, the approach of the Institutes of Justinian alone would be appropriate.

The National Environmental Management: Integrated Coastal Zone Management Act, Act 24 of 2008, now replaces the definition of the Seashore Act and states the following:

*"High-water mark means the highest line reached by coastal waters, but excluding any line reached as a result of:*

- *(a) exceptional or abnormal floods or storms that occur no more than once in ten years; or*
- *(b) an estuary being closed to the sea."*

The opening statement is reasonable. The problem is in the exceptions.

Exception (a) includes the false term 'floods' as discussed above. It also introduces the idea of a limiting return period of "once in ten years" without any further explanation or definition.

Notwithstanding the reference to a return period, the clear intention of the clause is to follow the opinions of Hale and of the Institutes of Justinian, and to adopt a pragmatic exclusion of extreme excursions of the sea. On a high-energy, micro/mesotidal shore, storm-induced events, not tidal events, will dominate. Hence, for this exception, a simple reference to 'exceptional excursions of the sea' would be adequate. However, an indication of how to assess this (how to exclude the extremes) is needed. The attempt to refer to a one-in-ten-year return period suggests an attempt to introduce a spurious sense of certainty into a fundamentally indeterminate environment.

Exception (b), in its present form, is unworkable. Many, if not most, of the small estuaries on the South African coast are commonly closed, but open on occasion. The wording gives no guidelines as to when an estuary is deemed to be closed.

# 5. Practical interpretation

In practical terms, the sea usually leaves an upper trace of its excursions – a sand, shell and flotsam limit on 'up-as-far-as-possible' and a complementary vegetation line on 'down-as-far-as-possible'. Hence, in practice, the only way to identify the HWM on a microtidal, high-energy shore is to walk along the coast and observe the signs (the swash line, the line of flotsam and, equally, the edge of terrestrial vegetation) to visually identify the median positions between the upper positions of marine and lower positions of terrestrial signs.

A practical approach to the exclusion of extreme events is to exclude all signs of excursion above this line.

This practice has traditionally been the interpretation of the HWM. It yields an irregular line that cannot be explicitly defined in the same way as straight-line boundaries between surveyed beacons can. Formally, it falls into the field of fractal geometry rather than Euclidean geometry (Mackie, 1994). The law does not seem to have a problem with such indeterminate boundaries. Deeds of properties with a seashore boundary that give the area of the property calculated exactly (described as *ager limitatus*) are judged to have a beaconed seashore boundary. Where the area is given approximately (described as *ager non limitatus*), the property is judged to be bounded by the HWM (Obree, 2014). Obree (2014) confirms that the concept of *ager limitatus* is recognised, but that cases where it is used almost never arise.

A suggested rewording of the definition of the HWM follows below:

*'High-water mark' means the highest line reached by coastal waters, as shown by signs of a stable nature on the seashore of the furthest excursions of the coastal waters, but excluding any line reached as a result of excursions of the coastal waters beyond the stable trace.*

This suggestion depends on the validity of the idea of a stable trace. It exists, but further empirical research is needed to establish that where it exists, it can be clearly identified, to determine when it fails and to determine what alternatives there are.

***Plate 1:*** *Extreme (in this case, a clear weather) storm swash reaching to the HWM.*

The photograph in Plate 1 shows a clear, albeit fractal vegetation line and a storm swash reaching to that line. The foreground shows clear signs of the swash overrunning the vegetation and includes signs of seawater burn to the vegetation, while in the background it has not reached the vegetation. On other occasions, however, the swash has penetrated the reeds shown in the background (Schrecker, 2012). Following Hale's approach, these occasional transgressions of the vegetation line should be ignored.

## 5.1 Proviso

The physical coastlines implicit in this discussion are geologically stable coastlines – generally rockbound coasts rather than mobile coasts. There are many sandy or otherwise mobile coasts that exist in a state of dynamic stability or fluctuate within a stable range and can therefore be included in a discussion of stable coastlines. Examples here are the summer-winter fluctuation of Llandudno Beach or the ca 100-year cyclic fluctuation of the Keurbooms Estuary at Plettenburg Bay.

***Plate 2:*** *Llandudno Beach showing summer (left) and winter (right).*

The photographs in Plate 2 show the extreme change in the sandy beach at Llandudno. Regardless of this change, the HWM, as indicated by the vegetation line, remains constant.

***Plate 3:*** *New mouth to Keurbooms Estuary (2010).*

The properties on the far shore in Plate 3 were established when the mouth of the Keurbooms Estuary was at the terminus against Lookout Rocks early in the 20th century. They are still safely behind the HWM after the mouth migrated back to that position in around 2010. The land for the hotel in the middle ground, granted while the mouth was still a few kilometres away, is below the long-term HWM and was nearly lost when the mouth made its final sally to the terminus. Half the property was lost and the remainder had to be armoured with large rocks. The HWM has remained constant despite the migrations of the mouth.

While the principles of the opinions of Hale and of the Institutes of Justinian do not cease to apply on mobile shores, the instability of these shores and the matter of sea-level instability vastly complicate the cadastral issues in ways that are beyond the scope of this chapter.

The subject is vastly complex and includes issues such as practice in other countries – tackled state by state for the USA by Graber (1980) – or the historical interpretations of various Surveyors-General in South Africa. Field testing of the practicality of a visual assessment of the HWM must also be tackled. Other issues pertain to unstable seashores. In general, the nature of the seashore that is quite alien to either the land or the sea, and is highly variable from shore to shore, needs much deeper understanding. A large body of information exists on all these aspects, but needs to be consolidated into a coherent summary relevant to property boundaries.

Far more complex is the interaction between the seashore and the march of civilisation and the built environment. Worldwide, there is an accelerating movement to the sea. This imposition is dominantly terrestrial in its nature and tends to either obliterate the unique character of the seashore or be attacked by the sea. Currently there is a real need for an optimisation of these conflicting interests (Mackie, 2012) – an approach that may well yield unanticipated results.

## 6. Conclusion

This chapter is restricted to the topic of the HWM and the current errors in its definition in South African legislation. Related topics are suggested for future studies.

When translated into plain modern language, the interpretations of both Hale and the Institutes of Justinian amount to straightforward common sense. Both exclude extremes of events with a low frequency of occurrence.

In tide-dominated, macrotidal estuaries or other protected waters, Hale's principles will apply. In these cases, a deterministically predetermined sub-extreme tide level must be used to delineate the HWM. On open oceanic, microtidal shores, where there is an insignificant difference between HAT and MHWS, the tides can be ignored.

On wave-dominated oceanic shores, the sub-extreme wave run-up of the winter storms generated by extratropical cyclones, as shown by stable signs on the seashore, must be used. The wave run-up generated by tropical cyclones (hurricanes or typhoons) can be ignored.

This means that, in practice, the only way to identify the HWM on a microtidal, high-energy shore is to walk along the coast and observe signs like the swash line, the line of flotsam and, equally, the edge of terrestrial vegetation.

Estuaries that are sometimes closed and sometimes open to the sea present two different water levels. When they are open, even on microtidal shores, they are effectively tide-dominated. Hale's principles must then be used to delineate the HWM, using HAT in the case of microtidal shores. When they are closed, they can be flooded to well above the equivalent HWM until the barrier dune overtops and breaches. This is not a HWM in the usual sense, but can be used to delineate a safe building or development line. It falls in the same category as flood lines of a predetermined return period or flood magnitude, shown on zoning plans, although in the case of these estuaries, the line is determined by the altitude of the barrier, rather than the magnitude of the flood.

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# Chapter 4 Scenarios for the South African Maritime Sector

*Marius Claassen, Nikki Funke, Meena D. Lysko, Cebile Ntombela*

## 1. Introduction

The economic importance of maritime trade around the southern tip of Africa was already appreciated by European explorers several centuries ago. In the 15th century, Bartolomeu Dias was appointed by King João II of Portugal to head an expedition to sail around the southern tip of Africa in the hope of finding a trade route to India. Muller (1969) reflects on the significance of Dias's discovery of this route:

> *"The sight, during the first days of February [1488], of the African coast west of Mossel Bay must have been a moment of triumph for Dias. At last, for the first time, south of the equator, the coast ran in a new direction, which indicated that the 'southern shore' of the African continent had finally been reached, after more than seventy years, and that the passage to the India of the priest king and the glamorous riches of the East was now in sight."*

In the classic work, *An inquiry into the nature and causes of the wealth of nations*, Smith (1776) states: "The discovery of America, and that of a passage to the East Indies by the Cape of Good Hope, are the two greatest and most important events recorded in the history of mankind."

International trade has grown steeply since these discoveries, with total international trade standing at $18,3 trillion in 2012 (UNCTAD, 2013). According to StatsSA (2004, 2006, 2012), water transport accounted for R4 594 million direct income for South Africa in 2002, which grew to R8 833 million in 2006 and R11 828 in 2012. In 2012, fishing and related activities showed a turnover of R7 914 million, whereas the building and repair of ships and boats had a turnover of R2 138 million over the same period (StatsSA, 2012). These figures exclude coastal and marine exploration and mining, construction, cargo handling and storage, research, tourism and social services.

While the promise of the maritime sector is highlighted in this retrospective view of the importance of discovering a trade route to India, it also provides a baseline to look at the future of the sector through the lens of scenarios. Scenarios can support future planning and action in South Africa's maritime sector, which has the potential of acting as a catalyst for investment, economic growth, employment creation and enterprise development in the country (Mokhele, 2012).

## 2. Scenarios

The concept of scenario planning originates in military applications. Sun Tzu (ca. 500 BCE) already acknowledged the importance of planning in the face of uncertainty 2 400 years ago by saying that "the general who loses a battle makes but few calculations beforehand. Thus do many calculations lead to victory, and few calculations to defeat: how much more no calculation at all! It is by attention to this point that I can foresee who is likely to win or lose" (Giles, 1910). In modern times, the scenario planning concept emerged as a method for military planning after World War II. The United States Air Force developed 'scenarios' of what the enemy might do to enable it to prepare alternative strategies. This exercise was aimed at achieving a desired outcome in an uncertain future (Mietzner and Reger, 2004).

In addition to military applications, researchers at the RAND Corporation started to investigate the scientific use of expert opinion in planning for the future in the 1940s (Landeta, 2006). This formed the basis for the Delphi method for forecasting and decision-making, where experts provide structured feedback to questionnaires in two or more rounds (Glenn and Gordon, 2004; Landeta, 2006; Banuls and Salmeron, 2007). Royal Dutch Shell also used scenario tools to good effect in the 1970s, leading to a competitive advantage that enabled them to act quickly during the oil price shock of 1973 (Daum, 2001; Wilkinson and Kupers, 2013).

While Royal Dutch Shell is credited with leading scenario development internationally, it was Clem Sunter who popularised the use of scenarios in South Africa with *The world and South Africa in the 1990s*, featuring the 'High Road' and 'Low Road' scenarios (Sunter, 1987). These scenarios were based on work done by Anglo American Corporation teams in London and Johannesburg, which included Pierre Wack and Ted Newland, who were both previously employed by Royal Dutch Shell. Scenarios subsequently continued to play an important role in the political, economic and social transition in South Africa. Adam Kahane facilitated a process that became known as the Mont Fleur Scenario Project, which was launched in 1992. It explored what South Africa will be like in the year 2002. This scenario development process drew inputs from a very broad group of stakeholders, with all members of the team endorsing the resultant scenarios as valid mental models for how the future might unfold (Kahane, 1996 in Galer, 2004). In addition, the Department of Arts, Culture, Science and Technology (DACST) deployed scenarios and technology foresighting with a 20-year horizon in the development of South Africa's National Research and Development Strategy. In relation to this, Michael Kahn initiated and led the development of the South African National Research and Technology Foresight Project (DACST, 1999). The Dinokeng team (2009) developed *3 futures for South Africa*, which characterises future scenarios for 2020 based on the effectiveness of the state and the engagement of society. The resultant scenarios were named 'Walking Apart', 'Walking Behind' and 'Walking Together'.

Scenarios typically characterise the contextual environment in which a particular focal issue will play out in the future (Wolters et al., 2013). The key question is: "What are the most significant and most uncertain elements that could affect this focal issue in the future?" The various answers to this question result in drivers of change that will typically be represented in a scenario matrix. Based on this matrix, scenario stories are developed that provide perspectives of what the world may look like under different conditions of the drivers of change. Strategies that are robust in the plausible future can then be developed. These strategies steer the drivers of change in the desired direction.

Scenarios can represent different future states for one particular driver, such as the four scenarios for the reinvention of Europe, which are all related to treaties (Leonard, 2011). These scenarios include 'Asymmetric Integration' (working around existing treaties), 'Smaller Eurozone' (existing treaties, but fewer countries), 'Political Union through Treaty Change' and 'Federalism without Federalists' (agreement outside the scope of the European Union (EU) treaties). The 'High Road' and 'Low Road' scenarios (Sunter, 1987) and the geopolitical scenarios for the BRIC countries (Brazil, Russia, India and China) (Suárez de Vivero and Rodríguez Mateos, 2010) were also developed around one main driver. Another popular approach to scenario development is to identify two key drivers and develop four scenarios out of these. This approach was adopted for the Dinokeng scenarios (2009), the Blue Growth Study (Ecorys et al., 2012) and the Water Sector Institutional Landscape by 2025 scenarios (Claassen et al., 2011). Scenarios can also be based on different combinations of multiple drivers, which has been the case for the Global Marine Trends 2030 scenarios (Lloyd's Register et al., 2013).

A number of scenario projects have recently been completed in the international maritime sector. *Global marine trends 2030* (Lloyd's Register et al., 2013) states that the marine world in 2030 will be almost unrecognisable owing to the rise of emerging countries, new consumer classes and resource demand. The authors identified 'Status Quo', 'Competing Nations' and 'Global Commons' as future scenarios for the marine world. The EU Blue Growth Study (Ecorys et al., 2012) set out to develop a comprehensive, robust and consistent analysis of possible future policy options to support smart, sustainable and inclusive growth from the oceans, seas and coasts. The study identifies sustainability and economic development as the main axes, which result in the presentation of four different scenarios: 'Boom and Bust', 'Pursued Growth', 'Fragile Recovery' and 'Sustainable Growth'. Suárez de Vivero and Rodríguez Mateos (2010) developed geopolitical scenarios that were named the 'Arctic Scenario' (global warming leading to Arctic waters becoming navigable and providing access to resources), the 'Indo-Pacific Scenario' (focused on the greatest concentration of people and the greatest seaway for maritime traffic in this region) and the 'Southern Scenario' (with the southern hemisphere assuming greater importance on the world stage).

The aim of this chapter is to present the development and storylines of different potential scenarios for the South African maritime sector (the Maritime Nation scenarios), and then to reflect on how to best utilise these scenarios as a tool to support decision-making, future planning and action for the sector.

## 3. Drivers of change

Contemporary policies and strategies do not deal comprehensively and systematically with the impact that changing conditions (drivers) may have on the future of South Africa as a maritime nation (DoT, 2008; RSA, 2013; RSA, 2014). This scenario development process drew on South African, as well as international scientific papers, strategy documents and institutional plans (listed in the footnotes of Figure 2 and Figure 3). It also drew on the proceedings of the National Integrated Marine and Maritime Technologies Workshop[1] (Funke and Claassen, 2014a) to identify key drivers related to the maritime sector that could cause significant change and indicate the uncertainty of change. The focal question against which the key drivers are assessed is: "What are the drivers that are most significant and most uncertain that could affect the degree to which South Africa will be a maritime nation by 2030?"

Such drivers should be relevant to the main themes and the cross-cutting themes that were used to structure the content of the presentations at the workshop and to help demarcate the scope of the sector (Figure 1). Shipping and transport, marine resources and marine tourism provide the broad scope for the sector, while the subthemes indicate application areas such as logistics infrastructure, offshore energy and mining, sports and recreation, and leisure.

1 This workshop brought together 103 stakeholders from across the maritime sector, representing universities, research organisations, government, parastatal organisations, non-governmental organisations (NGOs) and the private sector. The workshop provided an opportunity for stakeholders to present the latest research and technology in the sector and to engage in networking (Funke and Claassen, 2014a).

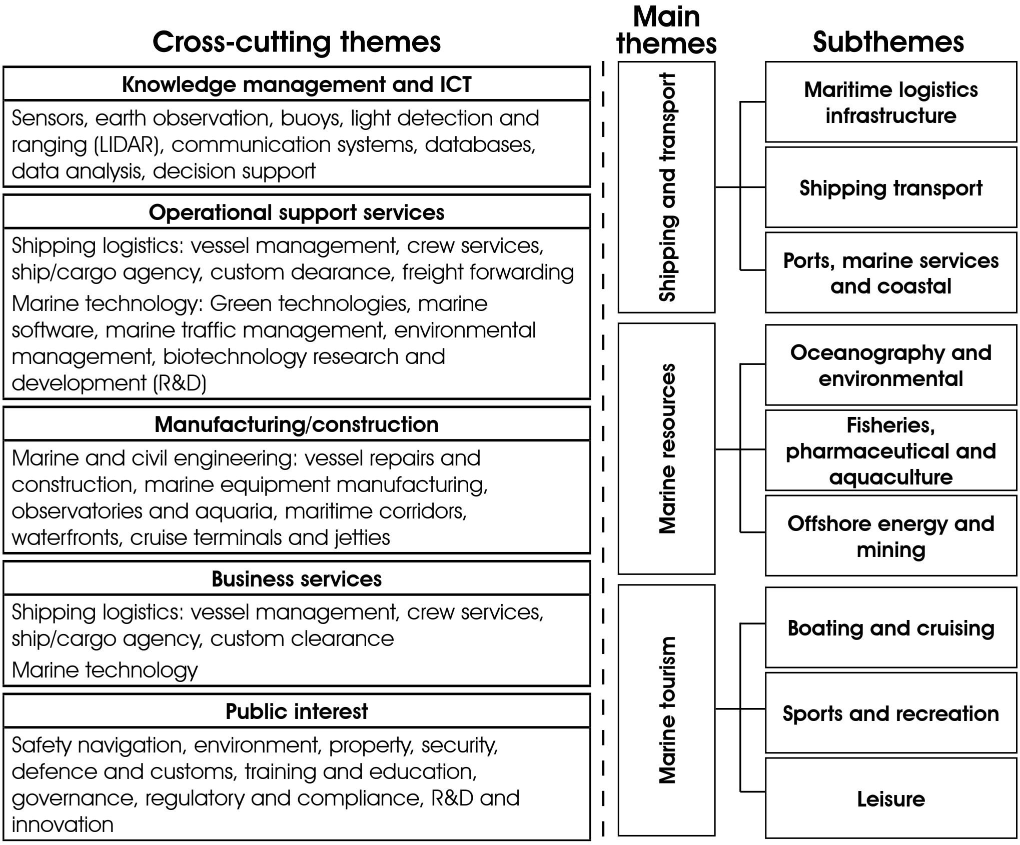
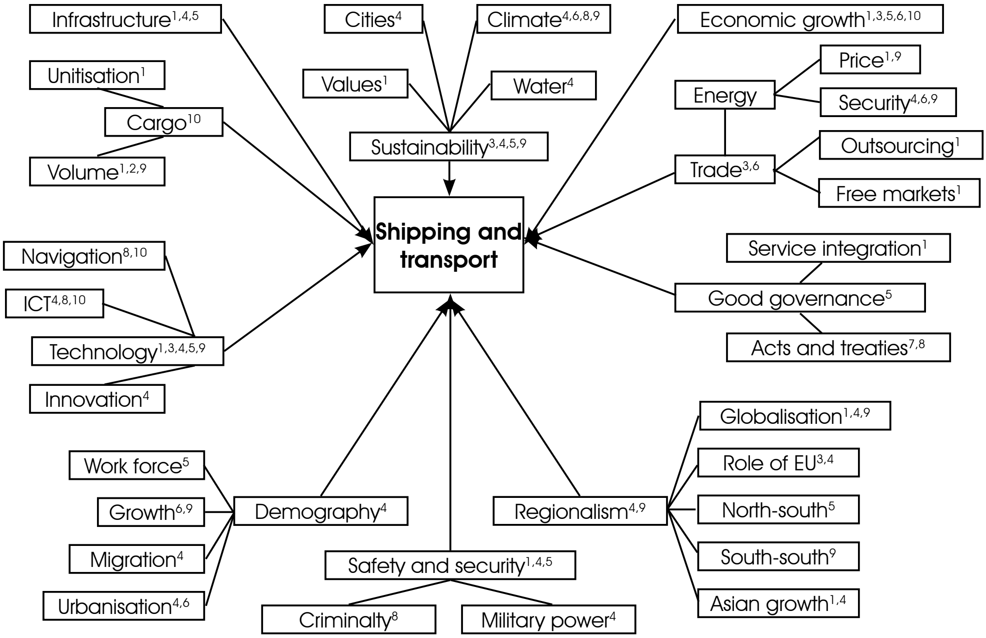



***Figure 1:*** *Main themes, subthemes and cross-cutting themes for the South African maritime sector (adapted from Mokhele, 2013).*

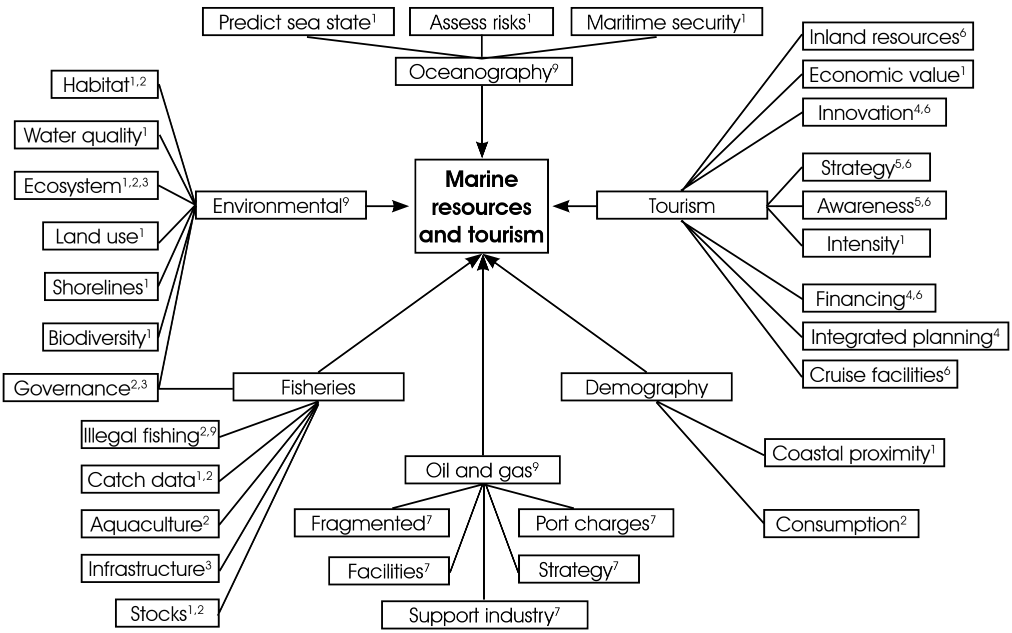
Drivers of change related to 'shipping and transport' were drawn from scientific papers, regional strategies, industry reports and workshop proceedings through data mining (DocFetcher Development Team, 2014). The specific sources are linked by the superscript numbering and footnotes in Figure 2. The drivers fall in the broad areas of sustainability, economic growth and trade, governance, regionalism, safety and security, demographics, technology, cargo and infrastructure. The context in which the drivers are mentioned is related to coordination within shipping and transport and linking different elements to improve overall efficiency (EC, 2011; Leonard, 2011; AU, 2012; Republic of Ireland, 2012; UNCTAD, 2013; Funke and Claassen, 2014a; Pekkarinen and Repka, 2014). The drivers are also listed in terms of the requirement to develop and implement advanced technologies and innovation (Kuronen et al., 2009; EC, 2011; Republic of Ireland, 2012; Leonard, 2011; AU, 2012; Funke and Claassen, 2014a).

The drivers that are significant and uncertain in relation to 'marine resources and tourism' were drawn from global reviews and South African analyses. They include oceanography, tourism, demography, oil and gas, fisheries and environmental issues. The drivers of change related to these areas are shown in Figure 3, with superscript numbering and footnotes indicating the sources. The drivers are also listed in relation to dependencies between different elements, as well as the advancement of new technologies.




*([1]Kuronen et al., 2009; [2]Pekkarinen and Repka, 2014; [3]Wolters et al., 2013; [4]EC, 2011; [5]Republic of Ireland, 2012; [6]Lloyd's Register et al., 2013; [7]Leonard, 2011; [8]AU, 2012; [9]UNCTAD, 2013; [10]Funke and Claassen, 2014a.)*

***Figure 2:*** *Drivers of change for the shipping and transport thematic area.*




*([1]Burke et al., 2001; [2] Berveridge et al., 2013; [3] Republic of Ireland, 2012; [4] EC, 2012; [5] Tourism Business Africa, 2014; [6]SAMIC, 2012; [7] SAMSA, 2012; ; [8]Funke and Claassen, 2014a.)*

***Figure 3:*** *Drivers of change for the marine resources and tourism thematic area.*

## 4. Scenario matrix

The drivers of change identified above were further evaluated from presentations and discussions at the Integrated Marine and Maritime Technologies Workshop (Funke and Claassen, 2014a), the proceedings of the Integrated Marine and Maritime Technologies Thought Leaders Indaba (Funke and Claassen, 2014b), and discussions that were held at regional workshops in Pretoria, Durban and Cape Town (Funke et al., 2014). All of these events (April and May 2014) dealt with the development of the *Research, Innovation and Knowledge Management Road Map for the South African Maritime Sector*.

The discussions at the abovementioned technologies workshop, indaba and regional workshops revealed key characteristics in relation to the drivers of change. The first relates to the extent of the uptake of research, innovation and knowledge management in the maritime sector, whereas the second relates to the extent to which the sector is unified. A unified sector would have shared objectives, coordinate activities efficiently and deploy resources effectively to achieve the shared objectives. These two characteristics constitute the axes for the scenario matrix, as presented in Figure 4. The two axes bring about four possible scenarios.

The bottom left scenario in Figure 4 describes a future where the maritime sector is divided and where there is limited uptake of research, innovation and knowledge management. In such a situation, South Africa could be described as a stagnant maritime nation. This scenario is entitled 'Lost at Sea'. The bottom right scenario in Figure 4 describes a future environment where the sector is divided, but the uptake of research, innovation and knowledge management is extensive. This represents an opportunistic maritime nation and it is called 'Islands of Excellence'. The top left scenario in Figure 4 describes a future where there is limited uptake of research, innovation and knowledge management, but where the sector is unified. This results in a maritime nation lagging behind international peers and competitors in relation to technology development and uptake. This scenario is called 'Rowing Together'. The final scenario (top right in Figure 4) combines the extensive uptake of research, innovation and knowledge management with a unification of the sector to support a prosperous maritime nation. This scenario is called 'Full Steam Ahead'. The characteristics of these scenarios are discussed in the next section.

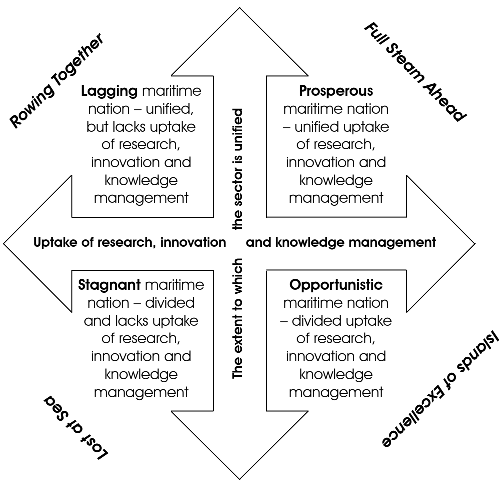



***Figure 4:*** *Scenario matrix, with sector unification and technology uptake as key drivers.*

## 5. Scenario stories

The 'Lost at Sea' scenario depicts a future with divergent actions and little progress. An investor, reflecting on his experience while looking for investment opportunities, may write the following in his diary on 6 June 2030:

> *"I returned from a series of engagements with actors in the South African maritime sector today. I was looking for opportunities to invest in a sector that clearly has a great deal of potential. At first glance, infrastructure investment seemed to be a logical choice. However, it soon became clear that the integration between application areas to optimise infrastructure is lacking. An example is the ship-building and repair sector, which can't secure sufficient long-term commitments with ports to justify specific investments. I was also very surprised at the poor coordination, communication and uptake of maritime-focused research results, which put investments in potentially very lucrative areas such as ecotourism and offshore oil and gas exploration at risk. I have come to the conclusion that the sector is too divided to warrant investment, while the lack of innovation paints a bleak picture for the future."*

The 'Islands of Excellence' scenario describes a future where vibrant innovation is supported by the uptake of research and effective knowledge management, but this is limited to specific actors in the sector and does not translate into an integrated maritime sector. A senior government official tasked with developing the maritime sector may make the following reflections in his management report of 12 April 2030:

> *"We have been successful in supporting the fisheries sector as a result of groundbreaking new technological developments. Applied research in the sector has contributed to the development of a solid understanding of existing fish stocks, which we can use to achieve our aim of ensuring productive and sustainable catches. Relevant information is available on an interactive web-based system, which gives fleet operators real-time information about conditions and catch trends. This system also provides processing facilities with relevant information about incoming catches and offers links to distributors and international markets. We also have modern and efficient fish-processing facilities, which could create jobs and contribute to food security. An issue hampering further progress in the fisheries sector is the lack of cooperation between stakeholders, as well as instances of rivalry. This has meant that the significant technological developments that have taken place only benefitted certain pockets of the sector rather than benefitting the sector as a whole."*

The 'Rowing Together' scenario reflects a situation where the actors in the maritime sector work together in an integrated way to make South Africa a maritime nation. However, effort towards this goal is constrained by a lack of innovation, limited uptake of research and poor knowledge management. A labour union leader may say the following in his annual address to the union's members on 4 April 2030:

> *"As a labour union, we are pleased to see the high level of cooperation and integration in the sector. This coordinated approach allows for an effective response to the changing demography in our coastal areas and connected inland areas. The development of primary skills, which is coordinated across the maritime sector and with other sectors, has resulted in increased opportunities for employment and skills development for our members. The coordinated sector voice is also conducive to*

*providing South Africa with a strong position in international negotiations and in response to regionalisation. Since the maritime sector is characterised by good governance, government and investors now have more confidence in the sector than ever before. Unfortunately, I don't only have good news… Our main concern at this point is the very slow uptake of research, the slow rate of innovation and poor knowledge management, all of which continue to constrain economic growth in the sector and have a detrimental impact on job creation. Comrades, the battle is not won yet! More is still needed to put bread on the ordinary worker's table!"*

The 'Full Steam Ahead' scenario represents a utopia for the sector. Under this scenario, the sector is unified in its approach to remaining globally recognised as a leading maritime nation and benefits from the commissioning and resultant uptake of research, high levels of innovation and effective knowledge management. The Minister of Maritime Affairs of another country may reflect on this in her address to that country's Parliament:

*"Honourable members. We may call ourselves a maritime nation, but we lag behind other nations in terms of how we leverage our maritime resources to support social and economic development. Here I will present South Africa as an example of a prosperous maritime nation that has managed to pull its maritime sector together into a coherent whole to support and empower national government and policy. This country's focus on maritime safety and security has led to the effective protection of its maritime resources, an improved level of national security and limited criminal activity in its Exclusive Economic Zone. This has resulted in a safer South African coastline and offshore environment, which has led to greater levels of local, regional and international trade. These impressive developments are also underpinned by very effective support infrastructure and knowledge-sharing systems. The country's coordination of its maritime sector is phenomenal, with relevant information flowing across the sector in a seamless way, leading to high levels of innovation and ultimately strongly supporting economic growth. If you think all of these accomplishments are remarkable, the most remarkable fact of all is that South Africa's maritime sector has managed to achieve all of this in only 15 years, after starting from very humble beginnings. I will now table our strategy to emulate South Africa, so that we can also move forward as a maritime nation!"*

## Conclusion

As already suggested, one of the purposes of developing scenarios for the maritime sector is to identify preferred future outcomes and to assist actors to navigate towards such outcomes through explicit decisions and actions. The drivers of change can be used as indicators (Figure 2 and Figure 3) to assess the current state and the trajectory of change related to the scenario matrix (Figure 4). The path towards the preferred option ('Full Steam Ahead') should be consciously planned and incorporated in government and private sector strategies and plans. Inadequate planning and action should be avoided, as this would likely cause a decline in uptake and collaboration and lead to South Africa ending up in the worst-case scenario ('Lost at Sea'). A push towards technology uptake without sector-wide coordination will take the sector towards the 'Islands of Excellence' scenario, whereas sector coordination without the benefit of innovation will lead to a future of 'Rowing Together'.

A potential way forward for the Maritime Nation scenarios presented in this chapter could be to present them to a wide representation of stakeholders in the sector to obtain further inputs and eventual agreement and 'sign off' on their contents. This would require a key stakeholder in the sector taking ownership of the scenarios and committing to making the time and funding available to finalise them. A communication strategy targeting potential users would subsequently need to be developed and implemented. The revised scenarios could then be used for strategy development, planning and management in the maritime sector.

The first group of potential users of these scenarios is made up of the different government departments that operate in the maritime sector. They would need to be made aware of the scenarios and their implications and they would need to apply their minds to how these scenarios (particularly the desired 'Full Steam Ahead' scenario) can be made relevant to the development of national strategies. The second group of potential users is made up of non-government actors. In this category, researchers would need to be made aware of these scenarios, since they can help detect and report change. Their inputs could then be used to track where the maritime sector is heading in terms of the different scenarios. In addition, members of civil society, non-governmental organisations (NGOs) and communities, have practical experience and awareness of what is happening in the maritime sector and could provide feedback on priorities and trends.

If all of the potential users above are aware of the possible preferred and adverse futures for the maritime sector, this may inspire them to consciously adjust their choices, plans and actions so that they can navigate towards and end up living in the 'Full Steam Ahead' scenario.

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# Part 3

## Current Research and Technology Advances in the Marine Sciences

# Chapter 5 Long-term Marine Research Platforms of the National Research Foundation

*Thomas Bornman, Lara Atkinson, Anthony Bernard, Paul Cowley, Shaun Deyzel, Wayne Goschen, Albrecht Götz, Juliet Hermes, Wim Hugo, Angus Paterson, Charles von der Meden*

## 1. Introduction

South Africa's 3 000 km-long coastline, three large surrounding oceans (the Indian Ocean, the Atlantic Ocean and the Southern Ocean), two contrasting boundary currents (the warm Agulhas Current on the east coast and the cold Benguela Current on the west coast) and the Prince Edward Islands provide an ideal location to study the role of the oceans on weather, climate, biodiversity and socio-economics. The world's oceans play a key role in global change (Beal et al., 2011; Backeberg et al., 2012), thus studying changes in the ocean environment holds the key to deciphering many of the intricate changes in our natural world.

The Ten-year Innovation Plan for South Africa of the Department of Science and Technology (DST) identifies five key Grand Challenges for the National System of Innovation (NSI) over the next decade (DST, 2009). One of these Grand Challenges in science and technology is the response to global change. This Grand Challenge has two main aspects: enhancing scientific understanding of global change, and developing innovations and technologies to respond to global change (DST, 2009). South Africa is well positioned to lead research on the continent in terms of understanding and projecting changes to the marine environment, the impact of these changes and mitigation to limit their long-term effects. Mitigating climate change also provides an economic opportunity for South Africa – the Blue Economy (DST, 2009).

The mandate of the National Research Foundation (NRF) is to support and promote research through funding, human resource development and the provision of research facilities. One of the strategic goals of the NRF is to provide cutting-edge research, technology and innovation platforms. This is achieved through the provision of state-of-the-art research platforms and specialised research capacity at its national facilities. The two national facilities that have a marine mandate are the South African Environmental Observation Network (SAEON) and the South African Institute for Aquatic Biodiversity (SAIAB).

A platform can be defined as a unique set of skills and/or infrastructure that is made available to the broader research community within the NSI. These platforms support research areas of strategic importance and provide researchers and research institutions with access to 'big science' equipment. It is through the national facilities of the NRF that South Africa can compete and cooperate with international counterparts. The South African Research Infrastructure Roadmap, developed by the DST in 2013 (Wood et al., 2013), defines research infrastructure (RI) as "facilities, resources and services used by the scientific community across all disciplines for conducting cutting-edge research for the generation, exchange and preservation of knowledge. It includes major facilities, equipment or sets of instruments, collaborative networks and knowledge-containing resources, such as collections, archives and data- and biobanks. RI may be 'single-sited', 'distributed' or 'virtual'." The road map further states that a national RI is a service to research that does the following:

- Awards free open access to users selected through a world-class peer-review competition
- Asks the users to publish/share their results in the public domain

- Manages access for proprietary and/or training activities
- Has a clear national priority

(Wood et al., 2013)

The mandate of SAEON's two marine nodes (Elwandle Coastal Node based in Grahamstown and Egagasini Offshore Node based in Cape Town) is to establish and maintain state-of-the-art observation systems, to drive and facilitate research on long-term change in South Africa's coastal and offshore marine ecosystems, to develop and maintain collections of accurate, consistent and reliable long-term environmental databases, to promote access to data for research and evidence-based decision-making, and to contribute to capacity-building and education in environmental sciences.

SAIAB's mandate is to provide a national institutional platform to develop human skills and capacity to conduct and promote world-class research on the biodiversity of African aquatic ecosystems to conserve and manage the resources effectively for the benefit of the people of South Africa. SAIAB also manages the African Coelacanth Ecosystem Programme (ACEP), a DST/NRF flagship programme that provides marine research platforms to the marine science community on the east coast of South Africa. The platforms include access to an open competitive research call, the Phuhlisa Programme (a dedicated transformation initiative) and marine infrastructure.

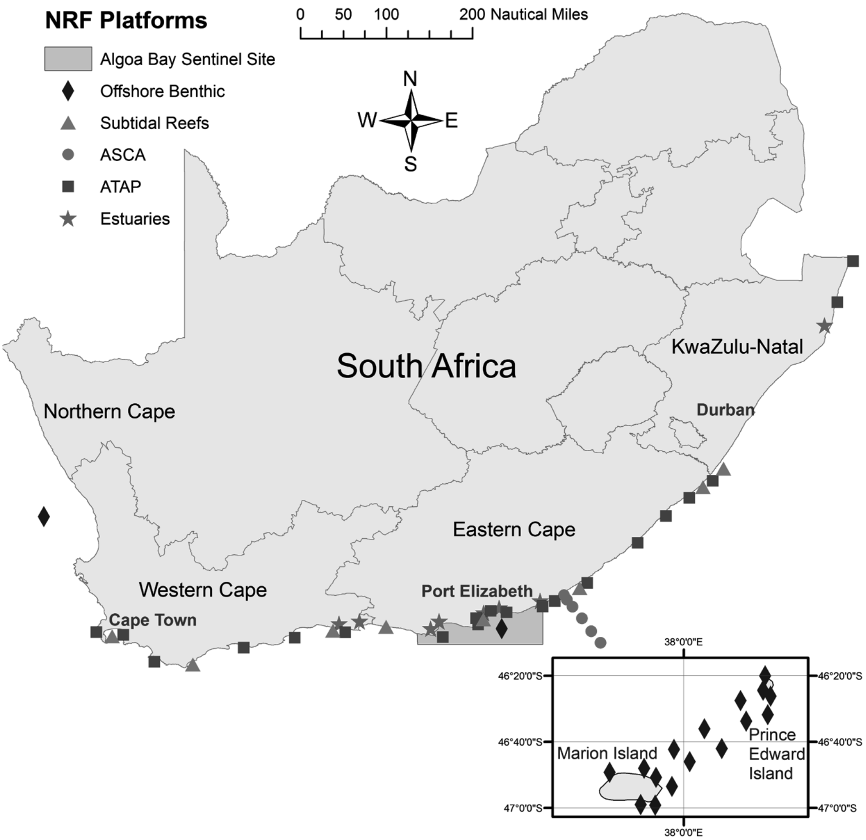


*__Figure 1:__ Marine research platforms of the NRF (Prince Edward Islands shown in the insert).*

This chapter highlights the following unique marine research platforms that the NRF provides to the broader research community in South Africa (see Figure 1):

- Continuous observation platforms for long-term ecological research (LTER) in Algoa Bay (*in situ* coastal environmental moorings, coastal pelagic ecosystem LTER and the Agulhas System climate array)
- The National Acoustic Tracking Array Platform
- National Subtidal Reef Ecosystem platforms
- National Offshore Deep Benthic platforms
- An information management platform

## 2. Discussion

### 2.1 Continuous observation platforms for LTER in the Algoa Bay Sentinel Site

#### 2.1.1 *In situ* coastal environmental moorings

**Research questions**

Understanding how global change will alter the coasts and oceans of South Africa requires many elements of the different ecosystems to be monitored. However, because long-term monitoring is very expensive, collecting data for the entire South African coastline (some 3 000 km) is not feasible. Sentinel sites, situated at key locations, are an alternative option, and can provide insight into real-time changes associated with global change. Algoa Bay, on the Eastern Cape coastline, is the first such sentinel site in the South African coastal environment. In a few short years, the Algoa Bay Sentinel Site Observation Network has become the most wide-ranging in Africa, arguably in the southern hemisphere. The monitoring effort, invested in by the DST and NRF through two national research facilities, SAEON and SAIAB, delivers long-term reliable data for scientific research and policy formation by decision-makers. Developing appropriate environmental policies will be crucial when implementing mitigation strategies against impacts of climate and global change in our coastal zone. There are two aspects to the Algoa Bay Sentinel Site initiative: to establish a sustained long-term monitoring platform within key areas of the coastal waters between Port Alfred and Oyster Bay, and to facilitate detailed, short-term, hypothesis-driven research projects principally conducted by collaborating universities and other research institutions. The long-term data sets were thus envisaged not only to contribute to SAEON's mandate to detect, understand and predict environmental change in South Africa, but also to augment data collected by short-term hypothesis-driven research projects.

The long-term monitoring component of the Algoa Bay Sentinel Site consists of two operational thrusts: the Continuous Monitoring Platform (CMP) that focuses on the physical oceanography of the coastal waters, and the Pelagic Ecosystem Long-term Ecological Research Platform (PE-LTERP) that collects specific physical, chemical and biological data in the long term. The primary objective behind the development of the CMP is to create a coastal observatory platform of suitable spatial coverage, delivering useful physical oceanographic data of sufficient quality to monitor changes in thermal structures and current profiles in the long term.

**Techniques and equipment**

Between SAEON, SAIAB, the Council for Scientific and Industrial Research (CSIR), the South African Navy Hydrographic Office (SANHO), the South African Weather Service (SAWS) and the Department of Water Affairs (DWA), more than 190 *in situ* sensors have been deployed in Algoa

Bay and St Francis Bay (see Figure 2). Sensors measure weather variables, river flow, salinity and temperature in the estuaries, sediment deposits, sea level, ocean currents, waves, ocean temperature, oxygen, pH, salinity, photosynthetic active radiation, fluorescence and turbidity. The data that is produced has already directly benefitted multiple student research projects from Rhodes University (RU), the Nelson Mandela Metropolitan University (NMMU), the University of Cape Town (UCT) and the University of Fort Hare (UFH), as well as long-term studies coordinated by other institutions, including Bayworld, NMMU, SAIAB and UCT. The following six types of observatories are currently maintained by SAEON:

- Acoustic Doppler current profiling (ADCP)
- Underwater temperature recorder (UTR) arrays
- Gully temperature probes (GTPs)
- The moored SeaBird (conductivity/temperature/depth (CTD)) recorder
- Conductivity/temperature (CT) sensors
- Rod sediment elevation tables (RSETs)

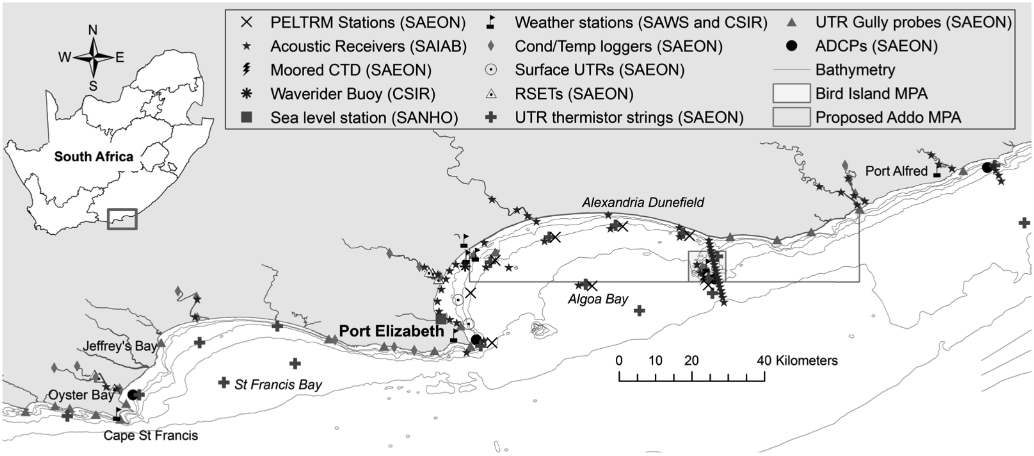


***Figure 2:*** *The Algoa Bay Sentinel Site Observation Network.*

## Acoustic Doppler current profilers

***Plate 1:*** *A SAEON diver conducting routine maintenance on a deployed ADCP (image by Dylan Howell).*

Teledyne ADCPs (Sentinel Work Horse 600 KHz) are moored on the seabed and measure speed and the direction of currents through the water column (at preselected depths) of up to 30 m. Measurements are made every 20 minutes for between six and eight months at a time. The positions of deployments were selected to measure the movement of water into and out of Algoa Bay at its eastern (Bird Island) and western (Cape Recife) perimeters. ADCPs require occasional maintenance to be carried out by certified Commercial Class IV scuba divers from

SAEON's Research Dive Unit (see Plate 1). For this reason, ADCP deployments are presently limited to depths no deeper than the legal operational dive limit of 30 m. Routine maintenance and data recovery is carried out approximately every six months. SAEON and SAIAB are in the process of acquiring additional ADCPs to expand the network alongshore and offshore.

### Underwater temperature recorder arrays

Seventeen UTRs are deployed at selected sites in the Algoa Bay Sentinel Site to monitor spatial (vertical and horizontal) and temporal changes in water temperature. There are 10 UTRs situated in Algoa Bay, of which seven are deployed at 30 m depths, one at 60 m and two at 80 m (see Figure 2). A typical UTR consists of several Onset HOBO U22 Water Temp Pro v2 data sensors attached to an appropriate length of polysteel rope (12 mm in diameter) anchored to the seabed by segments of wide-gauge railway line and buoyed up by 14-inch submersible trawl buoys. All UTRs extend vertically from the bottom of the water column to the subsurface at 10 m-depth intervals over most of the depth, but at 5 m intervals near the surface. Seawater temperature is recorded at one-hour intervals for longer than six months at a time. Those UTRs located in waters considered unsafe for scuba diving are fastened to the anchor system with a SubSea Sonics acoustic releaser. An acoustic releaser allows an operator to remotely detach the thermistor string and floatation device from the anchors. Those not on acoustic releasers are retrieved by SAEON's Research Dive Unit. Units are replaced within the hour of retrieval to ensure that synchrony of data records is maintained.

An example of the use of the Algoa Bay Sentinel Site data is in the study of the influence of the Agulhas Current on coastal waters. The Agulhas Current impacts on the waters of Algoa Bay by the onshore movement of plumes attached to the leading edge of large meanders and Natal Pulses (very large episodic meanders occurring on average 1.6 times per year (Rouault and Penven, 2011)) in the Agulhas Current. Plumes and warm water filaments occasionally penetrate into the bays where they increase nearshore sea temperatures and cause currents to change speed and direction (Goschen and Schumann, 1994). The penetration of these large meanders towards the shore has recently been associated with cold water events in Algoa Bay that last for several weeks (Goschen et al., in prep.) (see Figure 3). The cold bottom water is driven up the continental shelf edge and over the edge by interactions of the Agulhas Current and bottom topography (Ekman veering and divergence from the coastline). This cold upwelled water may also break the surface along the inshore boundary of the Agulhas Current (Lutjeharms at al., 2000). It keeps the bottom layers on the shelf replenished with cold water and provides the source of cold water for coastal wind-driven upwelling.

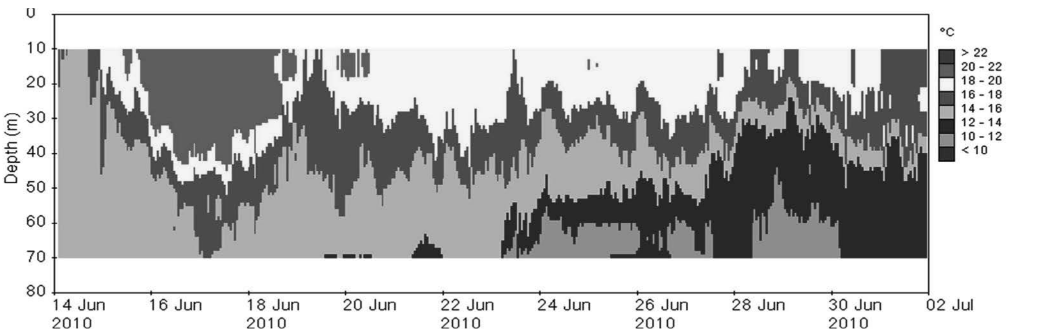


***Figure 3:*** *An example from one UTR mooring showing Agulhas Current-driven upwelling (purple and blue) in Algoa Bay during a Natal Pulse. The shoreward intrusion of a warm surface plume attached to the leading edge of the meander is shown in red. [See colour figure on page 308.]*

**Gully temperature probes**

A series of GTPs are deployed nearshore in water rarely exceeding 5 m in depth. The system is simple in design, consists of a single HOBO® U22 Water Temp Pro v2 temperature sensor fastened to a 0.5 m length of railway line. Each GTP is carefully hidden in a submerged gully associated with an accessible rocky shoreline. Seawater temperature is recorded hourly for six to twelve months at a time. Thus far, GTPs have been deployed at 24 sites between Port Alfred and Storms River (see Figure 2). The SAEON GTP network contributes significantly to our understanding of temperature responses to upwelling and Agulhas Current intrusions in the nearshore. The SAEON GTP data was also included in a publication by Smit et al. (2013) that highlighted the need for a national coastal temperature network. SAEON is planning to extend the GTP network in 2014 to fill the gaps in the national array of temperature recorders.

**Moored SeaBird CTD recorder**

A moored SeaBird CTD recorder has the unique function of recording a suite of hydrological measurements on a continuous basis for up to three months at a time. The SeaBird SeaCAT SBE 16plus V2 moored recorder measures temperature, conductivity, pressure, dissolved oxygen, pH, turbidity, fluorescence and photosynthetic active radiance. Four measurements are logged every second. The entire mooring system comprises three 1 m-wide gauge railway lines (ca. 50 kg each) used as anchorage, 12 mm diameter polysteel rope and a double flotation system (14-inch submersible fishing buoys) to ensure that the CTD is always kept vertical and off the seafloor. The fully assembled mooring extends 3.5 m from the seafloor and is deployed near Bird Island (see Figure 2).

**Conductivity/temperature sensors**

SAEON, in consultation with estuarine scientists and in collaboration with DWA (Resource Quality Services), is currently monitoring 12 estuaries. Multiple CT sensors have been deployed in seven of these estuaries: Knysna, Keurbooms, Kromme, Gamtoos, Swartkops, Kariega, Mbashe and St Lucia/Mfolozi. SAEON currently makes use of HOBO® U24 CT sensors (U24-00x), but to standardise with the Department of Agriculture, Forestry and Fisheries (DAFF) and the Department of Environmental Affairs (DEA), these sensors will be phased out and replaced with Star-Oddi DST CT salinity (conductivity) and temperature sensors in the near future. SAEON has also deployed CT sensors in supratidal pools for the long-term monitoring of recently discovered stromatolites in the Algoa Bay Sentinel Site as part of a multidisciplinary, multi-institutional research project involving three South African Research Chairs Initiative (SARChI) scientists from NMMU and RU.

**Rod sediment elevation tables**

Precise, non-destructive measures of sediment elevation in coastal wetlands are necessary to determine rates of elevation change, particularly relative to a rise in sea level, and to gain an understanding of the processes responsible for elevation change. Precise measurements (within 1 mm) of sediment elevation in the intertidal salt marsh (*Spartina maritima* zone) of four South African estuaries (Swartkops, Kromme, Keurbooms and Knysna) are being made relative to a fixed subsurface datum using an RSET (Cahoon et al., 2002). Long-term monitoring using RSETs provides a time series of the integrated effect of surface and below-ground processes on sediment elevation. Repeated measurements of elevation are taken at nine points on eight different fixed orientations at each station (nine stations per estuary).

This amounts to 5 832 measurements every year per estuary. Initial results from the first four years indicate that the lower and middle reaches of the studied estuaries are not accreting at the same rate as eustatic sea-level rise.

***Plate 2:*** *CT string ready for deployment in the Kromme Estuary (image by Tommy Bornman).*

***Plate 3:*** *RSET measurements taken by SAEON students in the Swartkops Estuary in 2014 (image by Tommy Bornman).*

## Research and infrastructure gaps

Results from the Algoa Bay Sentinel Site will only be applicable to the Agulhas Bioregion and it is therefore imperative that the sentinel site approach be expanded to the other bioregions in South Africa: the KwaZulu-Natal, South Western Cape and Namaqua Coastal bioregions, as well as the South-Western Indian Offshore and Atlantic Offshore bioregions.

Current research gaps include *in situ* measurements of ocean acidification, deep coastal ADCPs (between 30 m and 100 m) and offshore (> 100 m) instrumentation. The current network of subsurface *in situ* equipment does not provide real-time or near-real-time data either. Real-time data acquisition is useful as it can be used as an early warning system. To obtain data in real time will require the deployment of surface moorings. Surface moorings provide an additional opportunity to collect climatic data out at sea, but they are prone to vandalism and subject to storm damage (they must be engineered with a 9 m winter swell in mind) and collisions with surface vessels. Real-time surface moorings are also costly to acquire and maintain (requiring a large research vessel to service the equipment regularly).

To meet the needs of the research community, the existing research platform of one coastal research vessel and instrumentation needs to be expanded with at least two additional fully equipped research vessels (Wood et al., 2013). This will make allowance for one vessel to be stationed in Durban to service the needs of research conducted essentially along the KwaZulu-Natal coast. The existing vessel, stationed in Port Elizabeth, will be available for research on the south-eastern and southern Cape coast, with a further vessel stationed in the Cape to service research conducted on the coastal waters around the Cape and along the West Coast (Wood et al., 2013). Ideally, both additional research vessels should be somewhat larger than the existing vessel (more than 15 m) in order to increase the capacity to carry a larger selection of standard marine research instrumentation, including the capability of conducting marine geological and geophysical surveys (Wood et al., 2013).

### 2.1.2 Algoa Bay Coastal Pelagic Ecosystem LTER

**Research questions**

The PE-LTERP forges multiple collaborations between national facilities (SAEON and SAIAB) of the NRF and higher education institutions (HEIs). The PE-LTERP amalgamates multiple short-term research projects, lead by HEIs, with a sustained long-term physical and biological oceanographic research and monitoring platform, coordinated by SAEON and supported by SAIAB (through the provision of research vessels and skippers). Data from this programme also benefits municipal managers, environmental practitioners and conservation planners.

The key objective of the PE-LTERP is to provide a sustainable stream of quality oceanographic and lower trophic-level data over a long time-scale to develop an understanding of the following:

- Species diversity of phytoplankton and zooplankton and how it compares to other coastal areas for which complementary data exists
- Key spatio-temporal processes in Algoa Bay so that any future deviations from such trends can be measured in relation to potential changes in the environment
- The physical and chemical drivers of phytoplankton and zooplankton
- Nutrient dynamics (sources and fluxes) and how it influences primary productivity in space and time
- Phytoplankton dynamics and how it influences zooplankton dynamics in space and time
- The extent to which coastal upwelling, estuaries, river floods, coastal islands and anthropogenic impacts drive the ecosystem dynamics in Algoa Bay

**Techniques and equipment**

Physical, chemical and biological variables are sampled monthly by boat at eight sites distributed between Cape Recife and Bird Island in Algoa Bay (see Figure 4).

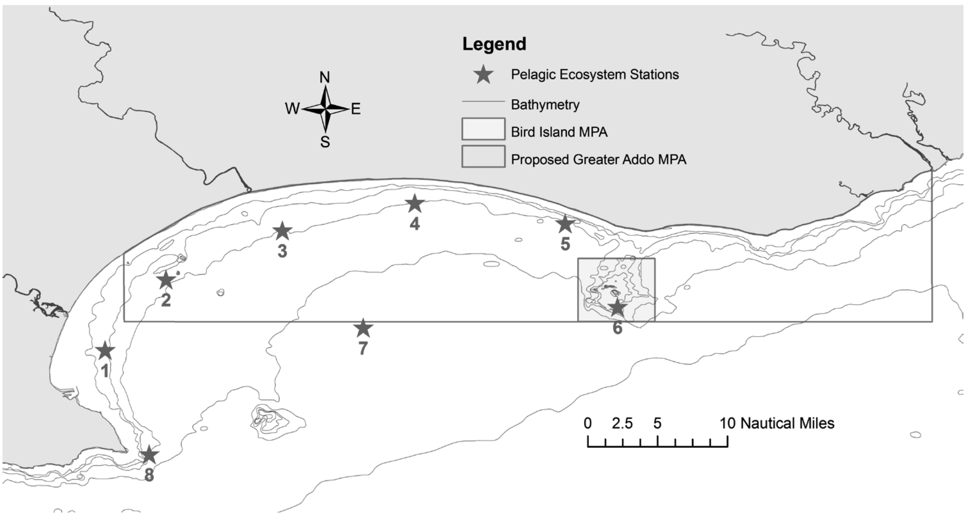


***Figure 4:*** *Map showing the location of eight PE-LTERP monthly sampling sites in Algoa Bay.*

## Physical variables

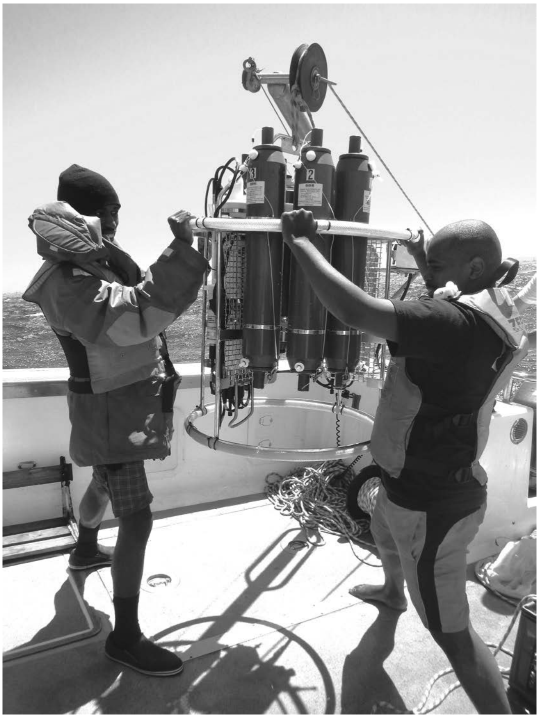

***Plate 4:*** *SeaBird CTD carousel being deployed off the research vessel* uKwabelana *(image by Shaun Deyzel).*

At each site, the water column is profiled with a SeaBird 19plusV2 CTD SBE 55 carousel. The SBE 55 carousel (see Plate 4) holds six Niskin bottle water samplers enabling collections from discrete depths. Measurements of temperature, conductivity/salinity, depth, dissolved oxygen, chlorophyll, pH and turbidity are recorded four times every second on a single down-and-up cast.

## Water chemistry

Three replicate water samples are collected for nutrient analysis from the water surface (0.1 m) at 10 m (most often the chlorophyll maximum) and ca. 30 m depth at all sites. At Site 7, samples are also collected from ca. 60 m (bottom) (see Figure 3). Samples are filtered onboard through GF/F filters and stored until being analysed later that evening at NMMU. Ammonium, nitrate, nitrite, soluble reactive phosphorous and silicate concentrations are measured using the methods of Griess (1879), Ilosvay (1889), Solórzano (1969) and Strickland and Parsons (1972).

## Phytoplankton biomass and species composition

Three replicate water samples (500 ml) are collected from the same depths as discussed above and filtered through GF/F filter paper to determine the total chlorophyll-*a* concentration (an indication of biomass). Chlorophyll-*a* concentrations and productivity are also determined onboard using a Waltz Phyto-PAM. Species composition is determined by towing a 30 cm diameter plankton net (80 $\mu$m mesh) just below the surface for three minutes at a speed of two knots. To account for any species that avoids surface waters, a second sample is collected by vertically hauling the net from the bottom to the surface. All samples are preserved in 2% glutaraldehyde, and species composition is determined using both light and scanning electron microscopy at NMMU.

## Zooplankton biomass and species composition

Zooplankton is sampled using a modified WP2 plankton net with a 57 cm mouth diameter and fitted with a 2 m-long plankton net (90 $\mu$m mesh aperture). The water volume filtered is calculated using a single one-way clutch General Oceanics mechanical flowmeter (model 2030R6) fastened centrally across the opening of the net. Three replicate semi-vertical hauls are made per site from approximately 5 m above the seafloor to the surface.

Samples are preserved on site with 10% formalin (seawater diluted). In the laboratory, the total catch is subjected to a 50% division using a Motodo plankton splitter (Motodo, 1959) to determine biomass and composition/abundance respectively. Biomass is determined by concentrating zooplankton onto a pre-weighed filter for drying at 60° C for 24 hours. The derived dry weight is then rendered to a final quantified expression of biomass, i.e. the milligram of dry mass per cubic metre of water (mg DM m-3). The remaining portion (50% split) is used for counting and identifying species to the lowest taxonomic level possible.

**Research and infrastructure gaps**

The scope for expansion of the temporal resolution of sampling, as well as the sampling of episodic events, is limited due to the high demand on the current research vessels during good weather/sea days. Additional fully equipped research vessels, stationed strategically along the South African coastline, are required to maximise the research effort during the few days that conditions are favourable.

### 2.1.3 Agulhas System climate array

**Research questions**

Sustained observations in the Greater Agulhas System have been identified as a priority area by the South African government through the DST's Global Change Grand Challenge and SAEON's Science Plan. In addition, international and regional programmes, such as the CLImate VARiability and Predictability of the Ocean Atmosphere System/Global Ocean Observation System (CLIVAR/GOOS) through the Indian Ocean Panel (IOP), as well as the Agulhas Somali Current Large Marine Ecosystem (ASCLME), have recognised the need for baseline measurements of climate change in the oceans off south-east Africa.

There are many scientific merits for sustained measurements in the Greater Agulhas System, relating to both regional impacts on the oceans and climate, as well as global-scale feedbacks on climate change. These are highlighted below:

- The large atmospheric moisture source of the warm Agulhas Current fuels storminess and rainfall over the African continent. Storms can cause infrastructure damage and rainfall effects subsistence farming and larger-scale crop productivity, with direct ramifications for hunger and poverty in the rural regions of south-east Africa. (Walker and Mey, 1988; Jury et al., 1993; Lutjeharms and De Ruijter, 1996; Crimp et al., 1998; Lee-Thorp et al., 1999; Reason, 2001; Reason, 2002; Rouault et al., 2002; Schouten et al., 2002; Rouault et al., 2003; Nakamura and Shimpo, 2004; Palastanga et al., 2006; Gimeno et al., 2010).
- Ocean and climate models need *in situ* observations for verification. In a highly variable and eddying regime like the Greater Agulhas System, robust long-term data is crucial to verify models and climate predictions. Such models are essential for a better understanding of processes in the system and provide forecasts, which are readily used by policy-makers.
- The East African countries that border the Greater Agulhas System, including South Africa, are vulnerable to degradation of their marine resources and fisheries, and to severe weather systems. They would benefit from sustained observations of the Agulhas, which directly impacts on their coastal zones. Such data will improve regional ocean and weather forecasting and preparedness.

- Variability in the path and strength of the Agulhas Current is linked to coastal upwelling, marine productivity and fisheries along the east coast of South Africa and over the Agulhas Bank (Roberts et al., 2010). For instance, the size of the coastal fish catch during the Natal sardine run is thought to be affected by Agulhas meandering (Van der Lingen et al., 2010).
- On a larger scale, the Greater Agulhas System is linked upstream to tropical climate modes, such as Indian Ocean Dipole (IOD) and El Nino Southern Oscillation (ENSO), and downstream with the strength of the Atlantic overturning circulation, making it an effective link between the Pacific, Indian and Atlantic tropical arrays and the conditions in the Southern Ocean (Gordon, 1986; Weijer et al., 1999; Beal et al., 2011; Van Sebille et al., 2011; Le Bars et al., 2014).

Climate change projections predict substantial changes in the Agulhas region, including the warming and strengthening of the Agulhas Current, increased leakage of Agulhas waters into the South Atlantic and increased heat input into the Southern Ocean (Beal et al., 2011). A warmer Agulhas Current could lead to increased storminess over the African continent and a collapse of local fisheries. Increased leakage into the Atlantic Ocean could have feedbacks on the climate system through changes in the Atlantic meridional overturning circulation, whereas increased heat input into the Southern Ocean could make the effect of climate change in this ocean more pronounced (Beal et al., 2011).

## Techniques and equipment

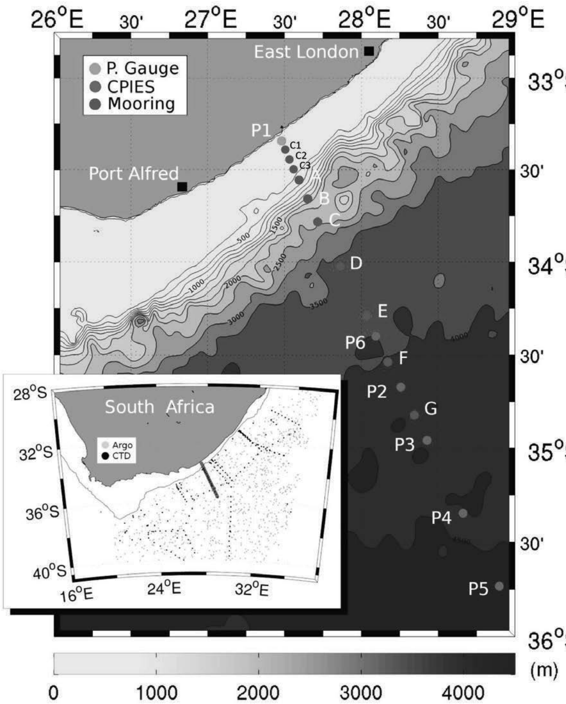


*__Figure 5:__ The proposed Agulhas System climate array off East London.*

Early in 2015, SAEON, along with national (DEA, UCT, Cape Peninsula University of Technology (CPUT) and NMMU) and international (Rosenstiel School of Marine and Atmospheric Science, University of Miami and The Royal Netherlands Institute for Sea Research) partners, will begin an initial five-year observation programme in the Agulhas Current. The observational system will comprise a mooring array across the Agulhas Current off East London (see Figure 5). The array will consist of ten full-depth current meter (CM) moorings and nine current- and pressure-recording inverted echo sounders (CPIESs), deployed across the width of the Agulhas Current out to 300 km offshore. The array will provide measurements of both the strength (volume transport) and heat transport of the full Agulhas Current, from the surface to the seabed, as well as their variability over time-scales from daily to inter-annually, and eventually once a decade.

**Research and infrastructure gaps**

Deploying and maintaining the Agulhas System climate array (ASCA) will require access to ship days on a suitable research vessel that can deploy and retrieve deep moorings, as well as conduct basic oceanographic sampling. Access to research vessels and available ship time remains problematic.

Given that observations in the marine offshore environment are costly and often restricted in both space and time, numerical ocean modelling capacity has grown significantly in South Africa over the past 10 to 15 years. However, models are still unable to correctly resolve the complexities of the oceans around South Africa, in particular. The Greater Agulhas System and modelling in the Southern Ocean are still in their infancy in South Africa. It is therefore vital that such long-term observational studies work hand in hand with numerical model studies. SAEON is involved in various modelling work in the Agulhas and its source regions, the Benguela and, more recently, expanding into coastal modelling to investigate the impact of the offshore environment on our coasts and resources.

## 2.2 The National Acoustic Tracking Array Platform

**Research questions**

SAIAB prides itself as a centre of excellence in acoustic telemetry research in South Africa, with over a decade of experience in this research field. The advancement of acoustic telemetry knowledge in South Africa has resulted in the emergence of SAIAB as a leading partner of the Canadian-based Ocean Tracking Network (OTN) project. The OTN is an international platform that unites scientists across the globe to comprehensively examine the local-to-global movement of tagged marine animals and to better understand the ever-changing environment in which they live. In collaboration with the OTN, the local Acoustic Tracking Array Platform (ATAP) was established under the auspices of SAIAB.

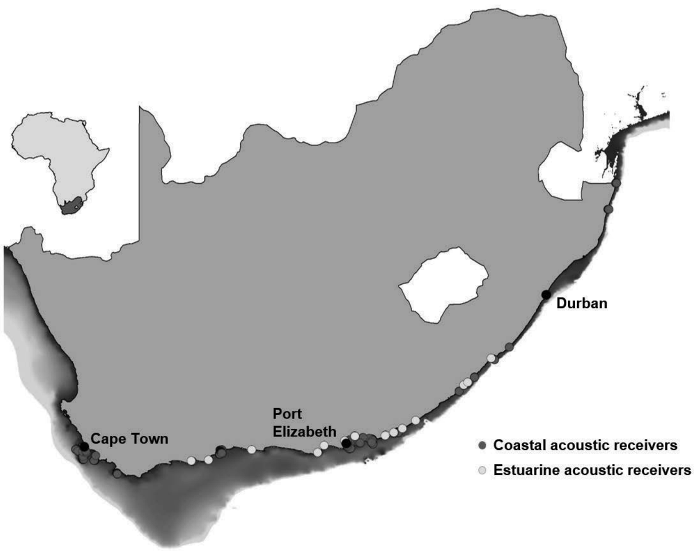


***Figure 6:*** *ATAP network in South Africa (image by Taryn Murray and Amber Childs). [See colour figure on page 308.]*

The ATAP is a collaborative research platform that provides a service to the greater marine science community by monitoring the movement and migration of inshore marine animals through the use of acoustic telemetry technology. This form of biotelemetry involves the tracking of aquatic animals through the transmission and reception of sound signals.

## Techniques and equipment

Fish are equipped with electronic transmitters or tags that emit unique signals that can be detected by a hydrophone attached to a data-logging acoustic receiver. When a tagged fish swims into the reception range of an acoustic receiver, the date, time and unique identification code of the transmitter are recorded and saved. This technology allows researchers to remotely track the continuous movement of fish in their natural habitat, thereby providing a comprehensive understanding of their behaviour. The simultaneous collection of environmental data also provides insight into the physical and biological factors that influence their movement.

***Plate 5:*** *Acoustic receiver mooring (image by Ryan Daly).*

The ATAP provides a nationwide research platform through an expanded network of stationary acoustic receivers that are moored to the ocean floor and in estuaries around the South African coastline. Since the launch of the OTN project in South Africa in August 2011, acoustic receivers have been deployed at monitoring sites from Hout Bay on the West Coast to Ponta do Ouro in Mozambique (see Figure 6). Receivers have also been deployed in selected estuaries to facilitate studies on the habitat connectivity of estuarine-associated animals (see Figure 6). The national network of receivers is maintained by SAIAB and its local collaborating partners, and the data is stored on a national database and at the OTN headquarters at Dalhousie University, Canada. The metadata on tagged animals is shared to ensure that any data collected on the ATAP network or any other privately owned receiver is made available to the researcher concerned (data owner).

Current research is focused on large predatory sharks and important coastal fisheries species. There are several multi-institutional collaborative projects currently benefitting from the expanded network of acoustic receivers in South African waters. These projects involve no less than 18 research institutions and over 70 scientists who have surgically equipped a host of species, including great white sharks, Zambezi sharks, ragged tooth sharks, seven-gill cow-sharks and bony fishes such as dusky kob, leervis, white steenbras and spotted grunter, with long-life acoustic transmitters.

The outcomes of the ATAP are expected to improve our knowledge of the spatial ecology of several conservation icon species, identify the environmental and biological factors that trigger marine animal movement and migration, acquire data for the improved management of over-exploited fisheries species and gain an understanding of shared fishery stocks and movements of whale sharks and manta ray (tourism species) between South Africa and Mozambique.

In addition, the ATAP endeavours to improve knowledge on shark-human interactions to improve bather safety. The recent spate of shark attacks (ten attacks, of which eight were fatal) at Second Beach, Port St Johns, has led to the initiation of a collaborative project between the KwaZulu-Natal Sharks Board and SAIAB. It has been suggested that the freshwater-dominated Mzimvubu Estuary in Port St Johns is an important aggregation area for Zambezi sharks. This project aims to monitor the localised movement of these and other shark species to investigate the causes of attacks and potential solutions to mitigate future attacks.

**Research and infrastructure gaps**

Logistical support in the form of manpower, access to boats and the provision of mooring anchors are provided by the ATAP partners at each of the deployment sites. The gaps in the ATAP network (see Figure 6) are largely due to a lack of partners or limited resources in those areas. Additional deployments along the KwaZulu-Natal coastline are, however, imminent. Funding to maintain the ATAP network is currently provided by the Save Our Seas Foundation and the ACEP.

## 2.3 National Subtidal Reef Ecosystem platforms

It is recognised globally that the marine environment is under extreme pressure to support the expanding human population. The cumulative impact of fisheries (from commercial fleets to the lone shore angler) has been identified as the greatest threat to the marine environment in South Africa (Sink et al., 2012). With the increasing recognition that fish populations are struggling under the weight of human need, research on subtidal reefs and the fish populations they support is needed now more than ever. In recent years, technological advances have led to innovative approaches to collect exploratory and quantifiable photographic and video data that has enabled ecologists to describe finer-scale patterns of reef ecosystems in both deep and shallow waters (Murphy and Jenkins, 2010; Mallet and Pelletier, 2014). This has the potential to advance our ability to understand reef ecosystems and design informed management plans to mitigate the impacts of human disturbance (Mallet and Pelletier, 2014).

**Research questions**

The current subtidal reef research focus areas are broad and include studies into sampling and analytical methodologies, fine- and large-scale patterns in biodiversity, ecology, trophodynamics and the impacts of climate change, fisheries, conservation and protected areas on the viability of reef fish populations and ecosystems.

**Techniques and equipment**

### Remote underwater stereo-video systems

Baited remote underwater stereo-video systems (stereo-BRUVs) are one of the most cost-efficient ways to monitor reef fish populations from just beyond the surf zone to depths in excess of 1 000 m

(Watson et al., 2009; Mcilwain et al., 2011; Harvey et al., 2012; Langlois et al., 2012; Zintzen et al., 2012). In South Africa, many reef fish species occupy broad depth ranges (> 100 m) with juveniles found on the shallow coastal reefs and adults on the deeper reefs of the continental shelf (< 200 m) (Mann, 2013). Stereo-BRUVs are an ideal standardised monitoring tool that is benign and causes little disturbance to the fish or the habitat, making it suitable for research on vulnerable populations and in marine protected areas (Murphy and Jenkins, 2010).

The beauty of the technique is its simplicity. It consists of a metal framework containing two standard video cameras in housings orientated to provide an overlapping field of view (see Figure 7). The overlapping field of view facilitates stereo vision and allows for accurate length measurement of the fish present in the videos. The stereo-BRUVs are deployed on the seafloor where they record the fish assemblages that are drawn to the bait, as well as habitat information. The systems are linked to the sea surface by a rope and buoy system, and multiple stereo-BRUVs can be deployed at the same time. The subsequent video processing is labour intensive, but large quantities of data (e.g. species richness, abundance, size, morphometrics and behaviour) can be extracted, and because the videos are recorded and stored, quality control can be implemented to mitigate observer biases. This makes the stereo-BRUVs a powerful tool to collect reef fish population data (see Plate 6) and provides the foundation to support and adapt current and future marine conservation and management policies.

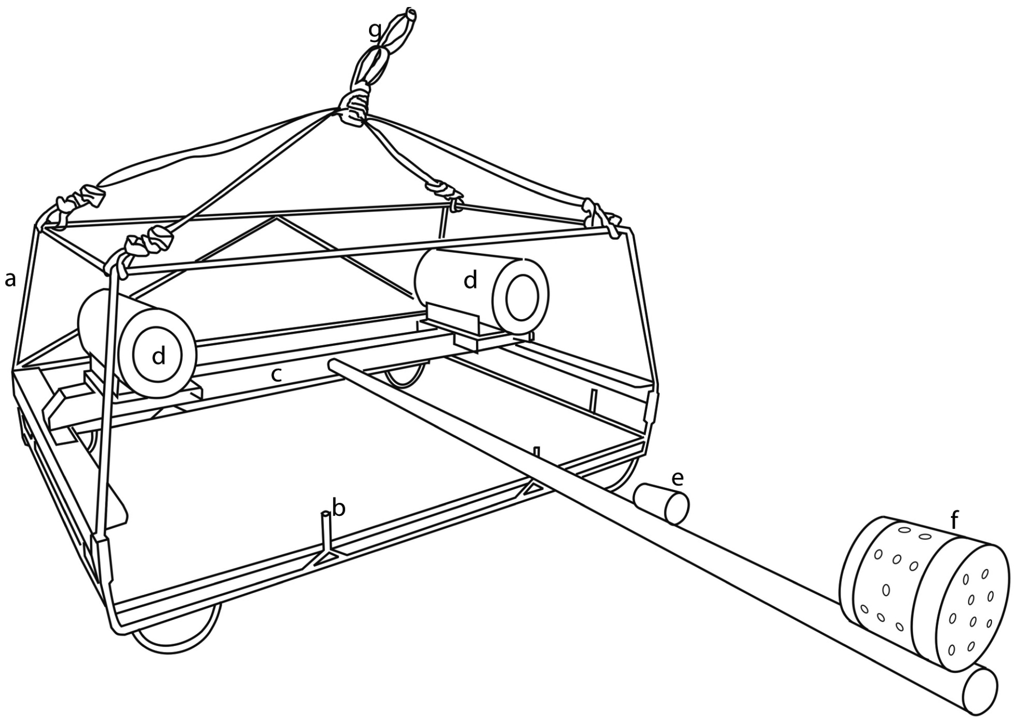


***Figure 7:*** *Illustration of a stereo-BRUV (image by Elodie Heyns).*

***Plate 6:*** *Typical reef fish community occurring on the rocky reefs along South Africa's southern coastline (image by Steve Benjamin).*

### Drop cameras

Reef invertebrates, such as corals, sponges and sea fans provide habitat, shelter and food for most of the over-exploited marine fish species in South Africa. Despite their dominant role in reef ecosystems (Choat and Ayling, 1987), reef invertebrates have received little attention in monitoring programmes that are the most important source of information to adequately and sustainably manage South Africa's marine resources (Pikitch et al., 2004). This is mainly due to the relative inaccessibility of reef habitats and a lack of cost-efficient methodological approaches that can be easily standardised throughout the scientific community, and the multitude of reef habitats and depth ranges.

With the recent improvements in digital camera quality, size and associated costs, photographic systems have become the preferred, cost-efficient approach to monitor reef invertebrates (Van Rein et al., 2001). Such systems may consist of downward-pointing (vertically mounted) small digital cameras in sturdy deep-water housings and lights mounted on a frame heavy enough to be lowered through the water column and prevailing currents onto the seabed. Here, these 'drop cameras' record standard-sized photographs of the encrusting invertebrates that can later be analysed quantitatively with the help of customised computer software. However, erect or tree-like growing invertebrates like sea fans, which can form extensive 'underwater forests' (see Plate 7), cannot be assessed quantitatively from such vertical photographs.

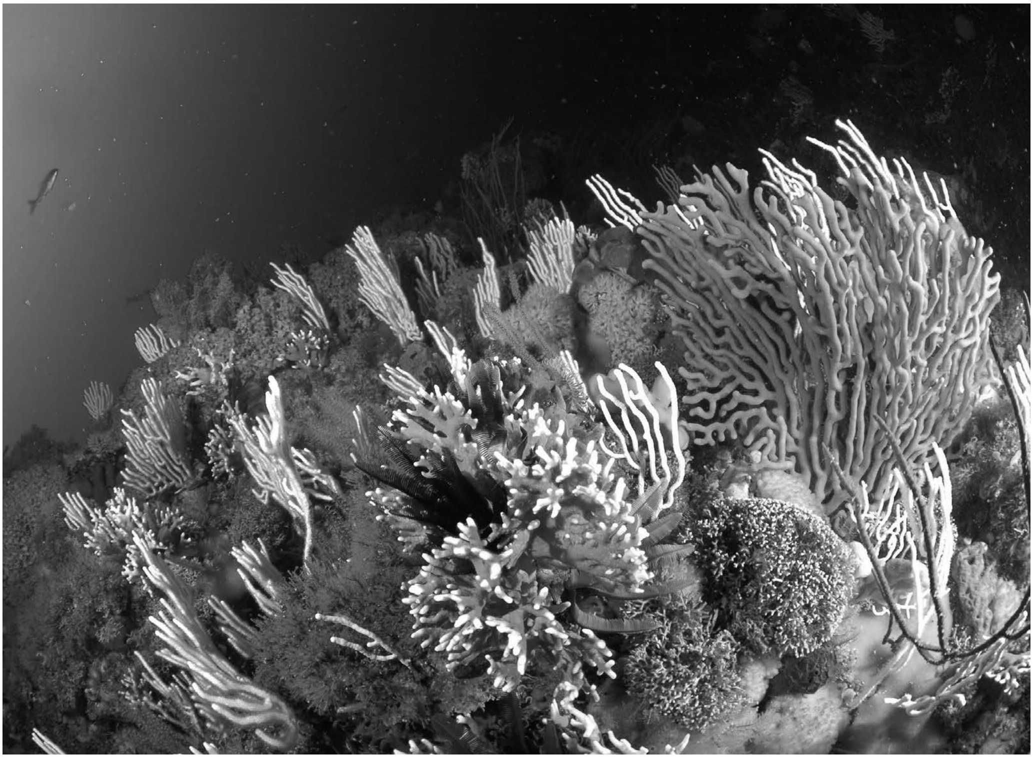

***Plate 7:*** *An 'underwater forest' seascape comprising sea fans and noble corals in the Tsitsikamma marine protected area (image by Steve Benjamin).*

To resolve this shortcoming, a new generation of drop cameras has been developed in which horizontally mounted paired cameras provide scientists with stereo vision and the ability to accurately document the size and growth form of erect invertebrates. This novel combination of vertical and horizontal stereo cameras mounted on the same standardised frame, deployable throughout all reef habitats and depth ranges found on the South African continental shelf, has been the latest significant technological advance in the field of marine invertebrate research in the country. The technology will enable scientists to collect large, standardised and high-quality datasets with a comprehensive spatial coverage. The resulting new insights on the functioning of reef ecosystems and their spatial extent are expected to significantly improve the spatial management of marine resources in the future.

### Remotely operated vehicles

Remotely operated vehicles (ROVs) (see Plate 8) have been widely used in the offshore oil and gas industry to survey and repair submersed structures. Due to high initial and operational costs, the applications for ROVs in research are limited to their specific strengths.


***Plate 8:*** *A small research ROV fitted with cameras, lights and a manipulator arm for sample collection (image by Albrecht Götz).*


***Plate 9:*** *Specimens of benthic growth being collected with an ROV's manipulator arm (image by SAIAB).*

With the arrival of stereo-BRUVs and drop cameras (see above), quantitative surveys of fish and invertebrates have become relatively cheap to conduct with limited skill requirements for operators. Although this has made scuba diving and ROV quantitative surveys rather redundant, these conventional techniques remain superior for exploratory purposes or where samples need to be collected without damaging the reef and beyond safe diving depths (see Plate 9). This method is particularly useful to obtain limited, but specific samples in sensitive areas such as marine reserves, where dredging would be detrimental.

In essence, an ROV can carry out almost every task that a scuba diver can, but without depth restrictions. This area, which is beyond the reach of scuba divers (deeper than 40 m), but accessible to ROVs for exploration and sample collection, is significant in size (95% of the seafloor) and of importance to science (e.g. hydrothermal vents) (Devey et al., 2007) and fisheries (e.g. productive seamount biome) (Pitcher et al., 2010). In South Africa, ROVs have been successfully employed to search for and find coelacanths, which inhabit caves at depths deeper than 100 m (see Plate 10) (Roberts et al., 2006). Coelacanths, which were believed to have become extinct some 70 million years ago, are the main evolutionary link between marine and terrestrial vertebrates (Heemstra and Heemstra, 2004). Their rediscovery and observation have provided scientists globally with support for evolutionary theories, and in South Africa with additional international funds to further develop deep-sea exploration and research.

## Research and infrastructure gaps

One of the major hurdles for reef ecological research in South Africa is a lack of comprehensive and fine-scale depth (bathymetry) and habitat maps for the continental shelf region. This is a research gap that should be addressed as a priority.

As work on deep-water reef habitats has only recently become feasible in South Africa, the exploratory and research opportunities are numerous. To date, remote video sampling has mostly focused on the continental shelf off South Africa's south and east coastlines (see Figure 1). Research is needed on the reefs off the West Coast, as well as on the deep reef habitats (> 300 m) away from the continental shelf. However, deep-sea research requires reliable access to suitably equipped research ships and sampling gear – something that is not readily available in South Africa at present.

While video and photographic techniques promise to provide much-needed data to support reef fisheries management and biodiversity conservation, extraction of data from the footage is labour-intensive. Software development to automate video analysis and image processing will thus contribute greatly to streamlining data acquisition.


***Plate 10:*** *The caves associated with underwater canyons form a crucial part of coelacanth habitat structure (image by SAIAB).*

## 2.4 National Offshore Deep Benthic platforms

**Research questions**

Until recently, offshore benthic fauna and habitats of the continental shelf and beyond have received little attention in South Africa (Gibbons, 2009; Griffiths et al., 2010; Sink et al., 2012). Apart from early nearshore benthic survey work conducted in the 1950s (Day, 1960), broad-scale ecological knowledge of the offshore benthos and, in particular, that of soft-sediment habitats, is severely limited. This is largely due to the inaccessibility of these areas, the technical infrastructure required and the high financial costs associated with investigating deep-sea habitats (Costello et al., 2010).

Global developments in deep-sea photographic research equipment and methodologies have facilitated visual access to previously inaccessible habitats of the deep sea. As with rocky reefs, researchers at SAEON are now using optical techniques to begin characterising offshore benthic habitats and biodiversity, and to address ecological questions concerning the functioning, long-term change and recovery from disturbance of offshore benthic assemblages. Currently, three ambitious projects, each located in carefully selected regions, are directed at four key issues: the acquisition of baseline benthic biodiversity and habitat data, long-term ecological change, investigating biophysical drivers and functional benthic diversity, and testing benthic ecosystem recovery following anthropogenic disturbance.

## Developing baseline knowledge of offshore benthic environments

Gathering quality, spatially explicit baseline biodiversity data from offshore benthic habitats is currently a worldwide priority (Bax and Williams, 2001; Thrush and Dayton, 2002; Kipson et al., 2011). This is because diverse benthic assemblages are of direct importance to the provision of ecosystem services, including habitat and nursery areas for commercially important species (Meyer and Smale, 1991; Lindholm et al., 1999; Lohrer et al., 2004; Ross and Quattrini, 2007). Furthermore, because benthic assemblages effectively integrate historical environmental conditions over time (Warwick, 1993; Salas et al., 2006), they provide useful indices to evaluate the status of marine ecosystems in monitoring for long-term responses, site-specific impacts and levels of disturbance (Salas et al., 2006, Fuller et al., 2008; Roozbahani et al., 2010). As such, they are essential to identifying and measuring functional ecosystem changes (Witman and Sebens, 1992; Tillin et al., 2006). Given the importance of such data, efforts to gather broad-scale information about offshore habitat types, species richness and abundance, and functional diversity are a national priority that drives SAEON's offshore benthic research.

Baseline data depends on the ability to properly identify deep-water species, particularly those from soft-sediment habitats. Through a collaborative initiative with DAFF and DEA scientists, a long-term soft-sediment invertebrate-monitoring initiative has been established, with output including an offshore trawl invertebrate field identification guide. This cataloguing effort is set to be extended to other offshore habitat types as part of the three-year NRF SeaKeys project.

As a priority area identified in the National Biodiversity Assessment (Sink et al., 2012), focused efforts to investigate benthic species and habitats occurring in the Agulhas Ecoregion form another part of baseline research. This offshore work is set to link up with the already comprehensive coastal sentinel site in Algoa Bay, with the overarching goal of providing long-term records of the offshore benthic fauna.

## Investigating the long-term ecological change in the benthic ecology of the Prince Edward Islands

The pristine marine environment at the subpolar Prince Edward Islands has long been used as a natural laboratory. The remoteness of the islands, situated approximately 1 500 km south-east of Cape Town in the Southern Ocean, enables investigation of ecological change without the confounding effects of direct anthropogenic influences, such as trawling, oil and gas prospecting or terrestrial inputs. Contrary to traditional assumptions, both shallow and deep benthic assemblages are known to respond to upper ocean change (Barnes, 2005; Glover et al., 2010). At the Prince Edward Islands, recent biological evidence indicates the potential for shifting oceanographic frontal systems to affect the benthic ecosystem (Allan et al., 2013). Now, digitised historical benthic survey images and software-assisted re-processing, together with updated photographic and video material, are being used to answer questions about how benthic invertebrate assemblages living at depths of between 40 m and 400 m may be responding to changing climate (see Figure 1). While primarily focused on investigating ecological changes over time, the work inherently addresses useful questions about how benthic assemblages function and relate to biophysical drivers.

***Plate 11:*** *Deep benthos at Marion Island, 211 m depth. Optical techniques provide insights into the behaviour and interactions of organisms at depth. On the right of the image, the sea pen (*Pennatula inflata*) is climbed by a brittle star (*Asteronyx loveni*) (image by Charles von der Meden).*

***Plate 12:*** *Diverse benthic assemblages in Algoa Bay (image by Ryan Palmer).*

## Experimental trawl closure to monitor potential benthic recovery

The impacts of demersal fishing have been cited as one of the largest global anthropogenic sources of disturbance to the seabed and its biota (Jennings and Kaiser, 1998; Kaiser et al., 2006). The effects of such fishing activities are largely unknown in South Africa, with only one formal study investigating this topic thus far (Atkinson et al., 2011). South Africa's demersal trawl fishery has existed for over 100 years and is South Africa's most valuable fishery (Atkinson et al., 2011). As a result, there is limited information on benthic assemblages prior to the onset of demersal fishing in South Africa, preventing true quantification of the impacts of such activities. However, with the introduction of areas closed to such commercial activities in the offshore regions (i.e. marine protected areas or fishery management areas), quantifying the changes in benthic biota after the cessation of trawling will be possible. This is referred to as a press and relaxation experiment, with the fishing activity having provided the press for many years (Kaiser et al., 2002).

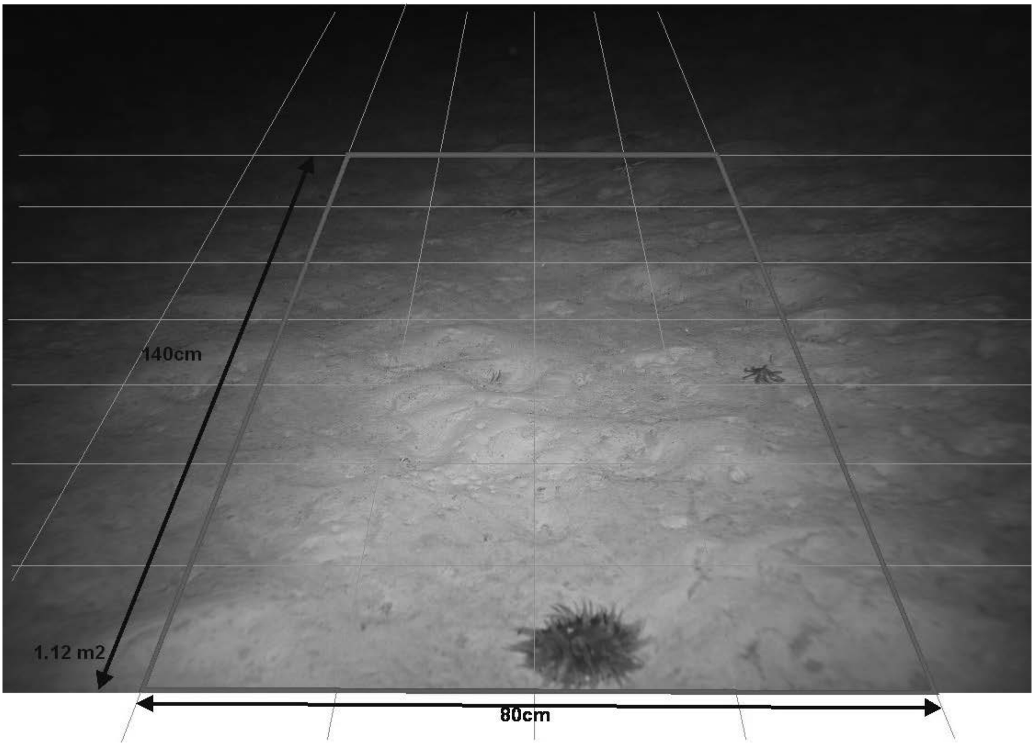


***Plate 13:*** *Benthic photographs, such as this one from the West Coast trawl grounds, are scaled and sampled by overlaying a perspective grid (image by Lara Atkinson).*

Through collaborations among researchers from UCT, SAEON, the South African National Biodiversity Institute (SANBI) and the South African Demersal Trawl Industry Association (SADSTIA), a 589 km$^2$ area offshore of Hondeklipbaai on South Africa's West Coast has been reserved for research on the potential recovery of the benthic ecosystem once trawling ceases (see Figure 1). In February 2014, researchers deployed SAEON's deep-sea benthic camera system, SkiMonkey III, to depths of 510 m to obtain baseline images of the seabed and biota prior to the closure of trawl activity (see Plate 13). Infauna (species living within the sediment) and sediment samples were collected using a traditional benthic grab. Subsequently, commercial trawl activity has been restricted to only two corridors through the area. Repeated annual surveys will allow for the quantification of changes that may occur in benthic biota and/or habitat once trawl disturbance has ceased. This project is the first such collaboration between industry and researchers investigating trawl disturbance effects in South Africa.

## Techniques and equipment

### Towed benthic cameras

Significant infrastructure and expertise are required for offshore research, including costly research vessels and specialised sampling equipment capable of descending to and working on the seafloor hundreds of metres below the surface. Each of the above projects makes use of a combination of optical techniques, such as underwater cameras, and traditional sample collection methods, such as benthic grabs and dredges. Photographic and video sampling at depths up to 750 m is done using the SkiMonkey III benthic camera. As the name suggests, this camera system is mounted on a frame with skis, allowing it to be towed along the seafloor by a large research vessel. The unit has its own power supply and necessary lighting and scaling lasers. A live feed of images and video from the camera is available to the scientists on the surface and allows full control of the camera system and settings. Because this system is towed, it is limited to working in areas of soft sediment and is not suitable for rocky reef habitats. Thus far, the SkiMonkey III camera has been successfully used aboard national research vessels such as the *SA Agulhas II* and the *RV Ellen Khuzwayo* (see Plate 14).

As already described, ROVs provide an additional tool for optical sampling at depths inaccessible to scuba (> 40 m). The utility of ROVs (such as that of the ACEP platform) overlaps both coastal and offshore benthic research, with the ROV enabling survey and sampling activities over selected areas of the continental shelf. Linking with SAEON's Algoa Bay Sentinel Site (see Figure 1), ROV sampling efforts are currently providing broad-scale data on benthic assemblages of the outer bay and shelf, with the aim of establishing a long-term dataset.

In addition to supplying baseline biodiversity data, gathering photographs and video footage of the seafloor provides unique insights into exactly where organisms live relative to habitat types and features, and into how they use these features. The techniques also allow for observing behavioural interactions that would otherwise be unknown (see Plate 11). These fringe benefits of optical techniques have a definite role to play in the so-called 'bottom-up' approach to habitat and biodiversity mapping and research. This approach advocates the identification of distinct units of habitat based on biological similarity (e.g. through video sampling). These can then be given 'environmental context' through a statistical investigation of relationships with environmental factors (Hewitt et al., 2004; LaFrance et al., 2010).

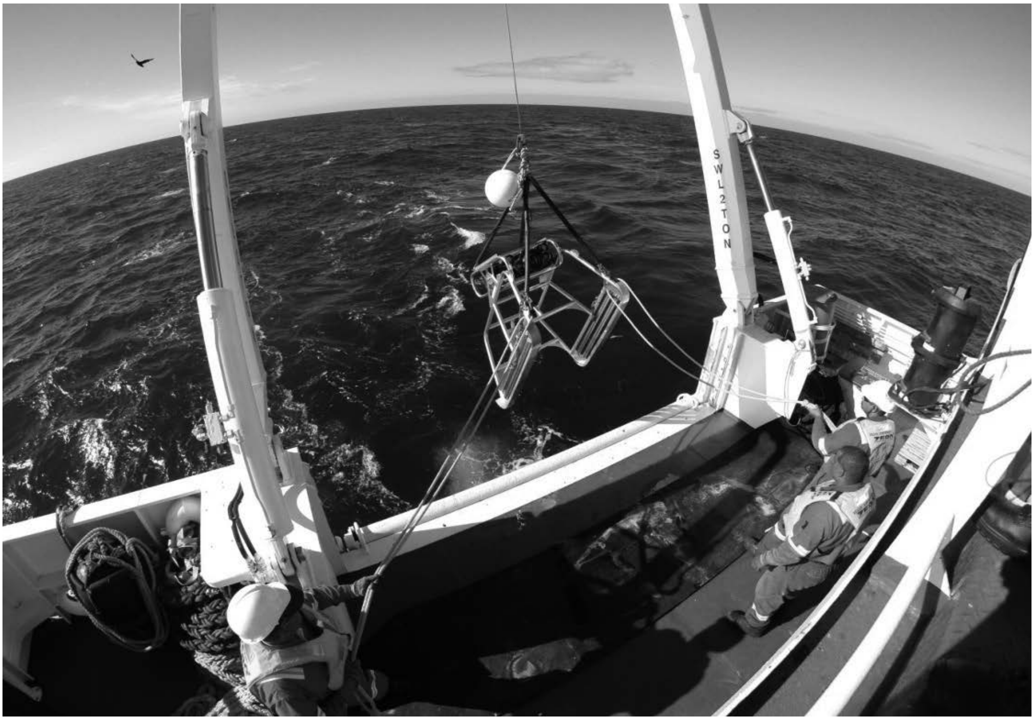


***Plate 14:*** *The SkiMonkey III benthic camera being deployed off the RV Ellen Khuzwayo during sampling of the West Coast trawl grounds (image by Charles von der Meden).*

### Environmental data and physical sampling

A recent addition to the SkiMonkey III camera system is an onboard microCAT CTD profiler, capable of capturing environmental parameters during benthic photographic surveys. Together with permanent *in situ* oceanographic instruments and remotely sensed data, this equipment will help document key environmental conditions on the seafloor. An additional component is the collection of physical samples of the benthic habitats and fauna. This remains a necessary part of benthic work, especially for habitat and taxonomic verification, as well as addressing questions around physico-chemical properties of the substratum and infauna. Obtaining intact representative samples from deep habitats is challenging.

## Research and infrastructure gaps

Research and infrastructure gaps often go hand in hand, with research questions driving specific infrastructure developments, particularly in technologically intensive fields of inquiry. Equally, as infrastructure platforms become available, they inherently open up the scope for novel research. In this regard, South African offshore marine research has seen excellent advances in infrastructure, including the ACEP research vessel, ROVs and the purpose-built SkiMonkey III benthic camera. Working from this base, it is imperative that these world-class pieces of equipment are put to use as widely as possible to extract diverse data that can be integrated across multiple disciplines.

On the broadest scale, a critical knowledge gap lies in the comprehensive mapping and verification of offshore benthic habitat types. Addressing this gap would require extensive acoustic ship-based sampling overlaid with benthic camerawork. An additional gap in current knowledge concerns how environmental factors influence the composition and distribution of benthic fauna and overall biodiversity. As more environmental and biological data becomes available, it will be possible to use biophysical modelling to test empirical observations. It is likely that, through the use of environmental surrogates, models will also contribute to our predictive capabilities. Like many marine environments, there is also a great need for molecular and taxonomic work – all of which will improve our inventories of benthic life. Finally, to understand some of the main mechanisms behind environmental influences on the maintenance of offshore benthic biodiversity, we need to understand phenomena such as bentho-pelagic links that describe the relationships between life cycles, dispersal, colonisation and biogeochemical cycling (Marcus and Boero, 1998).

At present, a challenging aspect of optical offshore benthic research is the proper identification of the organisms seen in the images. Given the goals of baseline species data and distribution information, identification is of crucial importance and requires the targeted collection of specimens from deep-sea environments. While the ACEP ROV system includes a manipulator arm for this purpose, the addition of an equivalent tool on the SkiMonkey III camera would prove invaluable to furthering our knowledge of offshore species diversity. This may be through the addition of a manipulator arm or a triggered scoop net. The ability to collect individual specimens as the camera passes them would be a great advantage in terms of combining images of the living organism with the taxonomic determination enabled by direct examination. Accurate geographical positioning of sampling equipment underwater is another challenge that is important to geo-referencing and mapping. While the ROV uses an underwater positioning system (Ultra-short BaseLine (USBL)), the SkiMonkey III camera system currently has no such capacity. This is something that, if addressed, would facilitate direct integration of biological and habitat mapping information. Much in the same way, an ROV with greater depth capability would fill a comparable infrastructural niche, expanding offshore research into bathyal (700 m to 1 000 m) and eventually abyssal zones (> 1 000 m). At this point, research efforts would benefit from upgrades such as the use of fibre optic data cables to provide significantly better data links to the cameras. Perhaps the most important and accessible infrastructural area through which research output capacity can and should be boosted is in software procurement and, where needed, custom development. Current optical techniques are digital and a significant amount of image processing time and expertise can be saved by software applications that streamline and automate processing tasks.

## 2.5 Information management platform

**Research questions**

Quality data captured over decades and longer provides the baselines for research to detect and analyse trends in environmental change. This data is expensive to gather and is never static. It needs to be analysed and enhanced to help people interpret it and to provide policy-makers with clear evidence. At SAEON, every effort is made to keep up with cutting-edge information technology (IT) infrastructures and tools to optimise the way data is managed and presented, and to add maximum value to the data and metadata.

The scientists who generate and use environmental data work in diverse disciplines and represent a vast number of organisations. This means that data often becomes fragmented and isolated. When a single custodian takes responsibility for preserving and sharing valuable datasets, it benefits current and future researchers. SAEON fulfils this role while preserving, processing, enriching and sharing valuable research data.

**Techniques and equipment**

SAEON has developed a comprehensive data management infrastructure – a so-called 'shared platform'. The shared national data platform currently hosts the SAEON data portal, the South African Risk and Vulnerability Atlas (SARVA), the South African Earth Observation System (SAEOS), the BioEnergy Atlas, the CSIR's Geospatial Data Infrastructure (GSDI) Geoportal, and a prototype World Data Centre for Biodiversity and Human Health in Africa (WDCBHH). The system provides access to data through a metadata repository aggregated from collaborators, partners and linked sites. Researchers who access the shared platform are also able to use cutting-edge data management tools to search for specific information and create composite geospatial visualisations of distributed datasets.

By using the facilities provided for packaged searches and Global Earth Observation System of Systems (GEOSS)-compliant search services, stakeholders, communities and partners can access the clearinghouse metadata repository in predefined ways to support research themes. The infrastructure allows query formulation pages and search results to be seamlessly embedded in other systems. Stakeholders can thus contribute to the shared platform's metadata repository, host data in its infrastructure and utilise its search and visualisation components, all from external systems. The metadata repository is capable of accepting and working with a range of well-established metadata standards. The platform also provides collaboration, sharing and content composition facilities for the distributed creation and management of value-added themes, discussions, blogs, community pages and more.

SAEON is currently the implementation agent for the platform and its hosted portals and can assist with the following:

- Guidelines in respect of the choice of metadata standard and supporting open source software
- The creation of metadata
- Guidelines in respect of applicable standardised data standards and services
- Hosting or archiving data in most circumstances

Access to datasets are determined by the preferences of the provider community, and can range from the ideal situation of open, automated standards-compliant services (Web Feature Service (WFS)/Web Map Service (WMS), Sensorweb, NetCDF, etc.) through download links or re-direction to provider-determined websites. Under ideal circumstances, data providers curate their own data holdings on a platform that is acceptable to them and the links to datasets are included into metadata records. The platform can also host data on behalf of a provider, should the requirement exist.

SAEON has also recently acquired a license for digital object identifiers (DOIs), which permanently identify data and metadata resources in the web. This is a critical element of the emerging practice of data publication and citation, which SAEON supports as a means of improved access to research outputs.

### Research and infrastructure gaps

There are currently several constraints with regard to rolling out a comprehensive data and information management system that serves the entire marine scientific community. These include the following:

- Lack of a coordinated data publication policy at a national level
- Network speed that slows down the upload and archiving of large datasets
- Storage space, especially for video and photographic datasets
- Qualified data technicians/informaticians to clean data, develop metadata records and upload datasets
- Scientists are often unwilling or distrustful of archiving their data elsewhere, and do not always regard metadata descriptions of data as an integral part of their research effort
- The large backlog of historical datasets that need to be captured

## Conclusion

In six short years, the NRF, with funding from the DST, successfully established cutting-edge long-term marine research platforms that are either on par or exceed those available in developed countries. The network of *in situ* instruments and long-term research is unrivalled in Africa, and South African scientists are increasingly being asked to advise and collaborate in the region. The platform networks are by no means complete and there are numerous infrastructure and research gaps that need to be filled to ensure that the drivers of change, the response of the ecosystem and the impact of change are fully understood so that appropriate mitigation measures can be implemented. The DST recently published *A South African Research Infrastructure Roadmap* (Wood et al., 2013) that outlines 17 potential physical research infrastructure needs for South Africa. These needs include a South African marine and Antarctic research facility, as well as shallow marine and coastal research infrastructure.

The most important gap is the spatial extent of the platforms, with the least number of platforms available on the West Coast, Wild Coast, northern KwaZulu-Natal, sub-Antarctic Islands (Van Jaarsveld and Biggs, 2000) and offshore. Offshore marine observations and research require access to large research vessels. Although South Africa has a relatively large and modern research fleet, gaining access to sea days has become difficult and unreliable in recent years due to constant changes in the government departments responsible for its management (Treasure et al., 2013).

For South Africa to upscale its long-term observation platforms will require the following:

- Developing real-time observatories and associated technologies
- Dedicated ship hours on appropriate research vessels
- Establishing a South African marine and Antarctic research facility as a national facility of the NRF to ensure equitable access to grants and research vessels to study and monitor the Southern Ocean and Antarctica
- A platform of at least three coastal research vessels and various instrument arrays for 'bay-scale' research aimed at studying physical, biological, geological and geophysical features of coastal marine environments to a depth of ~100 m
- A centralised data management facility that caters for the collection, storage and dissemination of all types of marine-related data and that also hosts the data portal for the South African Earth Observation System of Systems (SAEOSS)

- Skills development and training, especially of marine technicians, electronic engineers, data technicians/engineers, scientific divers and skippers
- Expansion of the sentinel site approach to other bioregions
- Partnerships with international institutions and programmes
- Secure and dedicated funding

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# Chapter 6 The Overlooked Foundation: Marine Microbes in the Oceans Surrounding South Africa

*Maya C. Pfaff, Flavia Flaviani, Gerda du Plessis, Edward P. Rybicki and Declan C. Schroeder*

## 1. Introduction

South Africa has more than 3 000 km of coastline and fringes three contrasting ocean systems: the cold productive Atlantic Ocean on the west, the warm subtropical Indian Ocean on the east, and the Southern Ocean surrounding the sub-Antarctic Prince Edward Islands. Marine and maritime economies, including fisheries, aquaculture, maritime trade and tourism, make up a major part of the South African economy, which has driven a long-standing tradition of excellence in marine research in the country. In this chapter, we review how marine microbes – the tiny organisms in the sea that are invisible to the naked eye, but give the sea its variable colouration – play a central role in driving large-scale earth system processes, and thereby have profound societal impacts. A deeper understanding of this forgotten foundation of marine ecosystems is not only necessary to deal with the increasing threats microbes pose as pathogens, but also holds novel opportunities to harness these powerful little creatures for the production of renewable energies, pharmaceuticals and food sources, which will contribute significantly to the fast-developing Blue Economy of South Africa. Due to their fast turnover rates and quick response to environmental conditions, microbes are also ideal bio-indicators of environmental change. A deeper understanding of marine microbial systems is thus integral to the management of oceans and coasts, which are under severe pressure due to human impacts, such as pollution and climate change.

This chapter focuses on the aspects considered to be important for the future of South African marine science with the potential for biotechnological applications. At the onset of this chapter, the reader is introduced to the ecological and societal importance of marine microbes, and to recent technological advances that hold promising opportunities for microbial research and technology. By focusing on the three main groups that make up marine microbes (protists, bacteria and viruses), a detailed account of the current knowledge and its current application in marine and maritime technologies is presented for each group. The chapter concludes by pointing out apparent gaps in our understanding and utilisation of marine microbes, with a special focus on the way forward for microbial research in South Africa.

### 1.1 Marine microbes drive ocean biogeochemistry

Marine microbes make up more than 90% of the living biomass of the ocean, yet remarkably they have mostly been overlooked in research and management concerning oceans and coasts. Microbial organisms have typically been classified according to size (Figure 1), as well as by evolutionary history (taxonomy) or functional traits (e.g. primary producers vs. consumers). Microbes comprise the taxonomic groupings of protists, bacteria, viruses and fungi. While bacteria dominate microbial communities in terms of biomass, viruses are by far the most abundant and diverse, and the most under-explored microbial group in the ocean. Fungi are considered to be relatively rare in marine environments, possibly because their osmotrophic feeding mode is disadvantageous for survival in most marine habitats. In the past decade, technological innovations have made it possible to unpack the apparent black box of microbial ecology, and scientists are now making remarkable discoveries of the biodiversity and functional roles of marine microbes (DeLong, 2005; Azam and Malfatti, 2007; Suttle, 2007).

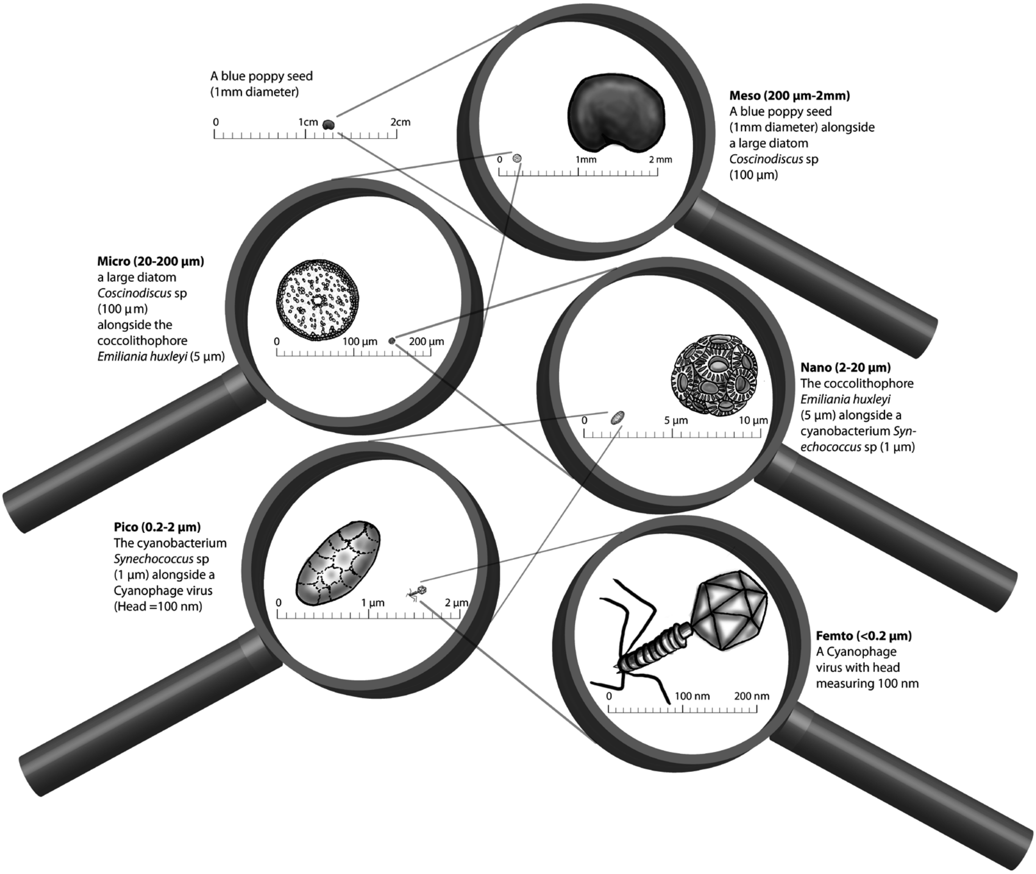


***Figure 1:*** *The enormous size range of microbes in relation to the size of a poppy seed (1 mm), spanning four orders of magnitude from minute viruses to large unicellular diatoms. Note that phytoplankton size varies across two orders of magnitude, from the cyanobacteria (picophytoplankton), through dinoflagellates, such as coccolithophores (nanophytoplankton) to diatoms (microphytoplankton). Modified from Sapp and Schroeder (2010).*

Due to their collectively huge biomass and fast metabolic turnover rates compared to larger organisms, marine microbes drive many important ecological processes in the ocean atmosphere system, such as nitrogen fixation, denitrification, sulphate reduction (which leads to the production of mercury), fermentation (which leads to the production of ethanol) and photosynthesis. They are therefore responsible for the cycling of elements and nutrients on a global scale. For example, all minute marine phytoplankton together – that is, photosynthesising bacteria and algae – accomplish a quarter of the global primary production of biomass on earth.

The mechanism of carbon export from the atmosphere into the deep ocean is called the biological pump. This complex biological machinery is entirely driven by marine microbes (Figure 2). It works by photosynthesising microbes taking up carbon dioxide ($CO_2$), which is transferred from the atmosphere to the upper layers of the ocean. By the simplest description of this model, these primary producers transform $CO_2$ into the organic carbon from which their cells are made up. When they die, the cells sink into the depth of the ocean, taking the carbon with them, which remains resident in the deep ocean for long periods. It is such organic matter deposited on the ocean floor millions of years ago, and chemically modified under high pressure, that formed the fossil fuels on which our modern economies are based. The well-recognised carbon pump reduces the greenhouse effect and thereby stabilises global warming (Raven and Falkowski, 1999).

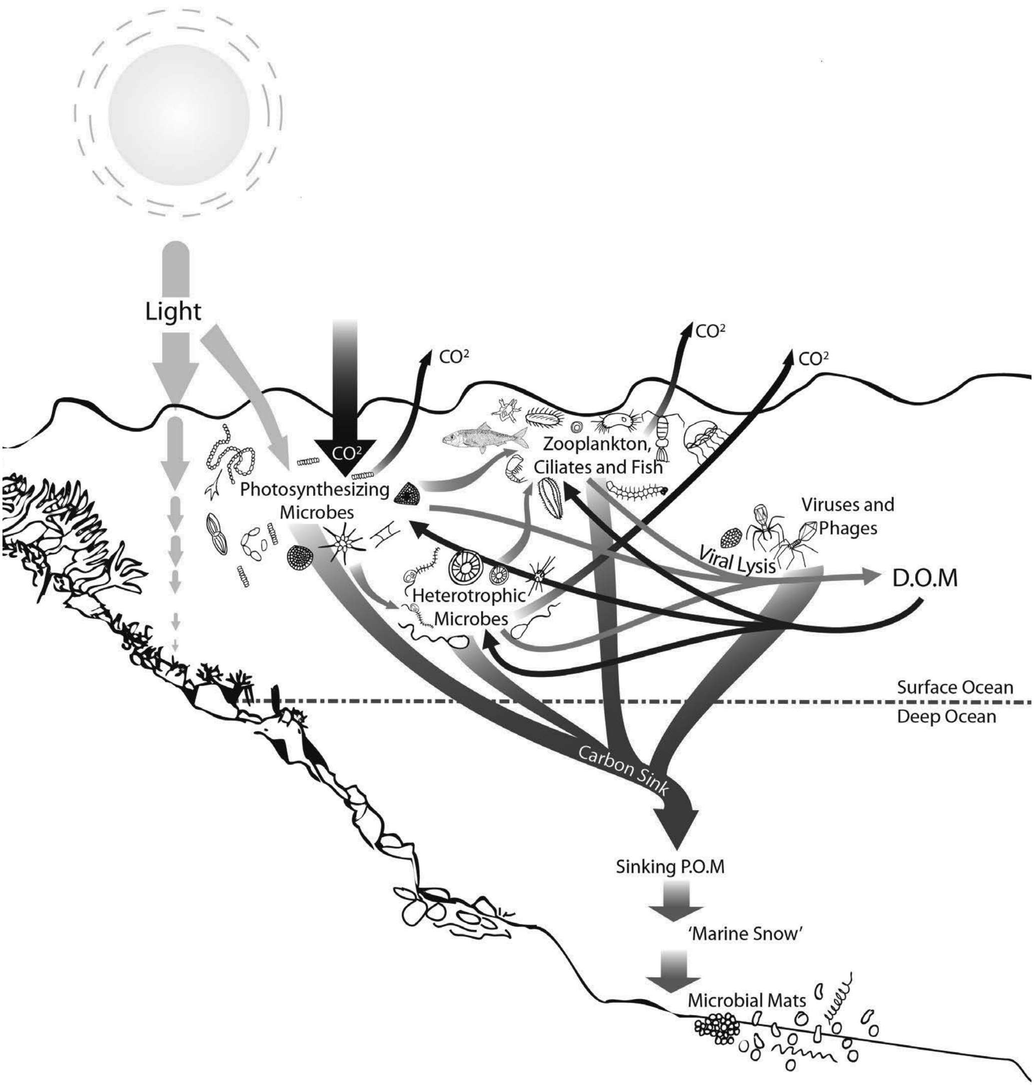


***Figure 2:*** *The biological pump in the ocean contributes in a major way to carbon sequestration on earth. Its machinery is driven by the complex interplay of various microbial groups. The efficiency of carbon export can be enhanced or hindered by the dominance of a certain group. An improved understanding of marine microbial ecology is thus essential for climate research, and the future management of the oceans.*

However, the efficiency of carbon exported by the biological pump is also regulated by microbes. For instance, when micro-zooplankton ingests phytoplankton, it excretes dissolved organic matter that stimulates microbial growth. Through this process, at least half of the primary production in the oceans is contributing to the growth of microbes instead of feeding larger zooplankton (such as krill), which, in turn, would feed fish, thus challenging traditional food chain models. Since dissolved compounds do not sink, micro-zooplankton grazing decreases the efficiency of the biological pump and slows down carbon sequestration in the deep ocean. Moreover, it is now becoming evident that viruses play a major role in causing the release of dissolved organic matter in the upper levels of the oceans and in marine sediments by killing all forms of cellular life (Suttle, 2005). In similarly profound ways, microbes are drivers of most other elemental cycles, some of which are poorly understood thus far.

Microbes shape the size structure of entire marine food webs. By selectively consuming other microbes, bacteria and protozoa determine which size class of phytoplankton prevails, which, in turn, determines which size class of grazing zooplankton and which fish assemblages dominate. Thus, through their profound effects on the biological pump and marine food web structure, microbes play a pivotal role in marine ecosystems. An understanding of microbial ecology is therefore essential for predictive models of global climate and fisheries dynamics, which are of major concern for human societies.

## 1.2 The use of marine microbes in biotechnology

The benefits of studying micro-organisms can be highlighted in the knowledge and compounds applied to industrial, pharmaceutical, aquaculture and conservation practices. It is well established that bacterial compounds, such as extracellular enzymes, are utilised for everything from biofuel production to the bioremediation of oil-contaminated sites, not to mention the anti-tumour, anti-cancer and antibacterial compounds that they produce (Hatti-Kaul et al., 2007). Similarly, several bioactive compounds have been identified in protist and microbial communities that are housed by several species of South African sponges (Davies-Coleman and Beukes, 2004). These examples, however, merely scratch the surface of the potential biotechnological and industrial applications of marine compounds. There is a worldwide drive towards an integrated multidisciplinary approach to the isolation and characterisation of marine compounds, with particular focus on novel antibiotics. For instance, South Africa's local need for new drugs to treat multidrug-resistant (MDR) and extremely drug-resistant (XDR) pathogens, such as the famous tuberculosis-inducing *Mycobacterium tuberculosis,* is merely one example of a desperate need for the discovery of novel compounds. As the discovery of novel compounds in terrestrial systems is reaching saturation, marine ecosystems still hold undiscovered treasures for the pharmaceutical industry, which fights a continuous arms race against pathogen resistance to drugs, and therefore depends on the development of new options.

## 1.3 Recent technologies that have revolutionised our understanding of marine microbes

Traditionally, the identification of microbes and the understanding of their roles in marine ecosystems were based on microscopy, culturing and laboratory experimentation. Microscopy is time-consuming, and although it is a necessary tool for morphology-based species-level identification, it has been shown to be insufficient for correct classification and unsuitable for high-throughput studies. Additionally, successful culturing has not yet been achieved for 99% of microbial species, due to the high diversity and difficulty in growing most species (Torsvik et al., 1990). Laboratory experiments, while effective for gaining a basic understanding of microbial physiology and ecological interactions, are invariably biased by artefacts, which confound any extrapolations from laboratory findings to real-world scenarios.

With the advent and rapid advancement of culture-independent 'next-generation' sequencing technologies over the last few years and their combination with advanced cell sorting technologies, it has become feasible to unravel the identities and ecological functions of microbes much faster and much more reliably, which has revolutionised our understanding of marine microbial ecology. 'Next generation' sequencing refers to a rapid method of constructing the sequence of genomes. Instead of being limited to viewing short snippets of genetic code, researchers can now look at whole genomes of organisms or communities of organisms. For microbes, which commonly occur in mixed communities of minute individuals, this has led to the discovery of numerous new sequences and opened up questions about the function of individual genes in ecosystems. The steady decrease in sequencing costs is continuously making this technology more suitable to developing countries like South Africa.

Other high-throughput technologies have been adapted for use in marine science. Rapid enumeration and classification of microbes can now be achieved by analytic flow cytometry, which is also applied to separate microbial groups from a mixed sample. Furthermore, fluorescence-based approaches, such as fluorescent *in situ* hybridisation (FISH), make use of fluorescent labels that attach to specific genetic sequences, which can be used to label specific species in a mixed sample, aiding their correct identification and enumeration. These and other quantitative methods have revolutionised the field of microbial ecology, as they have led to the identification of marine food web structures and host-parasite relationships.

These rapidly evolving technologies have led to quantum leaps being made in the discovery of novel biological compounds, which hold the potential for the development of new pharmaceuticals, cosmetics, nutritional substitutes and functional food sources. Protists (algae) have also been identified as ideal candidate organisms for the production of biofuel, wastewater treatment or increased carbon sequestration, and are thus important for the development of Green and Blue innovation-based economies in South Africa.

## 2. The status of marine protists in research and technology

Marine protists play key roles in the functioning of marine ecosystems, as primary producers and as consumers. The current uses of micro-algae, in particular, are numerous and varied, including the production of food, feed, healthcare products, energy and industry. For example, in South Africa, algae are used for the production of biofuels, wastewater treatment, $CO_2$ sequestration, and the production of food supplements. However, these biotechnologies are currently based on freshwater algae, while their marine counterparts have not been explored to their full potential. This section provides a background on marine protists in their natural environment, and shows their potential to serve a Blue Economy through examples of their current use in South Africa. The negative effects of harmful algal blooms (HABs) on coastal economies are also illustrated.

### What are marine protists?

Protists represent the third-most abundant taxonomic group in the oceans, after viruses and bacteria. These organisms differ from the other two groups addressed in this section by having more complex membrane-structured cells, which characterise the evolutionary lineage of eukaryotes. Protists comprise the vast majority of eukaryotic diversity on the planet, and incorporate autotrophic organisms that photosynthesise (micro-algae or phytoplankton), heterotrophic organisms that feed on other microbes (protozoa or microzooplankton) and mixotrophic organisms that can switch between these two feeding modes depending on the environmental conditions they face (Figure 3). Protists differ tremendously in size, with the smallest measuring less than 1 $\mu$m (one millionth of a metre), and the largest unicellular (non-colonial) protists reaching sizes greater than 1 cm – which reflects a size range equivalent to that of a ladybug to a blue whale. Protists are typically small, highly diverse and have complex life histories, which often involve transformations between radically different forms and functions within one individual's life span. Due to this complexity, the diversity and ecological roles of the vast majority of protists have long remained mysteries, most of which are still to be solved.

## 2.1 Biofuel production

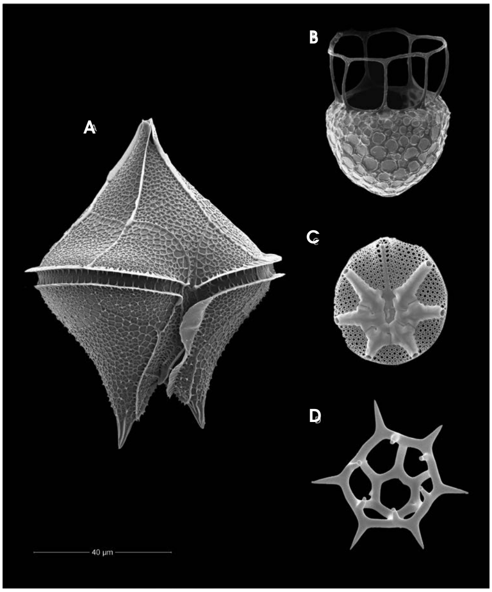


***Figure 3.*** *Representatives of the diverse grouping of marine protists illustrating their diversity in form and function: The bioluminescent dinoflagellate* Protoperidinium divergens *(A) and the tintinnid ciliate* Dictyocysta *sp. (B) both prey on phytoplankton, including harmful algae; the diatom* Asteromphalus *sp. (C) photosynthesises; and the silicoflagellate* Distephanus speculum *(D) is able to change its feeding mode between photosynthesising and preying on other microbes (scanning electron microscopy (SEM) image by C. Carbonell-Moore).*

The continuous societal demand for energy resources has led to the near depletion of fossil fuels, some of which are the result of transformed deposits of carbon derived from protists that lived millions of years ago. At the same time, mitigation measures of climate change promote carbon-neutral renewable energy sources to reduce emission rates of greenhouse gases in the atmosphere. Such solutions aim at fixing the same amount of $CO_2$ from the atmosphere during the production of fuels as are released during their combustion. The increasing production of biofuels is mostly based on oils from terrestrial plants, such as rapeseed, canola, sunflowers and other crops. Although they are carbon-neutral, these crops require agricultural space and water, which results in their production competing with food crops, the natural environment and other sectors of society that depend on water resources.

Micro-algae, like plants, fix atmospheric carbon to make up their cells, and commonly contain lipids that are equally suitable for the production of biodiesel, petrol and jet fuel. The added advantages of using algae over terrestrial crops are that they can be grown on land that is unsuitable for agricultural crop plants, such as arid areas or modified urban environments. In addition, algae yield far greater volumes of biofuel per area than terrestrial crops.

Algae have short life cycles, which aid the rapid development and testing of new strains for fuel production. Algal production can also make use of wastewater, instead of using valuable freshwater resources.

South Africa has huge arid areas, which are ideal for growing micro-algae for biodiesel production. Several algal energy research centres have been established around the country. These are mostly based at universities and the Council for Scientific and Industrial Research (CSIR). These centres' research focuses on algal bioprospecting, biodiesel production using wastewater, the optimisation of growth conditions and yield, downstream processing, lipid extraction and bioreactor design. Currently, freshwater algae are mostly used in biodiesel development, although experimental comparisons of traits, including ease of harvesting and fatty acid profiles, identified the marine genera *Cylindrotheca* and *Nannochloropsis* as being among the three most promising species of algae for biofuel production (Griffiths et al., 2012). With the depletion of freshwater resources, the interest in marine algae for energy research is on the increase, yet at this stage, the field is still in its infancy due to the relatively low investments in the development of renewable energies in South Africa.

## 2.2 Harmful algal blooms (HABs or red tides)

HABs are common natural phenomena and are particularly frequent in coastal upwelling regions such as the Benguela region off the west coast of southern Africa (Pitcher et al., 2010). Their extent and frequency have increased globally in recent years due to the nutrient enrichment of coastal waters from land-based sources of pollution, changes in coastal wind fields attributed to climate change and the introduction of HAB species from different parts of the world in the ballast water of transporting vessels (Drake et al., 2007). HABs have substantial negative effects on the coastal economy of South Africa. Fisheries and aquaculture industries suffer from the episodic mass mortalities of commercially exploited stocks caused by HABs (Botes et al., 2003; Probyn et al., 2010; Pitcher et al., 2011). In addition, the tourism industry suffers from the harmful effects of HABs on humans, foul smells and bad visibility during HAB events, which lead to reduced expenditures for marine recreation.

HABs are harmful in various ways. Some species contain toxins associated with poisoning symptoms in humans, such as paralytic shellfish poisoning (PSP), diarrhetic shellfish poisoning (DSP) and amnesic shellfish poisoning (ASP). However, the most common negative effects of HABs are not associated with their toxins, but with their tendency to occur in extremely high cell concentrations. The respiratory demands of bacteria decomposing the settling of such high-biomass blooms lead to the depletion of oxygen in coastal waters, which causes mass mortalities of coastal invertebrates and fish, including those of economic value.

In upwelling systems around the world, 29 algal species have been associated with HABs, which include 27 species of dinoflagellates, one diatom species, and one raphidophyte species, most of which are widespread and occur in more than one region (Trainer et al., 2010). In South Africa, one of the most troublesome species is *Alexandrium catenella*, which is common along the west coast and threatens the safety of shellfish consumption due to its PSP-inducing toxins, especially in the St Helena Bay region (Pitcher et al., 2001; Ruiz-Sebastian et al., 2005). Species containing DSP toxins, such as representatives of the genus *Dinophysis*, are also commonly found among the plankton (Pitcher and Calder, 2000). Species containing yessotoxins (YTXs), such as *Protoceratium reticulatum*, have led to closures for shellfish harvesting (Fawcett et al., 2007), with severe effects on the local economies. In 2014, the biggest recorded red tide occurred along the south coast, reaching from Knysna beyond Port Elizabeth and causing fish kills on various stretches of coastline. It contained the YTX-containing species *Lingulodinium polyedrum* (Bornman, 2014), which has thus far only been recorded as cysts from sediments on the West Coast (Pitcher and Joyce, 2009). Fish-killing blooms of *Karenia cristata* (Botes et al., 2003) and *Heterosigma akashiwo* have also been reported in South Africa (Pitcher and Calder, 2000).

Low-oxygen events, which occasionally lead to the hydrogen-sulphide poisoning of coastal organisms, have long been reported as a major factor for fluctuations in fish stocks off South Africa (Gilchrist, 1914). Numerous HAB species have been associated with mass mortalities along the West Coast. As these blooms decay due to nutrient limitation and/or viral infection, their decomposition by bacteria commonly leads to the depletion of oxygen in coastal waters, causing mass mortalities of commercially important fish and the stranding of rock lobsters, which walk towards the shore in search of oxygen. The most famous examples are the strandings of hundreds of tonnes of rock lobster in Elands Bay in 1997 and 2000. The latter resulted in losses to local fish stocks estimated at US$50 million (Pitcher and Cockcroft, 1998).

State-of-the-art methodologies for the rapid and early detection of harmful species in seawater samples include molecular technologies for specific identification and accurate enumeration, such as next-generation sequencing. While used in various other studies around the world (Coyne et al., 2001; Popels et al., 2003; Hosoi-Tanabe and Sako, 2005; Bowers et al., 2006; Lin et al., 2006; Moorthi et al., 2006; Fitzpatrick et al., 2010), these methods are thus far not routinely used for monitoring the conditions that lead to HAB formations in South Africa. The greater use of these methodologies would lead to a more informed prediction of risks to coastal consumers of shellfish.

## 3. The status of marine bacteria in research and technology

Marine bacteria make up 90% of the marine microbial biomass, which translates to about 80% of the total mass of living organisms in the oceans. There are approximately one million bacterial cells per millilitre of seawater, compared to a thousand fungal and 10 to 100 larval spores. Bacteria dominate metabolic activities in the oceans due to their high turnover of generations and collective mass. However, they have, for the most part, been overlooked in assessments of biodiversity and ecosystem functioning in most of the world's oceans (Azam and Malfatti, 2007), including those around South Africa (Griffiths et al., 2010). The technological advances of the past three decades have fortuitously led to the advent of microbial oceanography, a new discipline studying the interaction between micro-organisms and the oceans. There are few accounts of ecological research involving marine bacteria in South African systems, including estuaries (Froneman, 2002; Matcher et al., 2011), sandy beaches (Koop and Griffiths, 1982), rocky shores (Hanekom, 2013), coral reefs (Celliers and Schleyer, 2002), and the water column (Pommier et al., 2007). Based on findings from other parts of the world, research on marine bacteria has recently been propelled to the forefront of technological development with regard to Blue, or ocean-based, technology and conservation management (Davies-Coleman, 2010). Currently, applied research on marine bacteria has been conducted in the context of aquaculture, Blue technology and water quality assessments.

### What are marine bacteria?

Bacteria are unicellular organisms with genomes (DNA) that are not bound into a nucleus, and cell structures that lack internal membrane-bound compartments. Bacteria are adapted to thrive in most oceanic environments: they may be found in hydrothermal vents and deep-sea sediments, throughout the oceanic water column, and in diverse coastal, estuarine and hyper-saline ecosystems. Bacteria occur as free-swimming bacterioplankton (Acinas et al., 1999), as flocks or aggregates such as marine snow (Alldredge et al., 1986), as biofilms or bacterial mats, and in association with other organisms that they either benefit (through symbiosis) or parasitise on (Armstrong et al., 2001). Bacteria exhibit a wide variety of complex metabolic types and modes of nutrition, of which only the very basics are covered here. Autotrophic bacteria, such as the common group of cyanobacteria or 'blue-green algae', actively fix cellular carbon from $CO_2$ using photosynthetic pigments in a way similar to plants or protists (Figure 4). Heterotrophic bacteria utilise organic carbon compounds produced by other autotrophs, in a way similar to animals. In the absence of oxygen, bacteria utilise sulphur to transform inorganic carbon to organic matter. Through their fast metabolic turnover, bacteria drive many important ecological processes, such as nitrogen fixation, denitrification, sulphate reduction (which leads to the production of mercury) and fermentation (which leads to the production of ethanol), to name but a few. Thus, bacteria are crucial for the recycling of elements and nutrients (Zehr and Ward, 2002; Des Marais, 2003; Veldhuis et al., 2005), and serve as a food source for other marine organisms (Azam and Malfatti, 2007).


***Figure 4:*** *A selection of bacterial images and their applications. A: A bacterial colony consisting of millions of cells growing on an agar plate. B: SEM image of a bacterial colony under magnification. C: A group of bacterial colonies producing antibiotic droplets. D: An* E. coli *strain expressing a gene obtained from another organism that degrades cellulose (possible application in biofuel production).*

## 3.1 Marine bacteria in aquaculture research

In South Africa, aquaculture generates an estimated 21% of the world's abalone production. In addition, South Africa produces 227 tonnes of oysters, 737 tonnes of mussels and 1 834 tonnes of seaweed annually. Although aquaculture production has risen steeply worldwide, the industry is considered to be underdeveloped in South Africa, and is viewed as an important emerging source of protein.  The development of such a resource has, however, brought about concerns arising from the biocontrol of potential virus and pathogen contamination, especially in non-endemic species. As mentioned, bacteria can either enhance their hosts' defense, or colonise and negatively affect their hosts, and potentially the downstream consumers. At present, all aquaculture produce goes through a stringent quality control process for exports to the European Union (EU). Even so, the data regarding infection and pathogen prevalence is not publicly accessible. Several articles have, however, been published regarding the beneficial effects of a select few bacteria on the growth of captive abalone species (Doeschate and Coyne, 2008; Bolton et al., 2013). These have been proposed as future probiotic treatments to increase the growth rate. Other aspects needing further exploration include the effects of culture methods on culture-associated bacterial and viral communities, and the effects of wastewater generated from the feeding grounds on endemic microbial communities close to the discharge sites.

### 3.2 Marine bacteria as indicators for ecosystem health and water quality

Current international environmental monitoring practices focus mostly on marine invertebrates. Although benthic macro-invertebrates are a good indication of the health of marine environments, a similar bacterial monitoring system would be an ideal addition to such a database. A recent publication has motivated for the 'molecularisation' of monitoring practices associated with marine fauna and flora. The advantage associated with a 'molecularised' monitoring approach, such as by 'metabarcoding', is the elimination of bias associated with traditional methods of taxonomic identification. This has become a particular problem since the numbers of trained taxonomists have decreased, while the demand for monitoring has increased (Evans and Paulay, 2012; Bourlat et al., 2013).

South Africa is recognised for its relatively pristine coastline, which supports high biodiversity (Griffiths et al., 2010). Pollution levels in South African waters are considered relatively low compared to other parts of the world (Degger et al., 2011). However, there are currently 67 pipelines that discharge 1.3 x $10^6$ $m^3d^{-1}$ of partially treated wastewater from industrial and domestic sources into the sea (Mead et al., 2013), potentially posing a severe threat to biodiversity and coastal user safety. Worldwide effects of pollution on various aspects of the marine environment have received substantial attention, yet very little is known about the impact on marine microbial communities (Islam and Tanaka, 2004; Nogales et al., 2011). Certain bacteria, such as *Escherichia coli* (or *E. coli*) and Enterococci, are presently in extensive use as indicators for water quality monitoring, yet their effectiveness as water quality indicators has been questioned. With growing coastal populations and the associated increase in the discharge of wastewater into the coastal environment, there is an increasing need for research to determine the effects of discharges on coastal ecosystems and for the development of appropriate indicators to monitor ecosystem health and water quality. Due to their quick response time, bacteria will likely remain among the most appropriate indicator organisms.

### 3.3 Marine bacteria in Blue biotechnology

Blue biotechnology is defined as the application of biotechnological techniques to the marine environment. The discipline makes use of a range of molecular methods to study industrially and pharmaceutically important compounds derived from the marine environment. Compounds produced by marine micro-organisms include anti-cancer and anti-tumour compounds (Drewes, 2012), antibiotics, cosmetic pigments, bioflocculants (Cosa et al., 2011; Ugbenyen and Okoh, 2013), biosurfactants (De Carvalho and Fernandes, 2010) and extracellular enzymes. Recent advances in marine symbiont studies have indicated that natural products previously thought to originate from higher-order taxa, such as sponges, are in fact produced by microbial symbionts attached to the organism (Walmsley et al., 2012). This knowledge, in combination with the wealth of marine invertebrates along the South African coastline, has led to a renewed interest in the screening of marine symbionts for unique compounds (Davies-Coleman, 2010).

A recent study on bacterial isolates from Nahoon Beach (East London) isolated ten *Streptomyces* strains with activity against *Pseudomonas aeruginosa*, the causative agent of infections such as pneumonia and sepsis (Ogunmwonyi et al., 2010). A similar study on isolates from Algoa Bay identified a *Bacillus* and *Virgibacillus* species, which both produced novel bioflocculants that could potentially be used in water-treatment plants (Cosa et al., 2011; Ugbenyen and Okoh, 2013). While these species are often associated with pristine environments, contamination has driven the evolution of unique organisms. A study on marine isolates from Durban Harbour found a phenol-utilising bacterium that was able to degrade various aromatic hydrocarbons under saline conditions. These properties would make the isolate ideally suited for the bioremediation of oil-contaminated sites (Moxley and Schmidt, 2012). At present, South Africa does not have the capacity to bring all-new compounds into production, especially in the case of novel pharmaceuticals that require multimillion dollar investments, primarily for marketing. This stresses the importance of international collaboration to get promising local leads onto the market. In addition, a vast number of novel potential products remain to be discovered, which will undoubtedly expand Blue biotechnology in South Africa in the coming decade.

## 4. The status of marine viruses in research and technology

Viruses have been associated with all living beings (Munn, 2006; Drake et al., 2007; Rohwer and Thurber, 2009) since the beginning of evolutionary history. Life on earth originated in the oceans, so it is not surprising that these archaic forms of life still prevail in marine systems. What is astounding, though, are the immense numbers and amazing diversity of marine viruses, which have only recently come onto the agenda of marine science. An estimated minimum total of $10^{31}$ virus particles are present in ocean waters (Suttle, 2005), which translates into approximately 10 million viruses per millilitre (about 20 drops) of surface seawater (Wilhelm and Suttle, 1999; Breitbart, 2012). This means that viruses make up about 94% of all microbes, and 5% of all microbial biomass (Suttle, 2007). It also means that viruses contribute by far the greatest number of genes to the total gene pool on the planet. Most marine viruses are bacteriophages ('phage' or 'bacteriophage' are terms used specifically to describe viruses infecting and replicating in bacteria), and are therefore harmless to the more complex eukaryote life forms (including humans). That said, all life forms will be, or have been, infected by one or several of their own viruses. These include the marine megafauna (whales, dolphins, penguins, etc.) that inhabit the southern African coast. Based on the overwhelming number of viruses in marine systems, they are expected to play a pivotal role in driving marine ecosystem dynamics – largely by controlling the population numbers of the more dominant species, and thereby allowing weaker competitors to co-exist (Brussaard et al., 2008).

Some viruses are able to copy parts of their host's genome and insert it into themselves, or insert all or parts of their own genome into their hosts (Stevens et al., 2014), which is a strategy that has evolved to maximise their own genome's replication. One such process, referred to as horizontal gene transfer, has dramatically shaped the evolutionary history of the majority of organisms on earth. Recent discoveries from whole-genome sequencing have led to the discovery of the central role of viruses in the spread of important metabolic functions among organisms. One prominent example is the finding of enhanced photosynthesis-enabling photo-system genes in the genomes of certain marine viruses, which lack the cellular machinery to photosynthesise, but transfer this information to their hosts. One of the most astounding findings was that the majority of photosynthetic genes in the ocean exist in viruses (or phages) that infect cyanobacteria. This translates into the production of about 20% of the total oxygen on earth (or two out of every 10 breaths), based on genes that were once carried by marine viruses (Mann et al., 2003). These recent research findings illustrate that viruses, despite their minute size, are powerful ecological agents. Improving our understanding of the functional roles of marine viruses therefore holds great potential for innovations that may revolutionise marine and maritime biotechnologies.

Despite marine viruses being the most abundant and genetically diverse biological entities on earth (Suttle, 2005; Angly et al., 2006; Suttle, 2007), we still lack basic knowledge of viral diversity, viral life cycles and their host affiliations. This generally results in the exclusion of viruses from marine ecosystems or biogeochemical models. Several global surveys have been undertaken in the last decade to improve our understanding of microbial and viral diversity in the oceans (Breitbart et al., 2002; Angly et al., 2006; Williamson et al., 2008; Ray et al., 2012; Brum et al., 2013; Hingamp et al., 2013; Hurwitz and Sullivan, 2013 ), such as the Global Oceanic Sampling Expedition (Rusch et al., 2007; Yooseph et al., 2007; Williamson et al., 2008) and the Tara Ocean expedition (Karsenti, 2012). Despite these sampling efforts, South African waters remain largely unsurveyed. Recently, an interdisciplinary team, led by scientists from the University of Cape Town, started studying virus diversity in the Southern Ocean, Benguela (west coast) and Agulhas Current (east coast) systems. This is being done to characterise patterns of diversity, and to get a first glimpse of the ecological roles of viruses in these contrasting ocean systems.

**What are marine viruses?**

A virus is an acellular organism. Its genome, which consists of nucleic acid (DNA or RNA), is surrounded by a protective capsid made of proteins. Viruses take over their hosts' replication systems and form a pool of components, which assemble into the next generation of virus particles. Viruses occur in a multitude of shapes of widely varying sizes, with genome sizes ranging from the very small (2 000 bases) to the very large (over 2.5 million bases). In fact, our ignorance of the virus world was recently highlighted through the discovery of giant viruses, largely associated with aquatic environments, that have been given names such as *Mimi-*, *Mama-*, *Mega-* and now even *Pandoravirus*. These are generally referred to as nucleocytoplasmic large dsDNA viruses (NCLDVs) (Claverie and Abergel, 2013; Filee, 2013; Hingamp et al., 2013), for which the proposed taxonomic order *Megavirales* has been formed (Colson et al., 2012; Philippe, 2013). Virus particles are assembled inside host cells, mainly from protein components specified by the virus, in a programme of assembly specified by the structure and concentrations of the components. As a result, they often exhibit fascinating geometric shapes (Figure 5), such as the icosahedral heads and helical tails of many bacteriophages (viruses infecting bacteria). The morphology of a virus is, however, not indicative of which species it is or its specific host affiliation, which can only be determined with the use of molecular and culture methods.

Biotechnological applications include the development of viral products – such as the viral enzymes that cause cells to burst – to destroy biofilms (Sutherland et al., 2004), and their use as pharmaceuticals (Liu et al., 2004; Housby and Mann, 2009). With the advent of new technologies to study viruses, a new era of biodiscovery has started. For example, in phage therapy, the control of pathogenic bacteria is achieved by bacteriophages, which control a specific pathogen while leaving beneficial bacteria (such as the normal human intestinal microflora) intact. While this technology has promising advantages and has been investigated for nearly 100 years, it is still in its stages of early development.

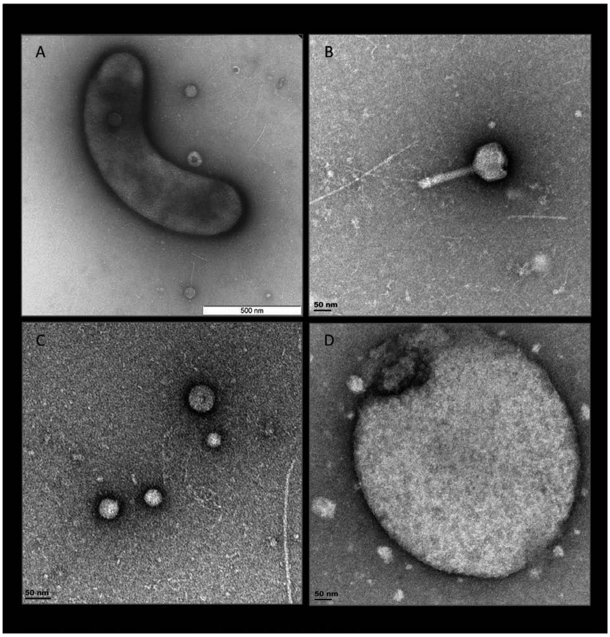


***Figure 5:*** *Examples of marine viruses from oceans surrounding South Africa, visualised by transmission electron microscopy (TEM). A: A bacterial cell surrounded by four viruses (bacteriophages). B: Member of the order Caudovirales characterised by an icosahedral head and helical tail; sample collected in the Benguela Current system off the West Coast of South Africa. C: Small unidentified viruses common in a coastal sample from the West Coast. D: A putative Pandoravirus, a member of a newly discovered group of giant viruses; sample collected in the Southern Ocean. Note: Figures B, C and D are represented on the same scale to show the great differences in sizes among viruses.*

## 4.1 Viruses and biogeochemical cycles

It is estimated that, per day, $10^{29}$ bacterial cells are infected with viruses across the world's oceans. This is mainly lytic infection, which means that cells burst and their contents become part of the dissolved pool of nutrients. This results in the release of hundreds of gigatonnes of soluble carbon compounds per day (Suttle, 2007), which get recycled by regenerated primary production. By transforming particulate organic matter (POM) at the ocean's surface to dissolved organic matter (DOM), this 'viral shunt' could profoundly slow down carbon export into the deep ocean by the biological pump (as mentioned above), which could have dramatic effects on global climate, such as speeding up global climate change (Suttle, 2005; Weinbauer et al., 2007).

However, recent models also suggest that carbon-rich cell walls and membranes are probably congregating to form flocculants, which sink in the deep ocean, thereby sequestering disproportionate amounts of carbon. The latter model suggests that viruses could speed up the biological pump, and may act to stabilise climate. This is just one example of how the tiniest ocean inhabitants drive large-scale biogeochemical processes (Azam et al., 1983; Wilhelm and Suttle, 1999; Suttle, 2005; Suttle, 2007; Bonilla-Findji et al., 2008; Brussaard et al., 2008). It also illustrates that the current understanding of the role of viruses in marine ecosystems is rudimentary, and investigations addressing their quantitative role in these systems are badly needed. This will require a multidisciplinary approach, and benefit from cross-fertilisation between the current largely separate research fields of virology, biogeochemistry and plankton ecology.

## 4.2 Marine viruses as pathogens

Even though they are in the water, marine viruses can have a large impact on human life. For example, although *Vibrio cholerae* is best known as a human pathogen, it is common in near-shore environments along the world's coasts as a native marine organism, and is generally harmless. However, it becomes a hazard for human health when a bacteriophage inserts itself into the cell genome, and causes it to make the infamous cholera toxin (Waldor and Mekalanos, 1996; Munn, 2006).

Viruses can heavily affect aquaculture systems, where unnaturally high numbers of organisms of the same species are grouped together in the same environment. In the last decade, aquaculture facilities have dramatically increased worldwide – and with them, the numbers of organisms of the same species in a confined area. Examples in South Africa include abalone, oysters and mussels, and certain species of freshwater and marine fish. Since the infectivity of micro-organisms such as bacteria and viruses is determined by host encounter rates, which are markedly higher in dense populations of one species, they thrive under such artificial conditions. Aquaculture systems are therefore highly subject to viral and other diseases, which can cause great economic loss – and which can contaminate natural environments as well. Different case studies have been reported during the past years, such as the spread of the white spot syndrome disease across crustaceans in Asia (Lo et al., 1996), which cause 100% mortality in a few days (Munn, 2006). Other cases include various viral diseases affecting salmon in intensive aquaculture systems around the world, as well as other fish aquaculture factories (Lotz, 1997; Ellis, 2001). More alarmingly, new research has shown that bivalves accumulate and concentrate nasty human viruses such as the vomiting norovirus (Lees, 2000). Marine life is therefore not only susceptible to viral infection, but it can harbour and be a source of new pandemics. Species already threatened by climate change, overexploitation or habitat destruction are under stress, which can lead to an increase in viral infections. For example, the increasing density of human settlements in proximity to breeding colonies of seals has apparently resulted in seals being fatally infected with morbilliviruses (Kennedy et al., 2000). Moreover, transmission the other way, from marine organisms to humans, is a likely mechanism to increase virulence. The most famous examples of such a vector are those of pandemic outbreaks of avian flu or swine flu, which have had drastic effects on human populations (Waltzek et al., 2012).

## 4.3 Marine viruses as biocontrol of harmful algal blooms?

As mentioned, there are some algal species that can become a nuisance by causing exceptional sudden blooms. Many often disappear as quickly as they are formed.

Several studies suggest that viruses frequently cause the natural termination of HABs (Nagasaki et al., 1994; Lawrence et al., 2002; Gastrich et al., 2004; Tomaru et al., 2008). This has led to scientists in Japan considering the use of viruses to control such blooms (Nagasaki et al., 1999; Nagasaki et al., 2002). This strategy would entail having a thorough understanding of which viruses are associated with the micro-algae linked with harmful blooms, and culturing both the algae and the viruses in order to have stocks of such potential biocontrol agents. Furthermore, extensive risk assessments will need to be conducted regarding the infectivity of other organisms by the viral biocontrol. This is a strategy that is not currently being investigated in the South African context.

## Conclusion – the way forward for microbial research in South Africa

In the oceans, microbes constitute by far the most dominant group of organisms in terms of their biomass, diversity and functional roles. Marine microbes provide the foundation of ocean food webs by producing the organic material for consumption by all other consumers, including fish and humans. Moreover, microbes are central in biogeochemical cycling, and thereby serve to stabilise the global climate and maintain ecosystem health. It is therefore alarming that there is an obvious deficiency of studies that address the diversity and functional roles of marine microbes. In South Africa and most of the rest of the world, microbes are currently not considered in assessments of the status of marine biodiversity, and microbes are not considered when setting conservation targets. Very few aspects of microbial activity, such as chlorophyll concentrations or *E. coli* counts, have thus far been integrated into systematic monitoring programmes that aid the management of fisheries, pollution and coastal user safety. Yet, as highlighted in this chapter, the discoveries made in marine microbial research hold great potential for application in conservation and Blue biotechnology.

There are several reasons for this enormous gap in knowledge, some of which are general and others specifically apply to South Africa. Firstly, until recently, microbial research was lacking technologies for high-throughput analyses, which made the generation of interesting results relatively slow and tedious. This chapter has outlined several novel molecular and automated approaches, which – if applied to the study of marine microbes – are bound to lead to groundbreaking discoveries. Secondly, advances in marine microbial science require the integration of traditionally separate research fields, such as those of molecular biology, microbiology and biotechnology with marine ecology, biogeochemistry and conservation. Despite recent efforts to support interdisciplinary approaches in South Africa, forming bridges between disciplines has been slow due to the lack of shared forums where researchers from disparate fields interact and form collaborations. For example, no clear microbial consortium with regard to monitoring and conservation exists that is on par with European panels, such as MICROCEAN. Thirdly, South Africa has limited research capacity and funding compared to more developed nations. This highlights the need for local and international collaborations and the identification of focus areas of microbial research, in which South Africa can take the lead. The unique advantage of South Africa is its position amidst three contrasting ocean systems (not to mention many estuaries), which have all been identified as key areas for oceanographic research concerning global climate change and fisheries management. This natural advantage and South Africa's access to several research vessels, including the state-of-the-art *Agulhas II*, enables participation in concerted international sampling programmes such as the Global Ocean Observation System (GOOS) in the Southern Ocean.

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# Chapter 7 Hydro-acoustic Technology and its Application to Marine Science in South Africa

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## 1. Introduction

The marine ecosystem of South Africa is one of the most diverse, complex and productive marine ecosystems in the world (e.g. Branch et al., 2010). However, the management of marine resources in South Africa and worldwide is challenging, and like so many other marine ecosystems, the South African marine ecosystem has been subjected to adverse anthropogenic effects brought about by mismanagement and overexploitation. The ultimate success of marine resources management in the long run depends on knowledge of the size and distribution of exploited marine living resources (e.g. Hilborn, 2007) and how their exploitation impacts on the remainder of the ecosystem (FAO, 2003). To achieve effective monitoring and management of marine living resources in a vast, mainly inaccessible and hostile environment requires innovation and the use of the best available technologies and methods.

Hydro-acoustic methods (Lurton, 2002; Simmonds and MacLennan, 2005) are effective for studying aquatic animals and their environment without causing any significant environmental harm or change. Human vision is capable of penetrating only a few metres below the surface of the water, whereas sound can travel to thousands of metres below the surface. Environmental conditions, such as temperature and salinity, affect the speed and propagation of sound in water. Sound travels faster in warmer water than in cold water due to the effect of water density on the propagation of sound waves (Urick, 1983). The speed of sound in water also depends on salinity; approximately 1 450 m/s in fresh water, increasing to around 1 500 m/s in salt water. This is 4.4 times faster than the speed of sound in air, which together with the low absorption rate compared to light and other forms of electromagnetic radiation, makes sound the most effective means of communicating under water.

This chapter presents a summary of the application of active hydro-acoustics in fisheries research, oceanography and geomorphology in South African waters. It highlights opportunities for further development and identifies areas that need further research, particularly in a South African context. The use of passive acoustics to study organisms that produce sounds is excluded in this chapter, since it is the subject of Chapter 8.

## 2. Basic principles

The active hydro-acoustic method entails the transmission of an acoustic pulse through the water and measurement of its reflection by objects that have a density that is different to that of seawater, and/or in which the speed of sound is different to that in water. These include boundaries such as the surface and the seabed, living organisms such as fish and plankton, and density discontinuities in the water column.

In a homogenous water column (without density gradients), sound travels in straight lines and there is a simple relationship between the strength of an echo and its distance from the sound source. However, because the density of seawater is usually vertically stratified because of temperature and salinity gradients, the speed of sound through the water column is not constant. A sound wave that is not travelling vertically will therefore be refracted, making for a more complex, variable relationship between distance and echo strength. Two types of directional transmitting techniques are commonly used in fisheries acoustics; those employing vertical sounding (echo sounders) and those using horizontal or near-horizontal sounding, known as sound navigation and ranging (sonar). Echo sounders are more reliable for quantifying fish biomass, as the vertical transmission of sound ensures that the intensity of the sound is not affected by refraction. Sonar systems, which are subject to the effects of refraction, are more suited to locating fish and observing fish behaviour over large distances in a 360˚ sector around the vessel.

An echo sounder consists of a transducer, transmitter and receiver (transceiver), interfaced to a computer that controls functioning through user-defined settings, and stores the received acoustic data. The transducer is conventionally mounted on the hull of the vessel, but can also be towed behind the vessel or fitted to a pole extended over the side. It converts electrical energy into vibrations that generate a longitudinal pressure wave (or sound wave) that propagates through the water. The elements of a transducer act together to form a beam that spreads spherically from the transducer face in the shape of a cone – much like the beam produced by a flashlight. The transducer also serves to transform the received pressure wave (reflected sound) back into an electrical signal. The transceiver transmits regular high-voltage electrical pulses of fixed duration to the transducer and also receives and amplifies electrical signals produced by the transducer from received echoes. The acoustic pulses generated by the system (called 'pings') are generally of short duration (milliseconds) and are sent out at an interval that depends on the range to the targets of interest – typically around one pulse per second.

Transducers commonly used in fisheries research operate over a range of frequencies between 10 kHz and 200 kHz. Low-frequency transducers produce wide beams and pressure waves of long wavelengths that generally travel further, whereas high-frequency transducers produce pressure waves of shorter wavelengths that have a more limited range since sound absorption increases strongly as frequency increases. However, high-frequency transducers have the advantage of generating short pulses in narrower beams, thus increasing the ability to distinguish between targets that are a short distance apart (the spatial resolution). The selection of which frequency to use therefore depends on the maximum detection depth, required resolution, the size of the target and its ability to reflect sound (known as its target strength), noise and interference with other equipment. For studies at great depths (> 1 000 m), a frequency between 10 kHz and 50 kHz is generally appropriate, whereas shorter-range applications in which a fine spatial resolution is needed require transducers operating at higher frequencies (typically > 100 kHz) (Simmonds and MacLennan, 2005).

Higher-frequency sound waves tend to produce stronger echoes from small targets (such as zooplankton) compared to low-frequency waves, which are more suited for the detection of larger targets, such as fish. The transducers recommended for fisheries research typically have beam angles (beam widths) of < 12˚ depending on the transducer size and frequency. They can be either single-beam or split-beam, in which the elements are divided into four separate quadrants, which enables the position of a target within the beam to be determined from the differences in the phases of the echo signals that reach each quadrant. This is important for estimating fish target strength by analysing echoes received from individuals in different parts of the beam in their natural state (the so-called *in situ* target strength estimation method).

Another application of acoustics in marine studies, which has increased rapidly with improvements in technology, is the use of acoustic telemetry to track the movements of fish and marine mammals fitted with acoustic tags.

Other acoustic systems used in marine research include net-mounted echo sounders (net sounders) to monitor the performance of trawl nets; side-scan sonars, which generate high-resolution acoustic images of objects (usually on the seabed) a short distance on either side of the ship's track; multibeam bottom-mapping systems that produce lower-resolution images of the seabed over a wider swathe, and a variety of high-intensity sound sources (sparkers, boomers and parametric sounders) to detect objects and reflecting surfaces below the seafloor. Acoustic technology is also widely used in oceanographic studies, including acoustic Doppler current profiling (ADCP) to measure current speed from shifts in the frequency of reflections from particles moving with the current, and the use of acoustic transmissions to locate, release and recover oceanographic moorings.

## 3. Applications in South African marine science

### 3.1 Fisheries surveys

Attempts to use acoustic techniques to assess the size of the Namibian sardine *(Sardinops sagax)* stock, in conjunction with night-time aerial surveys, were made by South African scientists in the 1970s (Cram and Hampton, 1976; Hampton et al., 1979). A few years later, this was followed by acoustic studies on the abundance, distribution and behaviour of Antarctic krill *(Euphausia superba)* as part of South Africa's contribution to the international Scientific Committee on Antarctic Research/Scientific Committee on Oceanic Research (SCAR/SCOR) Biological Investigation of Antarctic Systems and Stocks (BIOMASS) Programme (Cram et al., 1979; Miller and Hampton, 1989).

Fisheries acoustics research in South African waters started in 1982 with the commissioning of the fisheries research ship (FRS) *Africana* (see Plate 1) – a 79-metre, 2 400 HP diesel-electric-driven FRS – used by the Sea Fisheries Research Institute (SFRI) of the Department of Environmental Affairs and Tourism (DEAT) at that time. The vessel was designed to be exceptionally quiet for this specific purpose, and was well equipped with a wide range of commercially available acoustic survey equipment and a locally designed and built acoustic data-logging and analysis system (Anon, 1986). In 1993, the SFRI/DEAT capacity for acoustic surveys was augmented by the arrival of the FRS *Algoa*, a 52-metre converted stern trawler, equipped with, inter alia*,* 38 kHz and 120 kHz scientific echo sounders. In recent years, use has also been made of a commercial fishing vessel, FRS *Compass Challenger*, a 52-metre deep-sea stern trawler equipped with the basic scientific and trawling equipment needed for acoustic surveys.

***Plate 1:*** *FRS* Africana*, from which most of the acoustic surveys of fish stocks in South African waters have been undertaken (image by Johan Rademan).*

The first reliable estimates of anchovy *(Engraulis encrasicolus)* biomass were derived from an FRS *Africana* survey in 1984 (Hampton, 1992). Since then, acoustic surveys for estimating the recruiting and spawning biomass of anchovy and sardine *(Sardinops sagax)*, and the adult biomass of round herring *(Etrumeus whiteheadi)* – also known as red-eye – over most of the South African continental shelf have been conducted biannually every year as the primary basis for managing these resources (e.g. Hampton, 1992; Barange et al., 1999; Coetzee et al., 2008a). Between 1984 and 1994, the acoustic estimates of anchovy spawner biomass were combined with estimates derived from contemporaneous estimates of egg production (Armstrong et al., 1988) to give estimates that were more robust than those from either method alone (Hampton, 1996). Acoustic studies aimed at estimating biomass and elucidating behaviour and distribution patterns have also been conducted on Cape horse mackerel *(Trachurus trachurus capensis)* (e.g. Barange et al., 1998) and the non-commercial but ecologically important species lanternfish *(Lampanyctodes hectoris)*, lightfish *(Maurolicus walvisensis)* (In Hampton et al., 2008) and jellyfish (*Chrysaora hysoscella* and *Aequorea aequorea*) (Brierley et al., 2005). The routine pelagic surveys have been managed in turn by the SFRI, DEAT's Marine and Coastal Management (MCM) Division, and most recently by the Fisheries Branch of the Department of Agriculture, Forestry and Fisheries (DAFF).

Acoustic estimates of small pelagic fish and nearshore spawning aggregations of chokka squid *(Loligo reynaudii)* are also obtained from small boats fitted with a scientific echo sounder transducer mounted on a pole close to the stern (Lipinski and Soule, 2007; Soule et al., 2010). The transducer is positioned at a depth of one metre below the surface, which allows surveys to be carried out in water too shallow to be accessible to large research vessels. This is important for estimating the abundance of juvenile pelagic fish and squid that prefer the nearshore environment, and also for estimating the prey availability around important penguin

*(Spheniscus demersus)* breeding colonies, such as Dassen Island, Robben Island, St Croix Island and Bird Island. Monthly surveys around some of these islands provide frequent, high-resolution information on the abundance and distribution of forage fish in the vicinity.

Different models of scientific echo sounders have been used on FRS *Africana* since her commissioning, including the initial Simrad EK S-38, the Simrad EK 400 in 1991, followed by the Simrad EK 500 in 1996 and the Simrad EK 60 in 2003. The beam widths of the current 38 kHz, 120 kHz and 200 kHz transducers are approximately 7°, whereas that of the 18 kHz transducer is around 11°. These transducers are installed on a streamlined blister that protrudes 0.5 m from the hull (see Figure 1). FRS *Africana* is now also fitted with a modern multibeam, sector-scanning Simrad SP70 sonar, which is used for locating fish during aimed midwater trawling to identify targets detected by the echo sounders, and to study fish behaviour. A Simrad FS20/25 net sounder, with scanning transducers attached to the head rope, provides a real-time display of temperature, the number of fish entering the net, and the behaviour of the fish in front of the net. It also displays the distance of the footrope from the bottom, ensuring that the expensive trawl equipment does not get damaged or lost by coming into contact with rocky seafloors. Similar transducers mounted on other parts of the net are used during 'swept-area' trawl surveys of demersal fish to estimate the actual time that the trawl gear was in contact with the bottom, and the area effectively swept by the trawl.

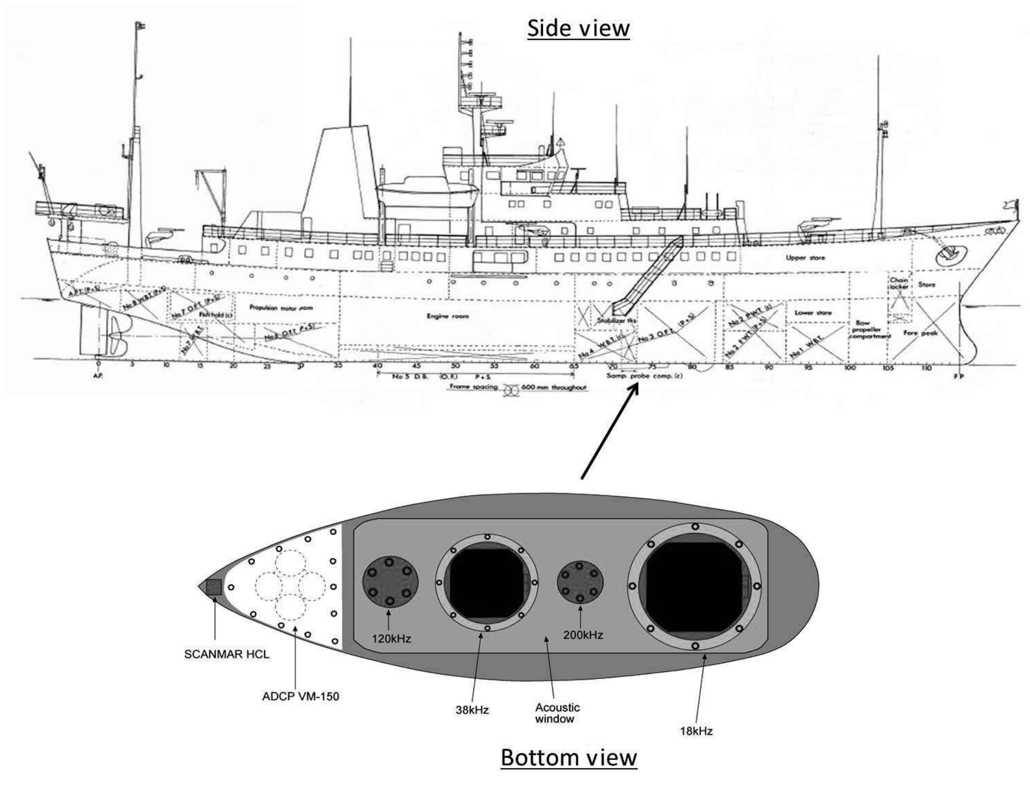


***Figure 1:*** *The layout of the four echo sounder transducers (18 kHz, 38 kHz, 120 kHz and 200 kHz) on the starboard blister of FRS* Africana*. The four-element acoustic Doppler current profiler transducer and the sensor for receiving communications from the transducers mounted on the trawl net are on the after end of the blister.*

Biomass estimates from acoustic surveys are made by the echo-integration technique, in which estimates of the average amount of acoustic energy reflected from the fish targets of interest are scaled by an estimate of the average target strength of a single fish (preferably obtained from *in situ* experiments) to give an estimate of the average fish density in the area surveyed, and thereby of biomass (e.g. Simmonds and MacLennan, 2005). For this, the sensitivity of the echo sounder and the beam characteristics have to be measured before, during or after the survey. In all but the earliest years of the South African pelagic fish surveys, this has been done routinely by measuring the reflection from a metallic calibration sphere of accurately known reflectivity (Foote et al., 1987) according to internationally accepted practice.

The estimation of target strength is a critical problem in the use of echo-integration to estimate biomass since a fish's ability to reflect sound at a particular frequency is a complex function of its size, anatomy (particularly whether it contains a highly reflective gas-filled swim bladder or not), morphology, physiology and behaviour, and cannot be predicted theoretically with the necessary accuracy. For this reason, it is usually estimated empirically from *in situ* experiments, in which the echoes selected for analysis are assumed to originate from single fish that are representative of the population under study.

In South Africa, target strength-length relationships have been obtained from *in situ* experiments on a number of commercially important pelagic fish species (Barange et al., 1996), including sardine, anchovy and horse mackerel (Barange et al., 1996); and for chokka squid on the Cape south coast (Soule et al., 2010). The relationships for sardine and anchovy have now been adopted in some acoustic surveys of these species elsewhere (Patti et al., 2004; Zwolinski et al., 2012). During the course of this work, a number of advances in the method have been made through controlled experiments on the problem of single-target recognition on model targets in the large hydro-acoustic test tank at the Institute for Maritime Technology in Simonstown (Soule et al., 1995; Soule et al., 1996); a unique facility for such studies. A new algorithm for distinguishing between echoes from single and multiple fish targets proposed and tested in these studies (Soule et al., 1997) was subsequently implemented in globally used commercial target-strength estimation software.

In a collaborative project with the SFRI, the Electrical Engineering Department of the University of Cape Town proposed, developed and tested a new acoustic method of estimating fish density from the statistical properties of the back-scattered signal (Weintroub, 1986; Smith, 1988; Denbigh et al., 1991). Although of limited applicability, the method has the attractive advantage of not requiring knowledge of target strength. In a later collaborative project between the same organisations, a high-frequency multibeam echo sounder for the counting of fish in relatively dense aggregations – code-named ABACUS (Advanced Beam-former for the Acoustic Counting of Underwater Scatterers) – has been built and tested to operational level (Wilkinson, 2004; Ng, 2005; Mussai, 2006). In principle, the counts enable number density to be estimated directly, which, if combined with measurements of the energy reflected from the same volume of water, would enable target strength to be estimated *in situ* from aggregations that are too dense for the application of conventional *in situ* target-strength estimation techniques. The system is awaiting further development and testing in the field.

An important aspect of an acoustic survey is the survey track, which should be designed in such a way as to deliver robust, unbiased estimates of biomass and sampling error to the maximum extent possible in practice. For this purpose, a random stratified sampling design was developed early in the programme by Jolly and Hampton (1990), which has subsequently become widely used in acoustic surveys of fish populations in the open ocean and enclosed water bodies (e.g. Gunderson, 1993; Simmonds and MacLennan, 2005; Parker-Stetter et al., 2009). The random element ensures that the estimates of biomass and sampling error are unbiased irrespective of the distribution, while the stratification (which is based on previous distributions and information gained as the survey progresses) assists in allocating effort to the high-density regions, thereby reducing the sampling error. An example is shown in Figure 2.

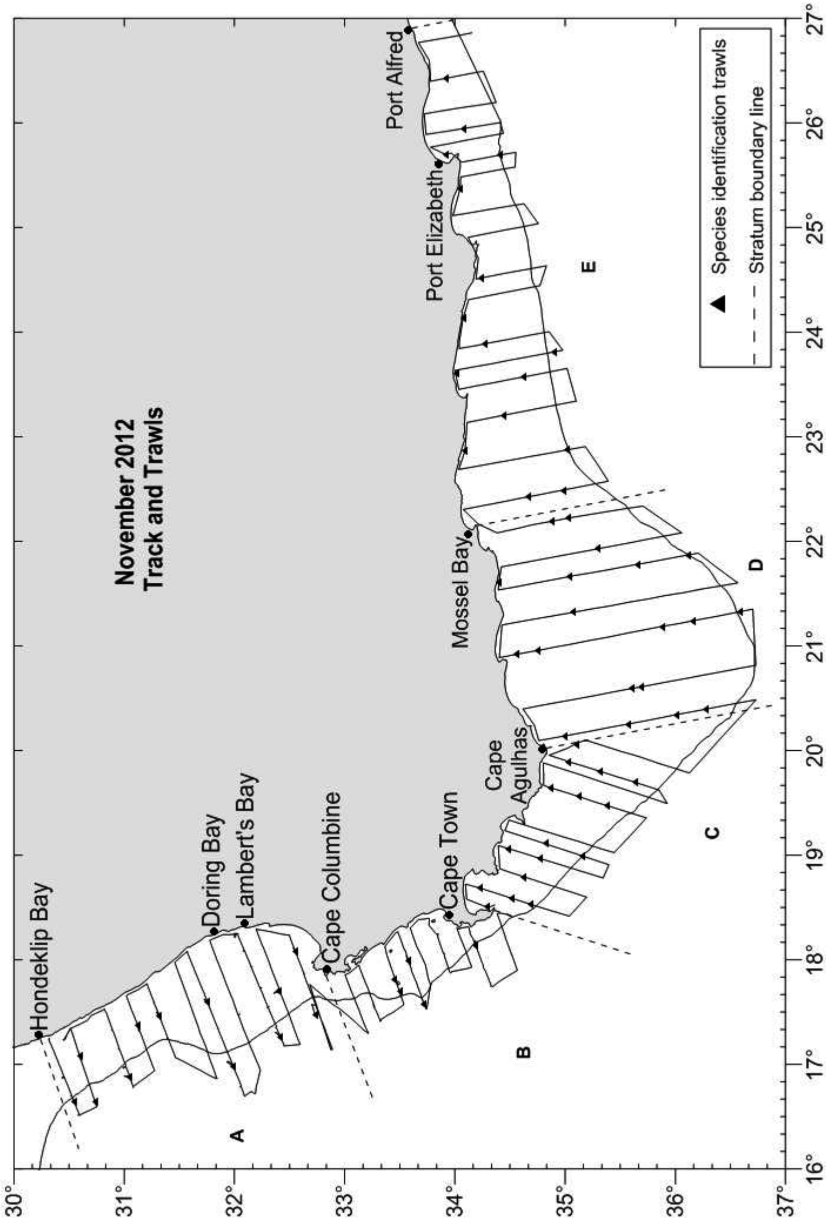


***Figure 2:*** *Map illustrating the stratified random survey design in a survey of the South African west and south coasts from FRS* Africana *(Strata A and B) and FRS* Compass Challenger *(Strata C to E) in November 2012. The triangles show where the midwater trawl was shot to identify acoustic targets.*

An example of echograms displaying aggregations of anchovy, sardine and round herring by day, and of a mixed layer of anchovy and round herring by night is shown in Figure 3.

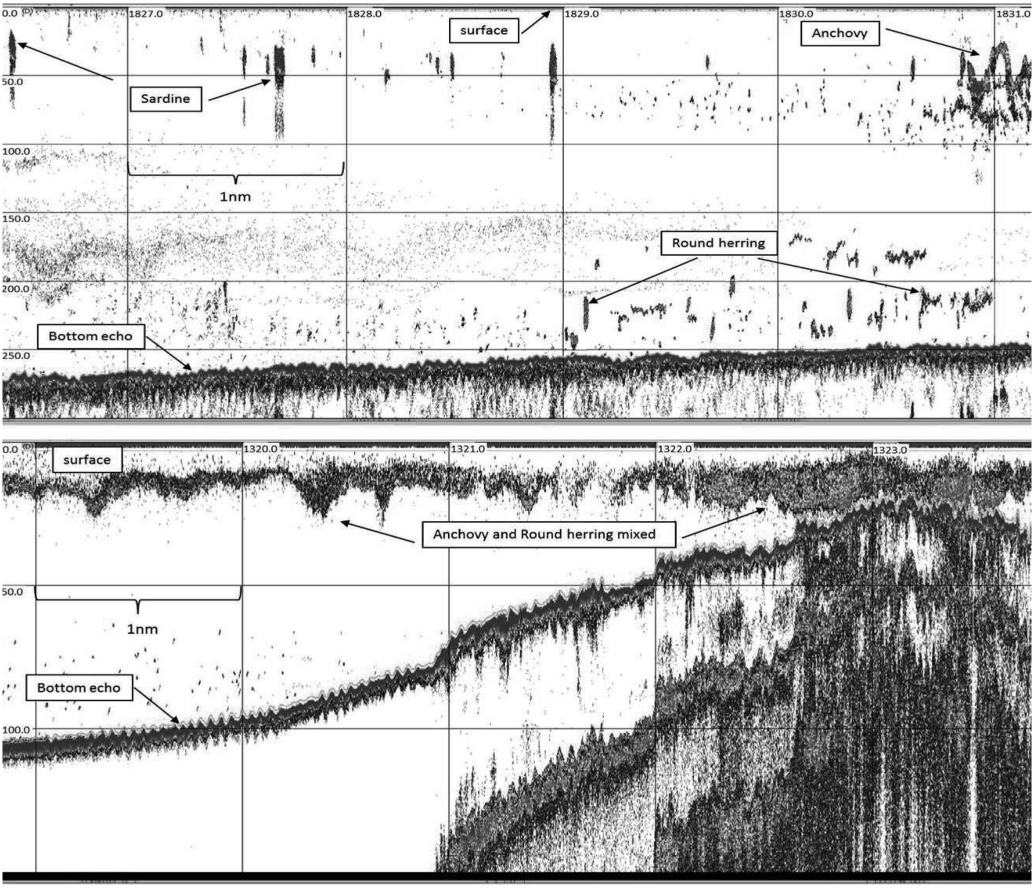


***Figure 3:*** *Two 38 kHz echograms showing aggregations of sardine, anchovy and round herring on the Agulhas Bank by day (upper panel), and a mixed layer of anchovy and round herring by night (lower panel). [See colour figure on page 309.]*

With experience, acoustic practitioners learn to identify the species likely to be responsible for aggregations such as those in Figure 3, based inter alia on their depth, location, appearance, behaviour and density characteristics. More sophisticated, automated ways of using this information for target identification have also been developed. For example, in South Africa, principle component and discriminant function analyses have been used to test the efficacy of 18 morphometric, energetic and bathymetric descriptors to distinguish between aggregations of sardine, anchovy and round herring (Lawson et al., 2001). The aggregations were extracted from the acoustic record through the Shoal Analysis and Patch Estimation System (SHAPES), a locally developed aggregation recognition system that, with some modification, has since been incorporated into Myriax ECHOVIEW (www.echoview.com), a widely used commercial software package for analysing acoustic survey data.

Despite the availability of target identification techniques such as the above, it is still necessary to verify target identifications periodically, and to sample the length distribution of the fish and the species composition of aggregations to estimate the proportion of the reflected energy that is contributed by each species. This is done with a small midwater trawl towed at the depth of interest (shown in Plate 2).

***Plate 2:*** *A midwater trawl on FRS* Africana *retrieving a catch of pelagic fish taken from a school detected by the echo sounder. The arrival of birds during retrieval is usually indicative of other schools in the area and of a good catch.*

The species and length compositions derived from the trawl samples are used in target strength-length expressions to generate biomass estimates and distribution maps for a number of species from each survey (see Figure 4). Other biological data are also obtained from the trawl samples, including information on fish condition, sex ratios and reproductive state, while otoliths are removed for later age estimation.

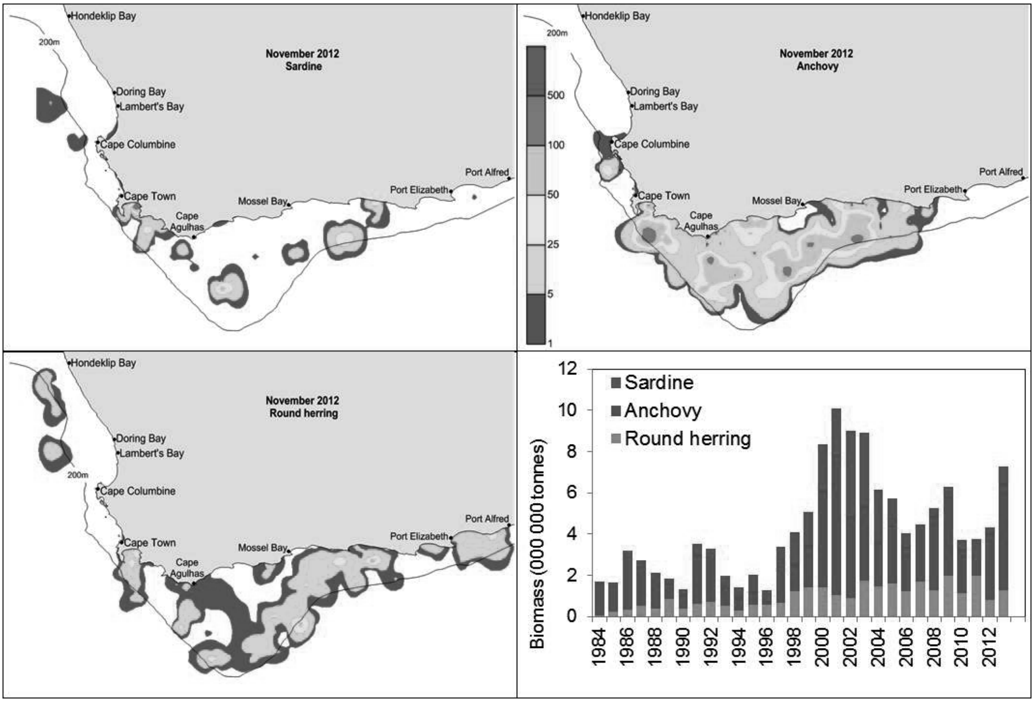


***Figure 4:*** *Maps of sardine, anchovy and round herring density derived from surveys by FRS* Africana *and FRS* Compass Challenger *in November 2012. The density scale is in gm$^{-2}$. The bottom right panel shows the biomass estimates for the three species from the surveys in November since the start of the time series in 1984. [See colour figure on page 309.]*

The estimation of error is important in acoustic surveys since the uncertainty in the biomass estimates is taken into account in the management of the resources on the basis of the survey results. This is done through the inclusion of error probability density functions in the models used to recommend catch limits (e.g. De Moor and Butterworth, 2009). The errors can either be systematic (constant throughout the survey) or random. Examples of the former are calibration error and errors in the factors used to convert measurements of acoustic energy into fish density, such as the target strength and corrections for sound absorption. These errors affect absolute estimates of biomass, but if they stay constant during the survey or between surveys, they will not affect comparisons of biomass (relative estimates) within or between surveys, which are usually sufficient to monitor changes in stock size and distribution. Random errors due to variable factors such as avoidance of the vessel, variation in the proportion of the population that is acoustically undetectable, signal loss due to weather conditions, interference and statistical sampling error affect relative as well as absolute estimates. They have to be minimised or, if they introduce a bias, should be corrected as far as possible.

In the South African pelagic surveys, corrections are applied for fish too close to the coast to be surveyed from the research vessel, the absorption of sound by the fish themselves in dense, vertically extensive schools of sardine, and for saturation of the receiver in earlier surveys, in which the receivers had too limited dynamic range (Coetzee et al., 2008a). The inshore corrections, which are based on density measurements made from the survey vessel when it is as close to the coast as possible, are currently being tested by small-scale acoustic surveys from a small boat working in conjunction with the survey vessel. Weather-dependent noise or loss of signal is minimised by reducing speed or suspending the survey in bad weather. On South Africa's new 134-metre polar supply and research vessel, *SA Agulhas II*, on which the transducers are mounted on a drop keel, the loss is minimised by extending the transducers three metres below the hull in bad weather. Direct corrections for bubble-induced signal loss in hull-mounted 38 kHz transducers are now possible based on recent studies by Shabangu et al. (2014). On some surveys, a horizontally directed sonar is used to detect whether schools are avoiding the vessel, or are too close to the surface to be detected reliably by echo sounders, in which case the survey may be suspended until the schools become more detectable.

The annual acoustic estimates of sardine and anchovy recruitment strength in autumn, and of their spawning biomass in early summer (see Figure 4), together with the estimates of sampling error, are used to manage these fisheries through a joint operational management procedure (OMP) developed by the Marine Resource Assessment and Management (MARAM) Group in the Department of Mathematics and Applied Mathematics at the University of Cape Town, in collaboration with scientists from DAFF (De Oliveira and Butterworth 2004; De Moor et al., 2011). The OMP, which has been under continuous development since the 1980s, is designed to optimise the harvest of the two species within safety limits based on the uncertainty in the estimates. The exceptionally long time series of standardised biomass and sampling error estimates, together with a sophisticated OMP that has been developed in association with the industry and has been subject to regular international review (e.g. Smith et al., 2013), has provided an invaluable scientific foundation for managing the South African sardine and anchovy fisheries over the past three decades. It is probable that their sustainability over this period is largely due to the management procedure and the acoustic estimates on which the procedure is based.

In addition to the information on abundance, the acoustic surveys and methodological studies have generated considerable information on the movement, vertical migration patterns and aggregating behaviour of pelagic and mesopelagic fish on the continental shelf. Examples include an investigation into the use of sonar to augment echo-sounder surveys (Misund and Coetzee, 2000), a study on the morphology of sardine schools and their reaction to a survey vessel using echo sounders, a sector-scanning sonar and side-scan sonar (a novel application) (Misund et al., 2003), and the use of SHAPES to characterise sardine schools and investigate their spatial and temporal stability (Coetzee, 2000). Information on pelagic fish distribution derived from the acoustic surveys has also been used to elucidate patterns in the composition and spatial structure of pelagic fish communities on the west and south coasts (Barange et al., 1994; Barange and Hampton, 1997; Barange et al., 2005), leading to a better understanding of their role in the ecosystem. Another product of the surveys has been the elucidation and monitoring of a large-scale shift in the distribution of sardine and anchovy from the Western Agulhas Bank (west of 20° E) to the Eastern Agulhas Bank in the late 1990s (Roy et al., 2007; Coetzee et al., 2008b) and of the westwards return of sardine after 2005 (Figure 5).
The eastwards shift had major repercussions for the pelagic fishing industry, and aroused considerable interest among fisheries ecologists as being possibly indicative of a regime shift in the southern Benguela (e.g. Cury and Shannon 2004; Van der Lingen et al., 2006; Roy

et al., 2007). Acoustic surveys, in conjunction with hydrobiological sampling, have also yielded valuable information on the ecology of small pelagic fish along the east coast of South Africa (Armstrong et al., 1991; Coetzee et al., 2010), leading to an improved understanding of, inter alia, the annual 'sardine run' off the coast of KwaZulu-Natal in winter (Coetzee et al., 2010; Van der Lingen et al., 2010).

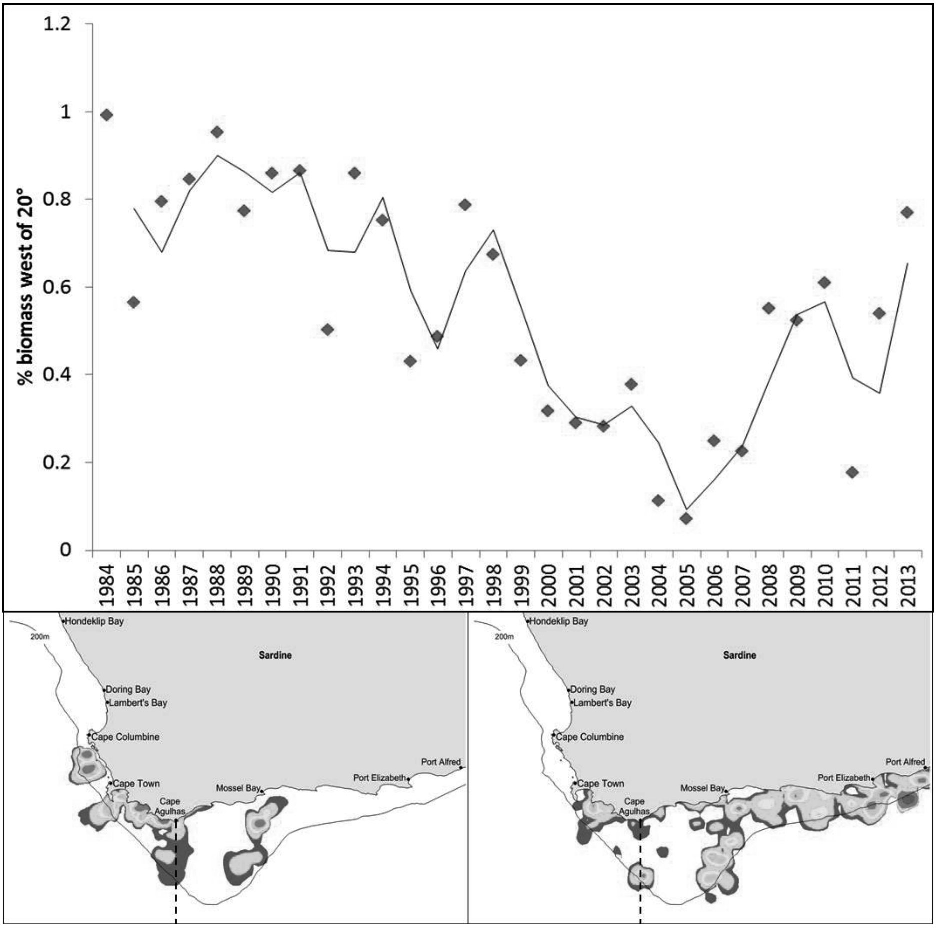


***Figure 5:*** *Changes in the proportion of the sardine biomass in November lying west of 20° E every year since the start of the surveys in 1984. The lower panels show the distributions in 1997 (left) and 2004 (right). [See colour figure on page 310.]*

## 3.2 Zooplankton studies

Zooplankton plays a critical role in structuring higher and lower trophic levels in the marine ecosystem, influencing the population dynamics of exploited species (Carlotti and Poggiale, 2010) and other ecosystem components such as marine mammals and seabirds.

Acoustics can provide insight regarding zooplankton abundance, behaviour and distribution, offering continuous and high-resolution observations that cannot be achieved with the discrete time and space scale of net sampling (Massé and Gerlotto, 2003; Koslow, 2009). Zooplankton, as any other acoustic scattering object, can be discriminated from other organisms such as fish by using its acoustic properties and its frequency dependence (Wiebe, 1988; Stanton et al., 1996; Kloser et al., 2002; Logerwell and Wilson, 2004). Aggregations of zooplankton typically contain a number of species with vastly different acoustic properties, varying in both species and size (Foote and Stanton, 2000; Lavery et al., 2007). Stanton et al. (1996) categorised zooplankton organisms into a few broad scatter groups according to their anatomy, as determined from their acoustic response (backscattering strength), namely fluid-like (euphausiid), hard elastic-shelled (gastropod) and gas-bearing (siphonophore).

Reflections from zooplankton appear in echograms as weak echoes when the animals are loosely aggregated, but can be much stronger when they are densely aggregated. Some zooplankton, such as siphonophores and jellyfish, can also produce strong echoes at low frequencies (Stanton et al., 1996; Brierley et al., 2004). Nonetheless, aggregations of zooplankton are relatively weak targets. This usually prevents their acoustic detection at great depths (Urick, 1983).

Echoes from zooplankton can often be isolated from those of fish by their relative weakness and characteristic differences in the scattering. Dual/multifrequency acoustic methods have been used to discriminate fish from zooplankton in many studies (Kloser et al., 2002; Logerwell and Wilson, 2004) and have become important tools for the discrimination and identification of acoustic targets. These techniques exploit the fact that scattering from zooplankton is more frequency-dependent than that from fish, particularly at high frequencies above about 100 kHz. They have also been used extensively to distinguish between, and thereby separate, different species and size classes of zooplankton (Korneliussen and Ona, 2003; McQuinn et al., 2013).

South African scientists have been involved in acoustic research on zooplankton since the pioneering work done by the SFRI on the abundance, distribution and behaviour of Antarctic krill *(Euphausia superba)* in the late 1970s and 1980s under the international BIOMASS Programme (e.g. Cram et al*.,* 1979; Miller and Hampton, 1989). Acoustic work on Antarctic krill has recently been resumed by DAFF from SA *Agulhas II*, which is equipped with 38 kHz, 120 kHz and 200 kHz scientific echo sounders. An example of a swarm of Antarctic krill detected at 120 kHz from *SA Agulhas II* in a recent study is given in Figure 6.

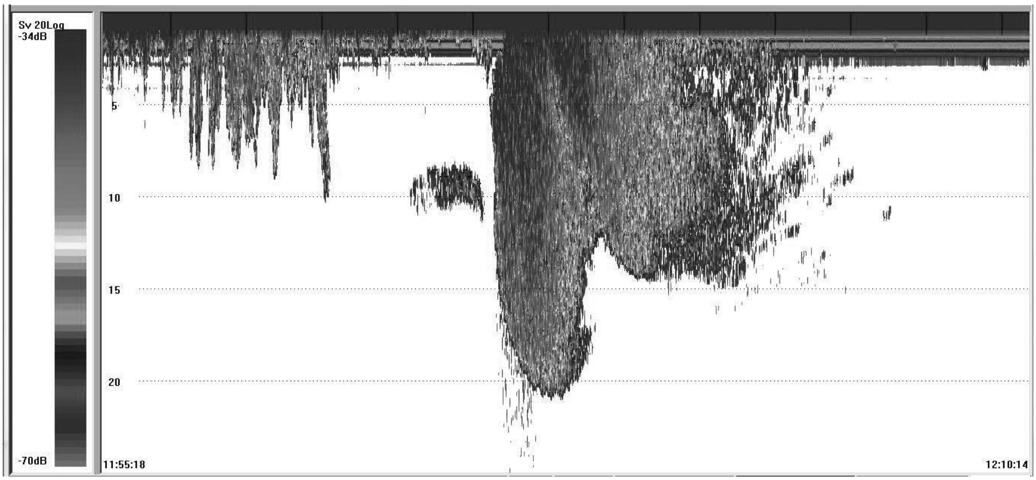


***Figure 6:*** *A 120 kHz echogram of a dense swarm of Antarctic krill in the upper 20 metres of the water column at midday. Data collected during the January 2014 South African National Antarctic Expedition (SANAE) from* SA Agulhas II*.*
*[See colour figure on page 310.]*

In recent years, multifrequency acoustic techniques have been used increasingly to study zooplankton distribution and ecological relationships in South African waters. An example of one of the more technologically sophisticated investigations is a study by Lebourges-Dhaussy et al. (2009), who used a multifrequency zooplankton profiling system, operating at six frequencies between 265 kHz and 300 mHz, to elucidate the spatial distribution zooplankton on the Agulhas Bank and its relationships with environmental parameters and anchovy distribution. Relationships between the larger size classes of zooplankton and environmental parameters were found at night in some areas, and a variety of size-dependent vertical migration patterns were elucidated. The study was also able to detect the effects of anchovy predation on small zooplankton in areas of high phytoplankton abundance.

Multifrequency acoustic methods using the echo sounders typically employed in surveys of fish (operating at the common survey frequencies of 38 kHz and 120 kHz) are increasingly being used in South Africa to identify and characterise zooplankton in the southern Benguela and Agulhas Current systems, and to distinguish between zooplankton and fish scatterers. An example of the discrimination between fish and zooplankton through a comparison of the scattering at 38 kHz and 120 kHz is shown in Figure 7. These are preliminary, unpublished results from a study by Lezama-Ochoa in collaboration with scientists at DAFF, the Department of Environmental Affairs (DEA) and the Institut de Recherche pour le Développement (IRD), France, based on methods recently developed by Lebourges-Dhaussy and Fernandes (2009). The methods were successfully applied in the Humboldt Current system by Ballón (Ballón, 2010; Ballón et al., 2011) and have recently been adapted to the Bay of Biscay by Lezama-Ochoa (Lezama-Ochoa et al., 2011; Lezama-Ochoa et al., 2014).

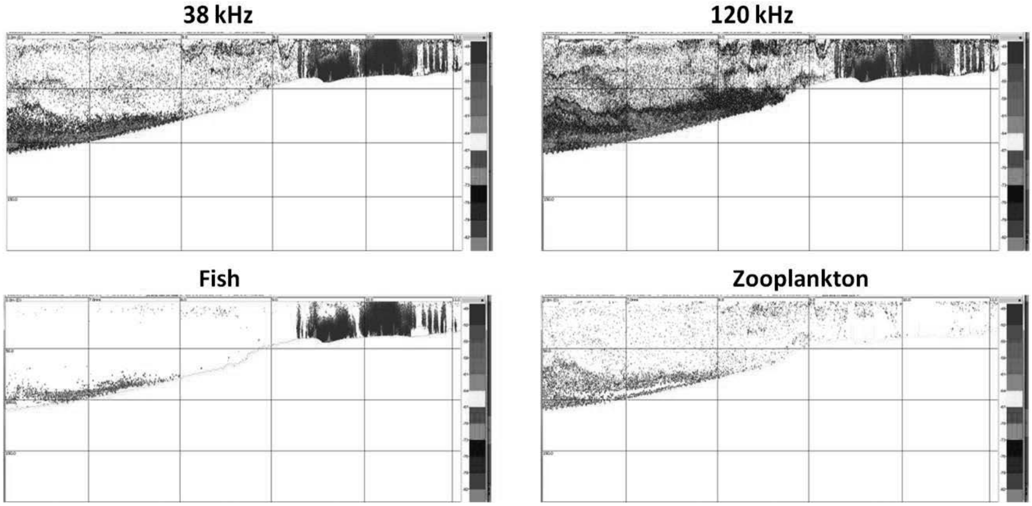


***Figure 7:*** *Acoustic discrimination between fish and zooplankton through the comparison of the scattering at 38 kHz and 120 kHz (top panels) and the filtering out of unwanted targets (bottom panels). [See colour figure on page 311.]*

In South African waters, acoustic identification is hampered by the frequent co-existence of fish, plankton, jellyfish and other sound-scattering organisms. To isolate these effectively through multifrequency acoustic techniques requires additional frequencies, since the ability to distinguish between scatterer groups improves as the number and range of frequencies increases (Napp et al., 1993).

An example of what can be achieved through the addition of a third frequency is shown in Figure 8, in which discrimination between fish and the three groups of zooplankton scatterers identified by Stanton et al. (1996) has been achieved by comparing the scattering at 18 kHz, 38 kHz and 120 kHz. This work can potentially lead to more accurate estimates of fish biomass through the removal of echoes emanating from dense layers of jellyfish and zooplankton. It will also contribute to an improved understanding of the distribution and abundance of the various zooplankton classes and the role that they play in the functioning of the southern Benguela ecosystem.

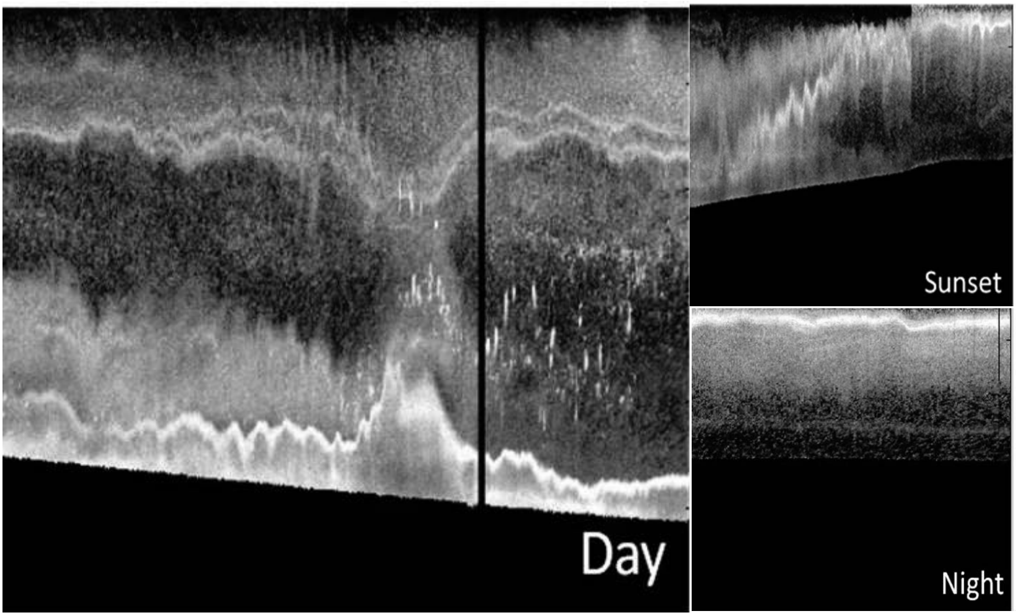


***Figure 8:*** *Discrimination of scatterers on the West Coast, based on the comparison of backscattering strength at three frequencies (18 kHz, 38 kHz and 120 kHz) at different times of the day. Four dominant classes of acoustic scatterers could be observed, namely (white) swim-bladdered fish, (pink) organisms with an echo maximum at 18 kHz (gelatinous zooplankton), (green) organisms with an echo maximum at 38 kHz (gas-bearing zooplankton), and (blue) organisms with an echo maximum at 120 kHz (fluid-like zooplankton).* *[See colour figure on page 311.]*

### 3.3 Bathymetry and mapping of bottom type

Acoustic methods are primary tools for mapping seabed morphology and bathymetry. They include single and multibeam echo-sounding, side-scan sonar and sub-bottom profiling, from instruments that are either carried onboard or towed behind vessels, or are mounted in remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs). Single-beam echo-sounding systems produce single-depth soundings directly under the hull of the vessel, while multibeam echo-sounding systems provide an array of multiple soundings transverse to the ship track, thus providing much greater detail and coverage than single-beam echo sounders (Keen, 1986; Jones, 1999). Single-beam echo sounders are used to collect bathymetric data over large areas, while multibeam echo sounding is usually confined to small areas for more comprehensive, high-resolution studies.

Side-scan sonar systems generate obliquely directed fan-shaped beams on either side of the transducer that are narrow (of the order of a few degrees) in the horizontal plane, but wide in the vertical plane. They produce a high-definition two-dimensional image (or sonograph) of the seafloor in a narrow swath on either side of the ship track, but are not capable of determining the depth of the seafloor accurately (Keen, 1986; Jones, 1999). Side-scan sonar systems are usually used in conjunction with single-beam echo-sounding surveys, and as a precursor for multibeam surveys. They are mainly employed to determine seafloor features in greater detail, the shape and position of man-made structures and wrecks, and to map the variation in sediments and other features on the seafloor, according to their ability to reflect, refract and absorb sound waves.

A bathymetric study was recently undertaken to produce a detailed bathymetric map of the South African continental shelf, using digital single-beam echo-sounding data collected during routine fisheries research surveys along the South African continental margin (De Wet, 2012), such as those described in Section 3.1. The data were assembled from 127 cruises of the FRS *Africana* between 1991 and 2011, and 102 cruises of the FRS *Algoa* between 1993 and 2005. They were used to produce the 1:2 000 000 scale bathymetric maps of the South African continental margin shown in Figure 9 and Figure 10. These maps are a major improvement on the well-known and widely used large-scale bathymetric map of the South African continental margin of Dingle et al*.* (1987), indicating previously resolved bathymetric features in much greater detail and revealing numerous new bathymetric features (De Wet, 2012).

Among the newly defined bathymetric features along the western continental shelf identified in this study is a northwest-southeast trending valley – termed the 'Unknown Valley' (Figure 9) – situated roughly 40 km offshore on the midshelf area of the Olifants Shelf (lying at a right angle to the main Olifants Valley). Another newly defined feature is a small, 5 km-wide depression situated on the midshelf area of the Cape Columbine Shelf directly west of Robben Island (± 60 km offshore). Other well-recognised features, such as Child's Bank, the Olifants Valley, Cape Canyon, Inner Shelf Terrace and Cape Point Valley, are depicted in much greater detail than they were in previous studies due to the far higher resolution of the new bathymetric dataset.

Along the southern continental margin, the newly delineated bathymetric features in Figure 10 include the Agulhas Arch Anticlines, the Gouritz River Drainage Valley and numerous wave-cut terraces situated between Cape St Blaize and Port Alfred (De Wet, 2012). The Agulhas Arch Anticlines were previously incorrectly mapped as being northwest-southeast trending, where the new bathymetric data suggest that they are orientated in a more east-west direction and lie parallel to the general trend of the Cape Fold Belt of which they form a part (De Wet, 2012). The wave-cut terrace that is situated along the southern continental margin is presumed to have originated from numerous sea-level low stands during the Late Pleistocene Era at depths ranging between 45 and 128 metres below present mean sea level (Tankard et al*.*, 1982; Ramsay and Cooper, 2002). Other major bathymetric features on the Agulhas Bank, such as the Alphard Banks and Alphard Rise, are also much better resolved in this new study.

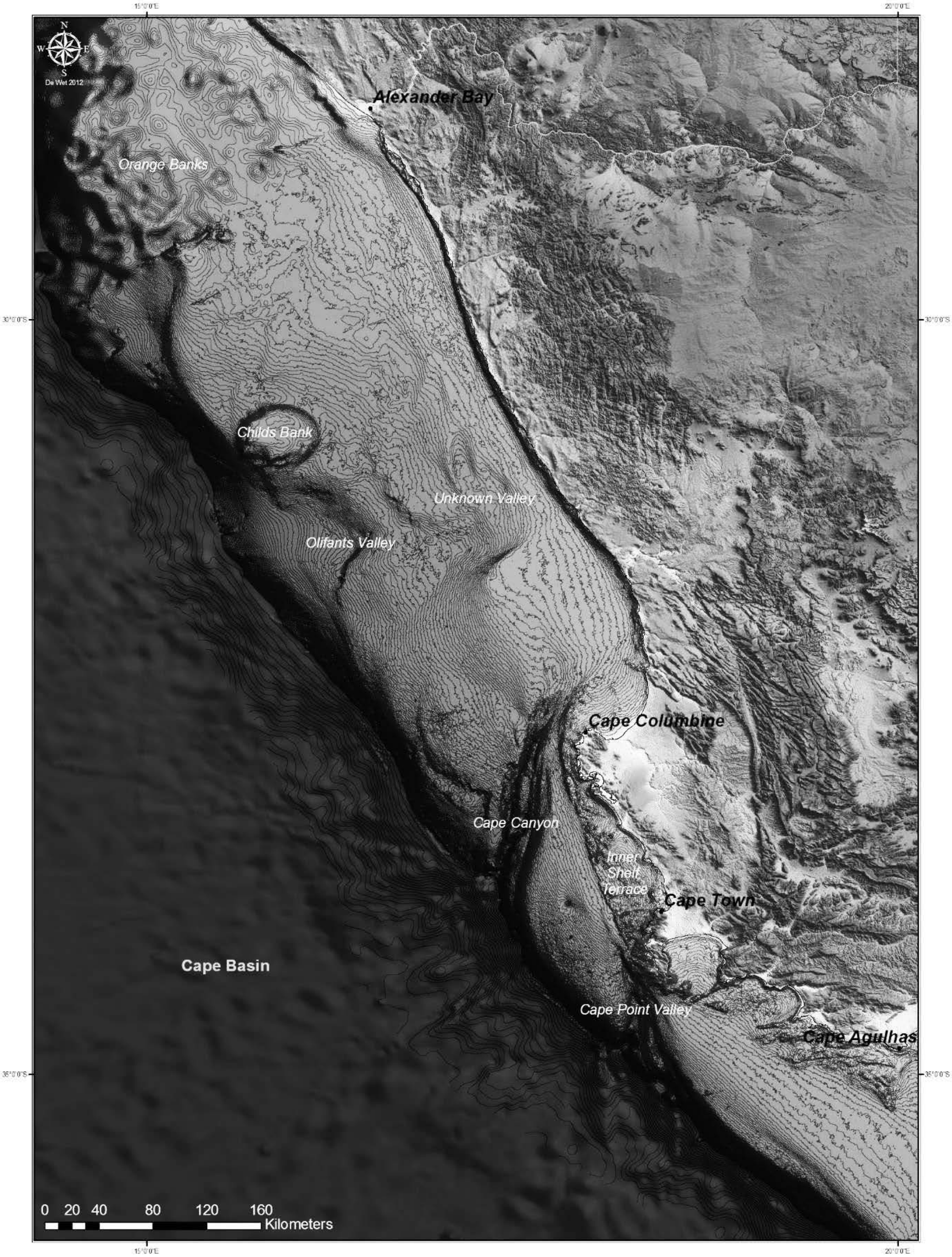


***Figure 9:*** *Bathymetric map of the western continental margin of South Africa and adjacent deep ocean area. Bathymetric isobaths are spaced at 5-metre intervals for water depths ranging between 0 and -500 metres, at 10-metre intervals for water depths ranging between -500 and -1 000 metres, and at 100-metre intervals for water depths greater than -1 000 metres (image taken from De Wet, 2012). [See colour figure on page 312.]*

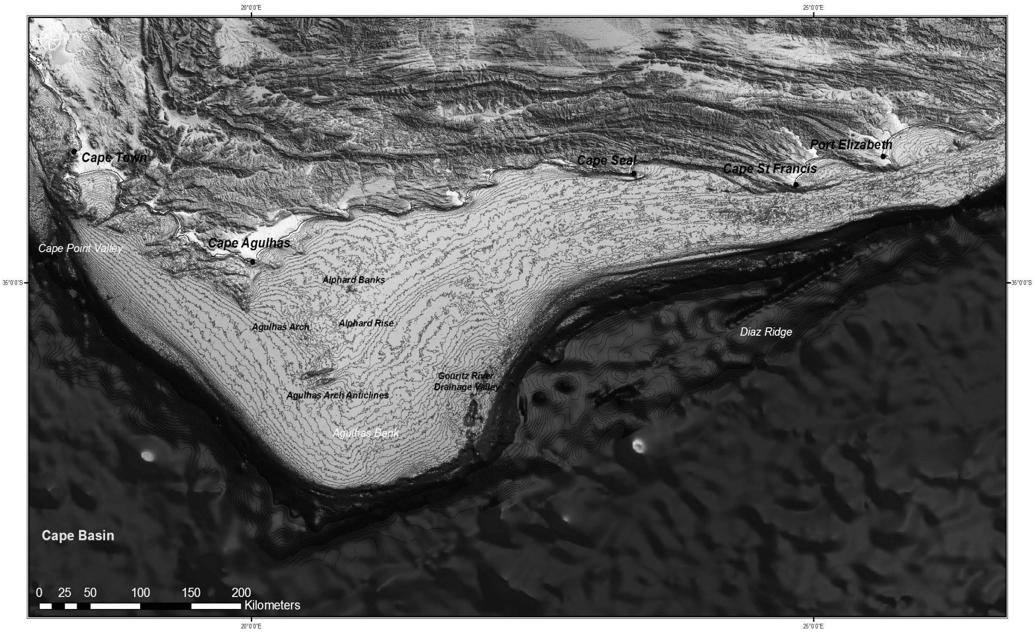


***Figure 10:*** *Bathymetric map of the southern continental margin of South Africa and adjacent deep ocean area. Bathymetric isobaths are spaced at 5-metre intervals for water depths ranging between 0 and -500 metres, at 10-metre intervals for water depths ranging between -500 and -1 000 metres, and at 100-metre intervals for water depths greater than -1 000 metres (Image taken from De Wet, 2012). [See colour figure on page 313.]*

## 3.4 Sub-bottom studies

Sub-bottom profilers and seismic systems are used to create two- or three-dimensional images of geological features to more than 100 metres below the seafloor, depending on the type of sediments and the depth of the underlying basement rock. These systems are widely used by the offshore oil and gas industry, offshore mining industries and offshore construction industries, and can provide information on sediments, which is valuable in developing models of benthic environments and habitats. A sub-bottom profiler usually consists of a single-channel source (such as an air gun) that sends sound pulses through the water column into the bottom. These sound pulses reflect off different sediment layers and rock types according to differences in their acoustic impedance (hardness).

There are a number of shallow sub-bottom profiler systems that operate at different frequencies and achieve different seafloor penetration depths and stratigraphic resolution. The 'pinger' is a high-frequency system that operates at single frequencies between 3.5 kHz and 10 kHz and can achieve seafloor penetration of up to 50 metres, depending on the type of sediment (Penrose et al., 2005). It is particularly useful for delineating shallow features such as faults, gas accumulations and palaeochannels. Parametric sounders, or parasounders (one of which – a Kongsberg Topas PS18 – is installed on *SA Agulhas II*) are more sophisticated instruments that use the non-linear propagation properties of two high-energy beams to produce a secondary narrow beam with a frequency of a few kHz, which can penetrate the bottom at depths of over 5 000 metres. By sweeping the frequencies of the primary beams, 'chirp' pulses can be produced, which, together with sophisticated pulse-shaping options, can increase the spatial resolution substantially. Seismic equipment includes low-frequency 'air guns', 'boomers' (500 Hz to 5 kHz) and 'sparkers' (50 Hz to 4 kHz). Boomers can penetrate between 30 and 100 metres, depending on the type of sediment, while sparkers can penetrate sediments and rocks up to 1 000 metres in ideal conditions (Penrose et al., 2005).

## 3.5 Oceanographic studies

The Doppler shift in reflections from particles moving passively with the water is employed in ADCP systems to measure current speed and direction through the water column, either from moving platforms (thus providing spatial coverage), or from moored arrays to monitor temporal changes in currents at locations of particular interest. ADCP systems generally operate in the region of 100 kHz. If fixed, they give absolute current velocities, whereas velocities obtained from moving platforms (Figure 1) have to be corrected for the velocity of the platform itself. Reflections from ADCP systems can also be used to estimate the density and direction of movement of marine targets (Demer et al*.,* 2000; Brierley et al*.,* 2006).

In South Africa, both forms of profiling have been extensively employed. Moored ADCP systems have been used to monitor currents over a period of 16 years at some 30 short- or long-term monitoring stations on the west and south coasts (e.g. Roberts and Van den Berg, 2005; Roberts, 2010). The moorings are located and released by acoustic signals transmitted from the surface in yet another widespread use of hydro-acoustic technology in the region. Vessel-mounted ADCP systems have been used to map currents during many of the acoustic and other surveys from FRS *Africana* and FRS *Algoa.* The combination of the information on current patterns and fish distribution derived from these surveys has provided valuable insights into the movement and life history of the pelagic fish assessed in these surveys (Boyd et al., 1992), including an elucidation, using both vessel-mounted and moored ADCP systems, into the role of currents in the annual sardine run along the coast of KwaZulu-Natal in winter (Roberts et al., 2010). ADCP data have also been used to explore the use made of currents by chokka squid on the Agulhas Bank to optimise the utilisation of different environments during spawning and in the early life stages (Roberts, 2005), and to investigate the role of currents in their recruitment success (Roberts and Van den Berg, 2002).

## 3.6 Acoustic telemetry

Acoustic telemetry has become a common technique for studying the spatio-temporal distribution and movement of marine organisms, in particular fish and sharks (Attwood et al., 2007; McCord and Lamberth, 2009; Kock et al., 2013). An acoustic tag or transmitter, attached to the study animal via a subcutaneous anchor or surgical insertion into the body cavity, emits an acoustic signal that can be detected by a hydrophone. If the attachment is done correctly, the animal resumes its natural behaviour and can be tracked for as long as the transmitter's battery life permits (Thorstad et al., 2009). Vessel-mounted, directional hydrophones are used for intensive, short-term and detailed studies on movements of single animals, whereas automated systems of semi-permanent receiver arrays are used to log data on the presence/absence of tagged animals within their detection range over extended time periods for up to several years (Attwood et al., 2007; Kerwath et al., 2007; Thorstad et al., 2009).

For studies of multiple animals, individual transmitters emit a unique pulse train that makes it possible to distinguish individuals and even code additional information, such as swimming depth and ambient temperature if the transmitter is equipped with those respective sensors (McCord and Lamberth, 2009). A special configuration of this type of acoustic array, the radio-linked acoustic positioning (RAP) system, can even triangulate the exact position of the tagged animal and transmit real-time movement data to a shore station (Kerwath et al., 2007; Kock et al., 2013). However, this type of intensive study has largely been abandoned in favour of large networks of acoustic arrays. In South Africa, most telemetry projects are now linked to the Acoustic Tracking Array Platform (ATAP), a programme lead by the South African Institute for Aquatic Biodiversity (SAIAB) that supports a network of acoustic receivers mounted in estuaries, bays and nearshore areas stretching from Hout Bay on the Atlantic coast to Ponta do Ouro in Mozambique (SAIAB, 2014).

In South Africa, the use of acoustic telemetry commenced with the monitoring of spawning chokka squid off Oyster Bay on the Cape south coast in 1993. By mooring a RAP system over a spawning aggregation, Sauer et al. (1997) were able to gain detailed insight into the mating and egg-depositing behaviour of this important fishery species by tracking eight animals over a period of 54 days. Building on this success, telemetry studies employing the RAP system, arrays of data loggers and active tracking of spawning squid and their predators were continued in the St Francis Bay area and yielded a wide range of information on the behavioural ecology of this species (Downey et al., 2010).

Great white sharks *(Carachodon carcharias)* (Plate 3) are consistently present along the coast of South Africa, and areas of high abundance are often associated with colonies of Cape fur seals *(Arctocephalus pussilus)*. Acoustic telemetry on this species started in False Bay in the early 2000s with a small array of listening stations around Seal Island to test the effect of chumming and the potential for ecotourism (Laroche et al., 2008). The array has since been expanded to more than 30 receivers within False Bay alone (Kock et al., 2013), and similar arrays have been deployed in several South African bays to study great white sharks (Johnson et al., 2009) and other large sharks, such as ragged tooth sharks *(Carcharias taurus)*, tiger sharks *(Galeocerdo cuvier)*, sevengill sharks *(Notorynchus cepedianus)* and Zambezi sharks (*Carcharodon leucas)* (McCord and Lamberth, 2009).

***Plate 3:*** *A great white shark with a subcutaneous acoustic tag (image by Mike Meÿer).*

The distribution and behaviour of fish in space and time has long been inferred from differences in catch rates by the target fisheries or through mass tagging programmes. Although these methods are useful for gaining a broad understanding on the stock or population level, acoustic telemetry has made it possible to study individuals and small groups in detail. Starting from tracking studies of spotted grunter *(Pomadasys commersoni)* from a small boat on the Kleinmond Estuary (Kerwath et al., 2005), fish telemetry projects on estuarine use (Næsje et al., 2012), home range behaviour and activity patterns (Kerwath et al., 2007), and marine protected area use (Kerwath et al., 2009) have been carried out on a number of popular angling species, including elf *(Pomatomus saltatrix)*, white steenbras *(Lithognathus lithognathus)*, dusky kob *(Argyrosomus japonicus)* (Cowley et al., 2008), roman *(Chrysoblephus laticeps)*, white stumpnose *(Rhabdosargus globiceps)* (Attwood et al., 2007) and garrick *(Lichia amia)* (Dunlop et al., 2013).

# 4. The way forward

## 4.1 Fisheries and zooplankton acoustics

Since acoustic techniques are used worldwide to study fish and zooplankton populations, there are likely to be many methodological advances over a broad front in the years ahead through work at a multitude of institutions. Areas where improvements in current abundance-estimation techniques can be expected include improved target-strength estimation through improved theoretical modelling and empirical studies, advances in the acoustic classification and sizing of targets, inter alia through wider use of multifrequency comparison techniques, and the refinement of methods to correct for bias arising from avoidance, weather effects, the inaccessibility of part of the population, etc. There will also be further improvements in commercially available scientific echo sounders and sonars, and in the power, scope and sophistication of processing software. A major new development, which is likely to accelerate, is the move away from dedicated, expensive research vessels for acoustic surveys and behavioural studies. This includes the increasing use of suitably instrumented fishing vessels for surveys, the use of acoustically equipped AUVs, such as marine gliders and wave riders to extend the spatial and temporal coverage of conventional shipborne surveys, and the deployment of arrays of moored transducers (often integrated with cameras) to study temporal changes in fish and zooplankton abundance and behaviour in locations of particular interest. A particularly promising instrument for such studies is the acoustic zooplankton and fish profiler (AZFP), which is an autonomous, low-power instrument equipped with multifrequency transducers. It is designed to study the abundance, distribution and behaviour of both fish and zooplankton, either from a fixed position or from marine gliders and other such moving platforms (ASL Environmental Sciences Inc., 2013).

Acoustic work in South Africa is likely to follow these trends to the extent that financial, manpower and time constraints allow. *In situ* methods of estimating target strength are currently being applied to derive a target strength-length relationship specifically for round herring, and are to be extended to non-exploited but ecologically important species such as lanternfish and lightfish. Current work on species identification and the classification of zooplankton through multifrequency acoustic techniques will continue (possibly with the use of AZFPs) with the aim of elucidating distribution patterns in relation to fish distribution, and thereby improving understanding of ecological relationships between fish and zooplankton. Methods to reduce bias in surveys of pelagic fish should be further improved and implemented and, where possible, applied retrospectively to the time series such as those in Figure 4. Since the FRS *Africana* and FRS *Algoa* are both reaching the end of their operational lives, and it is not certain when they will be replaced, it is likely that much of the routine survey work in the short to medium term will be carried out from commercial vessels. Although this will ensure the continuation of the essential time series of abundance estimates, the limited ability of commercial vessels to sample the physical, chemical and biological environment during surveys compared to research vessels makes these surveys far less effective for ecological investigations. Being largely restricted to the current vessels will also prevent South Africa from benefitting from the latest advances in acoustic technology that modern fisheries research vessels have to offer, such as more and better arranged echo-sounder transducers for multifrequency studies (e.g. Korneliussen et al., 2008), drop keels, high-resolution sector-scanning sonar and multibeam swath-mapping arrays.

A major constraint in South Africa is the shortage of scientists, engineers and technicians for development work, largely due to the highly specialised nature of the subject and the fact that little formal education in fisheries acoustics is offered by South African tertiary education institutions. This has been alleviated to some extent by regional courses and workshops for acoustic practitioners from Angola, Namibia and South Africa, held under the auspices of the Benguela Environment, Fisheries, Interaction and Training (BENEFIT) Programme (Hampton and Sweijd, 2008), and more recently in the science programme of the Benguela Current Commission (BCC). These have covered topics such as general theory, calibration, survey design, quantification of error, target-strength estimation and the use of multifrequency acoustic techniques.

South African acoustic practitioners have also received training from the manufacturers of the commercial hardware and designers of analytical software used in the surveys. A number of practitioners have studied and collaborated with acoustic specialists abroad, particularly at the Institute for Marine Research in Bergen, Norway. This situation is likely to continue, with the aim of maintaining a core of qualified, experienced personnel to carry out the routine surveys for many years to come. Most development work is likely to be undertaken by postgraduate students registered at South African or overseas universities who are working towards higher degrees, and through collaboration between more senior local and foreign scientists working in bilateral and other projects funded by international donor agencies. We hope that the long history and importance of fisheries acoustic work in South Africa, the exceptionally large datasets available for further analysis, and the existing facilities for further innovative work (notwithstanding the current vessel limitations) will attract more young South African scientists, engineers and technicians to this research field, and continue to draw fisheries acoustic specialists from abroad to the region.

## 4.2 Bathymetry and marine geology

Following the study of De Wet (2012), further refinements of bathymetric charts based on echo soundings collected from the country's research vessels can be expected in the years to come. Innovation in the application of hydro-acoustic techniques to marine geological studies may well depend on the extent to which the Kongsberg parametric sounder on *SA Agulhas II* is utilised for such studies by local scientists, either independently or in collaboration with foreign scientists experienced in the use of such instruments. In either case, since an instrument such as this has not previously been available to South African marine geologists, specialised training in its use and in the interpretation of the data will be necessary.

### 4.3 Acoustic telemetry

The national network of receivers for the acoustic monitoring of the movement and migration of inshore marine animals, maintained by SAIAB, is likely to be expanded through the ATAP Programme, with telemetry equipment largely provided by the Canadian-based Ocean Tracking Network (OTN). This programme holds much promise for broadening the understanding of fish migration patterns around the entire South African coastline, which will be of considerable value, inter alia, for setting up marine protected areas (MPAs) and studying their effectiveness (Attwood et al., 2007; Kerwath et al., 2009).

### 4.4 Oceanography

In the years ahead, ADCP and acoustic systems to communicate with oceanographic moorings will continue to be used in oceanographic studies on the South African continental shelf. Further attempts to increase understanding of the effect of currents on the distribution and movements of fish and cephalopods by integrating ADCP and acoustic survey data through studies similar to that of Roberts et al. (2010) can be expected. These tools are also likely to be increasingly used in studies of changes in ocean circulation in the Southern Ocean from *SA Agulhas II,* particularly in relation to incipient climate change (Thomalla et al., 2011).

## Conclusion

Acoustic surveys of pelagic fish abundance on the South African continental shelf are of great importance for the management of the pelagic fisheries on the west and south coasts. They have contributed significantly to the sustainability of these fisheries over the past three decades, and thereby to the livelihoods of those who depend on them. This work can be expected to be a priority of whatever statutory body is charged with providing scientific advice on the management of these resources (currently the Fisheries Branch of DAFF).

Information on the distribution, movements and behaviour of ecologically important fish species and zooplankton gained from these surveys and other acoustic studies has contributed substantially to understanding their life histories and role in the ecosystem. This could be of major importance in predicting ecosystem responses to long-term changes in the environment brought about by climate change and/or other sources of environmental perturbation.

Improvements in acoustic survey techniques in South Africa are likely to follow global trends, but will probably be limited by a shortage of funds, trained personnel and, in the short to medium term at least, the lack of a modern fisheries research vessel fitted with the latest acoustic equipment for fisheries investigations. While the shortage of opportunities for formal education in fisheries acoustics in South Africa is a drawback, education through ad-hoc regional training courses and workshops, and interaction with specialists in fisheries acoustics overseas at various levels should be sufficient to sustain the current survey programme, and enable methodological improvements to be made in some key areas in the years ahead.

Tracking of the movement of inshore marine animals by means of acoustic telemetry, through the ATAP Programme, is already yielding information that is useful for management. The programme is likely to continue, and be expanded considerably within the framework of the international OTN. It promises to yield much new information to improve the management of a large number of harvested inshore species around the South African coastline.

The use of ADCP to measure currents, and of acoustic systems to communicate with them, is well established in South Africa. ADCP systems in fixed locations and mounted in vessels (possibly including AUVs) will continue to be used in oceanographic studies on the South African continental shelf, and will probably be increasingly used in the Southern Ocean as well. This work can be expected to expand in scope and sophistication as the technology improves.

The acquisition of a parametric sub-bottom profiler with the recent acquisition of *SA Agulhas II* opens up the potential for kinds of marine geological research in South Africa that was not previously possible. However, collaboration with foreign specialists in the use of this instrument may be necessary to realise its full potential.

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# Chapter 8 Passive Acoustic Monitoring of Marine Mammals in South Africa, with Special Reference to Antarctic Blue Whales

*Fannie W. Shabangu and Ken Findlay*

## 1. Introduction

Marine mammals are an important predator component of marine ecosystems, both through the transfer of nutrients in and between various elements of the ecosystem, and through the ecosystem roles they play in the top-down forcing of the system structure (Huang et al., 2011; Leaper and Miller, 2011). Antarctic blue whales *(Balaenoptera musculus intermedia)* are one of the top predators that feed directly on the low-trophic-level prey in the krill-based trophic ecosystem of the Southern Ocean (Nicol et al., 2008).

There are four supposed blue whale subspecies that occur in different oceans (Jefferson et al., 1993; Bannister, 2002; Best, 2007). These are the northern hemisphere blue whale *(B. m. musculus)* (Linnaeus, 1758), the Antarctic blue whale *(B. m. intermedia)* (Burmeister, 1871), the pygmy blue whale (*B. m. brevicauda)* (Ichihara, 1966) and the Indian Ocean blue whale *(B. m. indica)* (Blyth, 1859). However, presently, only the first three subspecies are recognised internationally (Reeves et al., 1998; Jefferson et al., 1993; Best, 2007), as there is a broad uncertainty in morphologically distinguishing *B. m. indica* from other subspecies. It is therefore considered an approximate synonym of *B. m. brevicauda* (Reeves et al., 1998; Rice, 1998). The Antarctic blue whale is the biggest of the blue whale subspecies, growing up to 30 metres and weighing up to 163 metric tons (Mackintosh and Wheeler, 1929; Best, 2007).

Blue whales have a cosmopolitan distribution, although they do not frequent coastal low-latitude waters (Mackintosh and Wheeler, 1929; Best, 2007). Antarctic blue whales are widely distributed in the southern hemisphere (Best, 2007; Širovic et al., 2009; Samaran et al., 2013). Like other large Southern Ocean baleen whales, the majority of Antarctic blue whales migrate seasonally between summer high-latitude feeding grounds and winter breeding grounds in low-latitude waters, although the exact locations of such breeding grounds remain unknown (Jefferson et al., 1993; Best, 2007; Double et al., 2014). It has been shown from passive acoustic monitoring (PAM) studies that not all Antarctic blue whales migrate to the so-called 'overwintering/breeding grounds' in the mid and low latitudes (Stafford et al., 2004), since some individuals remain in the feeding ground at the high latitudes all year round (Širovic et al., 2009; Samaran et al., 2013). Then again, some individuals vocalise all year round on the breeding grounds (Stafford et al., 2004; Širovic et al., 2009; Samaran et al., 2013).

Antarctic blue whales primarily filter feed on zooplankton prey, chiefly Antarctic krill *(Euphausia superba)* (Best, 2007; Branch et al., 2007). Little or no feeding is thought to occur during winter migrations and their distribution during the austral summer is particularly determined by prey distribution (Best, 2007; Branch et al., 2007). Year-round passive acoustic recordings show that Antarctic blue whales might be feeding on their breeding grounds and move in between regions in a season, possibly to make use of available food resources in those regions (Samaran et al., 2013).

The International Union for the Conservation of Nature (IUCN) considers the Antarctic blue whale – which was once considered to be one of the most abundant large whale species (Clapham et al., 1999; Clapham and Baker, 2002) – to be Critically Endangered. This is due to their heavy exploitation through whaling during the last century (Klinowska, 1991, Jefferson et al., 1993; Rice, 1998; Clapham et al., 1999). Based on catch statistics (Figure 1a), it is clear that Antarctic blue whales were harvested at unsustainable rates that exceeded the maximum sustainable yield (MSY) by great margins (Best and Ross, 1989). With some 360 000 blue whales caught in the southern hemisphere during the last century (Clapham and Baker, 2002), Branch et al. (2004) estimated in 1996 that modern whaling had reduced the Southern Ocean blue whale population from a pristine 239 000 (95% interval 202 000 to 311 000) to a low of 360 (150 to 840) animals (Figure 1b) before being protected by the International Whaling Commission (IWC) in 1964. Currently, it is estimated that 1% to 3% of the pristine Antarctic blue whale population remains. The population is estimated to increase at a rate of 7.3% (1.4% to 11.6%) per annum (Branch et al., 2004).

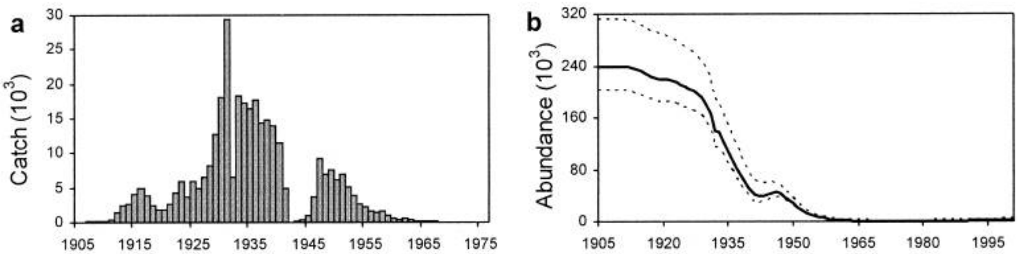


***Figure 1:*** *Multi-decadal patterns of catches (a) and abundance estimated by logistic models (b) of the Antarctic blue whale in the southern hemisphere showing the discovery, exploitation and subsequent collapse of the species (adapted from Branch et al., 2004).*

It is currently difficult from sighting surveys to monitor the population recovery of the Antarctic blue whale, which was so extensively decimated by commercial whaling (Branch et al., 2007). The difficulty with sighting surveys is that trained observers can only see Antarctic blue whales for a short period of time when these mammals surface to breathe, and those sighting surveys can only be done in adequate daylight during good weather conditions (Mellinger and Barlow, 2003; Thomas and Marques, 2012). Such monitoring ideally requires an absolute abundance or at least a relative abundance estimation over a sufficiently long period for a population trend estimation to be apparent over the confidence limits of the abundance estimates (Buckland and York, 2002; Branch et al., 2007).

Absolute abundance is the actual number of whales estimated in a spatial unit, while relative abundance gives the relative indices of abundance, which may be used to estimate trends when constant proportions of the population are estimated each year (Buckland and York, 2002). Abundance estimations of Antarctic blue whales have been and still are centred on visual line-transect surveys or mark-recapture methodologies (Oleson et al., 2007; Kelly et al., 2012), both of which may be subject to costly and logistically difficult research operations (Buckland and York, 2002; Kelly et al., 2012; Thomas and Marques, 2012). Furthermore, factors affecting the reliability of data (for example, limited population sizes, and the surfacing or aggregation behaviour of the Antarctic blue whale) and factors affecting data collection (for example, weather or sighting conditions) may increase the confidence limits of estimates compromising the required data to estimate population trends in the Southern Ocean (Branch et al., 2004; Branch et al., 2007; Kelly et al., 2012).

PAM can be used to estimate the relative abundance of vocalising animals as Antarctic blue whales are particularly vocal. It can also be used to provide information on behaviour and distribution. The use of PAM to estimate Antarctic blue whale abundance is an emerging methodology and a number of issues still need to be addressed before the method will be as mature as visual surveys in South Africa and worldwide. The South African Blue Whale Project (SABWP) is an initiative of the Mammal Research Institute's Whale Unit based at the University of Pretoria, which aims to investigate the distribution and relative abundance of the Antarctic blue whale using both sighting survey and PAM methods. The SABWP conducts research over a range of spatial and temporal scales, which contribute to the international management and conservation of these marine mammals. However, relatively low levels of PAM research have been done in South Africa. The work of the SABWP is pioneering many of the deep-water PAM studies to follow. In this chapter, a remote and autonomous acoustic method is presented that can provide indices of relative abundance and therefore population trends of marine mammals, with particular reference to Antarctic blue whales as the most severely depleted large whale species that occurs in South African waters. It should be noted that PAM has considerable application to other baleen species that occur in South African waters, including fin whales *(B. physalus)*.

## 2. Sound in the sea

Acoustics research is the science that examines the physical properties of sound. The research into sounds produced by living organisms is often referred to as bioacoustics (Au and Hastings, 2008). The ocean is by no means a quiet environment. Sounds are produced by a number of sources, including the following:

- Natural events, such as rain, wind, seismic events or ice (Urick, 1983; Au and Hastings, 2008; Zimmer, 2011)
- Marine animals that are often very vocal and produce diverse loud and/or soft sounds (Urick, 1983; Zimmer, 2011)
- Man-made noise sources, such as shipping or other anthropogenic activities (Urick, 1983; Au and Hastings, 2008)

Urick (1983) states that, as early as 1490, Leonardo da Vinci discovered that "If you cause your ship to stop, and place the head of a long tube in the water and place the outer extremity to your ear, you will hear ships at a great distance from you." It was therefore from this rather simplistic observation that modern hydrophones and transducers were developed to study and explore the marine world (Urick, 1983; Simmonds and MacLennan, 2005).

Sound comprises waves of energy moving through a medium as oscillations of particles in that medium. Important characteristics of a sound include its frequency, or rate of oscillation, which is measured in Hertz (Hz), period (the duration of an oscillation cycle in seconds (s)) and wavelength (the length of a single oscillation in metres). A decibel (dB) is the unit of measurement of the acoustic intensity of a sound. Acoustic energy is the energy in a sound wave. The power of a wave is the energy measured over a period of time. Acoustic intensity is the acoustical power per unit area in the direction of propagation. The energy, power and intensity of a sound wave are proportional to the mean square pressure. Acousticians consequently refer to ratios of pressure or pressure squared, using a standard reference pressure against which sounds can be measured. A reference pressure of 1 μPa is used for water, whereas 20 μPa is used for air.

When comparing the relative intensities of two sounds, the responses are logarithmic, which is why sound intensities $(I)$ are measured on a logarithmic scale (in decibels) as:

$$Intensity\_levels(dB) = 10 \log \frac{I}{I_0} \tag{1}$$

where $I_0$ is the reference intensity.

As intensity is proportional to pressure squared, the sound pressure level $(SPL)$ of sound pressure $(P)$ is defined as:

$$SPL(dB) = 20 \log \frac{P}{P_0} \tag{2}$$

where $P_0$ is the reference pressure, e.g. 1 μPa for water.

The principles applied in acoustics are similar to those applied in light, since both physical processes are subject to absorption, reflection and scattering. Both comprise energy waves that travel through a medium and follow elementary laws of physics (Mobley, 1994; Simmonds and MacLennan, 2005). However, the heterogeneous properties of water disrupt the basic linearity principle of a perfect wave transmitting energy through a homogeneous 'lossless' medium explained in most physics textbooks (Mobley, 1994; Simmonds and MacLennan, 2005). Thus, electromagnetic, thermal, light, chemical and other forms of energy attenuate very quickly in turbid waters due to scattering and absorption (Urick, 1983; Tyack and Miller, 2002; Au and Hastings, 2008). Providentially, sound propagates faster and weakens less in water than in air (Tyack and Miller, 2002).

## 3. Acoustic research of marine mammals

Sound is important to marine mammals as they use it for communication, searching for prey, navigation, and to avoid unfavourable conditions or predators (Purves, 1967; Kenshalo, 1967; Tyack, 1998; Tyack, 1999; Sears, 2002; Mellinger and Clark, 2003; Simmonds and MacLennan, 2005; Zimmer, 2011). Consequently, many marine mammals have evolved hearing and mental capacity to detect and interpret acoustic signals with good sensitivity and accurate localisation of the waterborne sound (Ketten, 1992; Ketten 1994; Au and Hastings, 2008) and many have specialised sound-generating organs (Kenshalo, 1967; Frankel, 2002; Au and Hastings, 2008). However, the hearing sensitivities of marine mammals are generally not well studied, with best hearing sensitivities often assumed around the frequencies at which the animal vocalises (Ketten, 1992; Ketten, 1994; Frankel, 2002).

Several balaenopteridae species of mysticete (or baleen) whales produce high-energy, low-frequency (< 100 Hz) or infrasonic (< 20Hz) sounds (Ketten, 1992; Ketten, 1994; Sears, 2002; Mellinger and Clark, 2003; Au and Hastings, 2008; Zimmer, 2011). Antarctic blue and other baleen whales have larynxes like humans, but unlike humans, lack vocal cords to produce sound, thus these mammals are presumed to recycle air in their bodies (presumably the lungs) to vocalise (Frankel, 2002; McDonald et al., 2009). Antarctic blue whales and other baleen whales use sound for "long range contacts, assembly calls, sexual advertisement, greeting, spacing, threat and individual identification" (Dudzinski et al., 2002). Odontocetes (toothed whales and dolphins) produce higher-frequency (ultrasonic) whistles and broadcast clicks using the upper portion of the head, called the dorsal bursae, and the nasal passage, called the phonic lips, while directing the sound through the melon that combines vibrations produced by both the dorsal bursae and phonic lips (Frankel, 2002). Whistles are used mainly for social interaction and clicks for echolocation (Au and Hastings, 2008). Non-cetacean marine mammals like seals are said to produce underwater sounds comparable to those of their terrestrial relatives via the vibrations of their throats without emitting air through their mouths (Frankel, 2002).

### 3.1 Applications of passive acoustic monitoring

The use of passive acoustic techniques for estimating the abundance, behaviour and distribution of marine mammals has many advantages over the conventional abundance estimation methods (Urick, 1983; Simmonds and MacLennan, 2005; Au and Hastings, 2008; Zimmer, 2011). Models of Peel et al. (2014) depicted the fact that real-time acoustic tracking can result in increased encounters and subsequent photographic captures of Antarctic blue whales by two to four extra times compared to conventional visual transect surveys. Furthermore, based on the modelling of sighting rates, Kelly et al. (2012) argue that the sole utilisation of the line-transect survey design is not the best method of estimating the circumpolar abundance of Antarctic blue whales, but that mark-recapture using acoustics as a supplementary tool would provide better results. For instance, some areas might be logistically difficult for sighting surveys because they are remote, not accessible to direct observation, too expensive or difficult to survey (Best, 1993).

PAM can be used as a cost-effective method to monitor and track both the population and individuals in such areas (McDonald et al., 2006a; Mellinger et al., 2007; Van Parijs et al., 2009; Marques et al., 2013). PAM can be carried out as real-time or archival, manual or autonomous operations over a considerable duration (Van Parijs et al., 2009). Recording equipment can be mounted on stationary platforms, such as oceanographic moorings, or on moving/drifting platforms, such as research vessels or wave gliders (Bobbitt et al., 1997; Boisseau et al., 2008; Baumgartner et al., 2013). Real-time PAM has been conducted as part of the Listening to the Deep Ocean Environment (LIDO) project (André et al., 2011) and, more recently, from ocean gliders (Baumgartner et al., 2013). Digital acoustic recording tags (DTAGs) are used to monitor the behaviour of marine mammals and their response to sound stimuli, as archival sensors onboard the suction cup tags measure the dive cycles, 3D orientation and movement of the animals (Tyack, 2011). Instruments of this kind are unavailable in South Africa and the SABWP aims to conduct such research in the near future.

Sonobuoys are sound-receiving buoys primarily used by the military to detect submarines, and relay detected sounds to research platforms via ultra-high frequency (UHF) or very high frequency (VHF) transmission (Zimmer, 2011). These have been utilised in PAM whale research (McDonald, 2004; Rankin et al., 2005; Oleson et al., 2007; Miller et al., 2012; Miller et al., 2014a; Miller et al., 2014b). Sonobuoys with differential frequency analysis and ranging (DIFAR) enable estimations of the vocalising marine mammal's bearing relative to the sonobuoy and the surveying research vessel that can be used to track the animal in real time (McDonald, 2004; Rankin et al., 2005; Oleson et al., 2007; Miller et al., 2012; Miller et al., 2014a). The advantage of this type of sonobuoy is that acoustic research can be conducted simultaneously with visual surveys, for example, to improve the probabilities of encountering vocalising and non-vocalising animals for abundance estimation (Rankin et al., 2005; Oleson et al., 2007; Miller et al., 2012; Peel et al., 2014).

The abovementioned acoustic research techniques have particular advantages and disadvantages. Their choice of use is often specific to sites or species. For example, acoustic recorders towed behind research vessels may be limited to large baleen whales, as the low-frequency calls of whales are masked by the underwater noise of the ship's propellers at the same frequency (5 Hz to 500 Hz) (Au and Hastings, 2008). However, these recorders are particularly valuable for the monitoring of odontocete cetaceans that vocalise at a high frequency, such as sperm whales *(Physeter macrocephalus)* (Thode, et al*.,* 2002; Mellinger et al., 2003).

## 3.2 Factors determining the detectability of marine mammal sounds

The speed of sound in seawater is approximately 1 500 m $s^{-1}$. When assuming constant temperature and increasing static pressure, this speed will increase by 1% for each 1 000 m of depth, while a 1 °C increase in temperature will result in a 2% increase in sound speed (Rossing, 2007). Sound refraction and reflection occur at both the surface and the seafloor due to sound speed changes, with these directional changes resulting in waveguides at different ocean depths (Urick, 1983; Simmonds and MacLennan, 2005; Rossing, 2007). Sound transmitted in both the upward and downward angles tends to propagate towards the minimum sound velocity region from its source and refract towards the depth of its source (Urick, 1963; Rossing, 2007; Au and Hastings, 2008). During World War II (1939 to 1945), Ewing and Worzel (Urick, 1963) discovered a deep sound channel in which sound waves could travel long distances. This channel is known as the sound fixing and ranging (SOFAR) channel (Urick, 1963; Urick, 1983; Medwin and Clay, 1998; Rossing, 2007). The SOFAR channel occurs at shallower depths in high latitudes and at deep depths in low latitudes due to sound waves bending towards the lower sound velocity region caused by the temperature or depth profile (Urick, 1983; Rossing, 2007; Au and Hastings, 2008). Antarctic blue whales and other baleen whales are known to use the SOFAR channel for transmitting sounds over great distances, since the sound at this axis encounters the least geometric spreading loss compared to surface or bottom reflection (Urick, 1983; Au and Hastings, 2008; Samaran et al., 2010b).

During World War II, military engineers developed the sound navigation and ranging (sonar) equation (Equation 3), with the aim of determining the maximum range of sonar equipment (Urick, 1983). The sonar equation models the functions of source level, transmission loss and received levels over the sound travel path (under the source-path-receiver model introduced earlier). Numerous parameters that affect the performance of the underwater sonar model were therefore conveniently and logically merged into small units in the sonar equation. In turn, the equation accommodates the effects of the propagation medium, target and the equipment itself (Urick, 1983). In a biological context, the sonar equation therefore addresses the acoustic energy reception in the animal's *in situ* setting (Urick, 1983; Tyack, 1998; Au and Hastings, 2008). Given that the aim of research relating to PAM is to listen to sounds produced by animals, biologists are primarily concerned with the transmission loss from the animal of interest (Tyack, 1998; Au and Hastings, 2008).

The simple passive acoustic sonar model of evaluating sound propagation in water is measured in dB re 1 $\mu$Pa as:

$$RL = SL - TL \qquad (3)$$

where $RL$ is the received level, $SL$ is the source level at 1 m from the source and $TL$ is the transmission loss.

The intensity levels of acoustic signals weaken as sound propagates farther from the source through a medium due to transmission loss caused by spreading, absorption, scattering, reflection and rarefaction (Urick, 1983; Tyack, 1998; Swift, 2004). The majority of energy in any given acoustic wave is concentrated at the centre of the sound source, hence, as the sound propagates to a range ($r$), the acoustic energy will be spread in all directions over the sphere's area of $4\pi r^2$ (Tyack, 1998; Swift, 2004). Thus, the signal intensity is expected to decrease exponentially with distance from the calling animal or sound source. This is called spherical or geometrical spreading (Tyack, 1998; Lurton, 2002; Swift, 2004; Simmonds and MacLennan, 2005).

The transmission loss due to spherical spreading is calculated as follows:

$$TL = a\log r = 10\log\frac{I}{I_{ref}} = 10\log\frac{4\pi r^2}{4\pi r^2_{ref}} = 20\log\frac{r}{r_{ref}} \qquad (4)$$

where $a$ is the environment-dependent absorption coefficient, $I$ is the intensity of the signal, and $I_{ref}$ is the intensity at the reference source. For the Southern Ocean, $a$ is estimated to be 17.8 dB/m under spherical spreading considerations (Širovic, et al., 2007). For South Africa, $a$ is undetermined, but it should be much less than 17.8 dB/m as the water is warmer around the coast.

Spherical spreading assumes that sound propagates through a uniform or homogenous environment (Swift, 2004) and occurs until the sound hits a boundary with a different acoustic property, such as the sea surface, seafloor or waters of different densities, where the sound waveform will refract in a plane according to Snell's Law and cylindrical spreading results (Tyack, 1998; Swift, 2004). In such cylindrical spreading, the sound energy spreads in a cylindrical fashion over the cylinder's cross-sectional area of, $2\pi r$ where the sound energy will not be restricted by planes. The cylindrical spreading is therefore calculated in the form of:

$$TL = 10\log\frac{I}{I_{ref}} = 10\log\frac{2\pi r}{2\pi r_{ref}} = 10\log\frac{r}{r_{ref}} \qquad (5)$$

While the spreading of sound in the water column defined in Equation 4 and Equation 5 weakens the acoustic signal, the conversion of sound to heat results in further loss of sound. This is known as absorption or attenuation (Tyack, 1998; Lurton, 2002, Shabangu et al., 2014). However, Tyack (1998) agrees with Cummings and Thompson (1971) that, for species like Antarctic blue whales, no significant absorption loss should be encountered as these animals transmit acoustic signals at very low frequencies, for example, less than 1 dB per 100 m will be lost to absorption for a 100 Hz frequency signal.

As established in Equation 3, the ability of a hydrophone to detect an animal's call depends on the received noise levels $(NL)$ (Tyack, 1998; Au and Hastings, 2008). $NL$ is expressed in dB re 1 $\mu Pa^2/Hz$ (Swift, 2004; Au and Hastings, 2008). Therefore, the modified passive acoustic sonar equation will take the following form:

$$DT = SL - TL - (NL - DI) \qquad (6)$$

where $DT$ is the detection threshold (dB) and will obviously vary for each animal species, and $DI$ is the directivity index of the receiving hydrophone (measured in degrees) relative to the direction of the vocalising animal from the hydrophone.

Au and Hastings (2008) propose that, provided marine mammals have a specific acoustic detection system with a boundary specified by a direct filtering bandwidth, Equation 6 could be revised to incorporate the filter effects in the sonar equation to fit the new measurement system as follows:

$$DT_A = \mathrm{SL} – \mathrm{TL} – (\mathrm{NL} – \mathrm{DI} + \Delta f) \tag{7}$$

where $DT_A$ is the new detection threshold of the system and $\Delta f$ is the filter bandwidth of the system.

This is calculated as follows:

$$\Delta f = \frac{2^n – 1}{2^{n/2}} fc \tag{8}$$

where $n$ is 1/3, 1/2, or 1 for a 1/3-octave, 1/2-octave, or 1-octave band, respectively. Octave bands are commonly utilised sets of frequency bands with $fc$ (the centre frequency of the band). A one-octave bandwidth has an upper band frequency twice the lower band frequency, while a one-third octave band is a frequency band where the upper band-edge frequency is the lower band-edge frequency multiplied by the cube root of two.

Au and Hastings (2008) further explain that if $DT_A$ equals zero, the mammal hearing system would only detect the signal half the time due to equal intensities between the received signals and received ambient or background noise. This defines the animal's auditory system critical ratio. However, a $DT_A$ of 3 dB would enable the animal to easily detect a signal because the signal intensity will be twice as strong as the ambient noise intensity. This principle can also be applied to acoustic systems to determine the transmission loss that can be tolerated by a hydrophone without missing any signal detections (Tyack, 1998; Au and Hastings, 2008).

Marine mammals can tolerate transmission loss to a certain degree where they can hear a signal. The transmission loss threshold is calculated as follows:

$$TL = SL – (NL – DI + 10 log \Delta f) \tag{9}$$

Following the computation of the amount of transmission loss an animal can tolerate in Equation 9, the probability of a signal being detected can be mathematically computed as the signal-to-noise ratio $(SNR)$ expressed in a subtraction form:

$$SNR = RL – NL \tag{10}$$

$SNR$ is not only determined by $RL$, but also by external environmental noise and any internal noise in the receiver (Tyack, 1998).

The source level, frequency and bandwidth of a call are the most crucial acoustic parameters. However, their significance is determined by the transmission range and ambient noise (Tyack, 1998; Xiaohong et al., 2012). For a receiver (hydrophone or sonobuoy) to receive the most prominent *SNR*, an animal must transmit sound at a carrier frequency and bandwidth of the receivers' detection capabilities (Xiaohong et al., 2012). The receiver can therefore be designed to correspond with the frequency and time characteristics of the animal of interest, and if the receiver bandwidth is tuned effectively to fit the signal bandwidth, the noise spectrum level outside the frequency range of interest will be reduced (Tyack, 1998). Building on from the octave bands in Equation 9, the frequency band $(W)$ among the ambient noise spectrum levels of the energy and at distinct frequencies can be calculated in the following form:

$$Band\_level = Spectrum\_Level + 10\log W \quad (11)$$

For the minimisation of the integration effects of signals throughout a given time period within a given receiver, the integration time must be well matched to the duration of an animal signal (Tyack, 1998). For example, a fin whale can produce an infrasonic pulse that lasts for 1 second and contains 20 cycles (Tyack, 1998).

Therefore, if the receiver integration time $(t_{int})$ is longer than a given short pulse $(t_{pulse})$, the following equation will reduce the effective source level of the sound signal $(SL_{eff})$:

$$SL_{eff} = SL + 10\log \frac{t_{pulse}}{t_{int}} \quad (12)$$

The $SL_{eff}$ is important to determine the detection range and the distance the sound will travel. Another factor that determines the detection range or source level of the vocalisation is the size of the animal. Bigger animals will generally produce higher-intensity sounds (Tyack, 1999).

### 3.3 Antarctic blue whale density estimation

Although challenging, once factors affecting the detectability of a signal are addressed and considered, the estimation of Antarctic blue whale density based on PAM is possible if both the cue rates per individual and group sizes are known (Marques et al., 2013). PAM density estimation is an ongoing research area, with working algorithms required for each vocalising species based on the species' acoustic behaviour (Thomas and Marques, 2012). Density $(D)$ is generally defined as the number of animals in a given area, and calculated by the following formula:

$$D = \frac{n}{a} \quad (13)$$

where $n$ is the whale number/count, and $a$ is the survey area. Given that the area surveyed by the recording instrument is known for the assumed source level, the abundance can be estimated from density as $n = D$ x $a$ (Marques et al., 2009). Since $n$ detected in the area $a$ is now known, the abundance $(\hat{D})$ can be estimated as:

$$\hat{D} = \frac{n}{a\hat{P}} \quad (14)$$

where $\hat{P}$ is the probability of a whale sound being detected by the PAM recorder, which is dependent on source and noise levels as shown above in Section 3.2.

The estimated density of blue whales over time $(\hat{D}_t)$ can be determined from PAM by upgrading Equation 14 through the consideration of further parameters:

$$\hat{D}_t = \frac{n_c(1-\hat{c})}{K\pi w^2 \hat{P} T \hat{r}} \quad (15)$$

where $n_c$ is the number of calls, $\hat{c}$ is the estimated amount of false positive detections, $K$ is the number of replicate recorders used, $w$ is the distance away from the recorder where vocalising whales are assumed not to be detected, $T$ is the time, and $\hat{r}$ is the estimated call rate.

Thomas and Marques (2012), Marques et al. (2009) and Marques et al. (2013) provide methods of estimating cetacean density from PAM data collected through arrays of hydrophones. Call rates, sound propagation and the frequency and source level of calls are important for the determination of blue whale density. PAM data recorded through DIFAR sonobuoys during the IWC's International Decade of Cetacean Research (IDCR) and Southern Ocean Whale and Ecosystem Research (SOWER) cruises have bearing on detected calling animals, but single instruments were usually deployed at the time. Thus, the above density estimation mechanisms are adequate for experiments with replicates extending to large spatial and temporal scales. These are also applicable to a single recorder, while some additional errors are introduced (Kusel et al., 2011, Thomas and Marques, 2012; Marques et al., 2013).

## 3.4 Antarctic blue whale calls

Blue whales are a good example of a sound producer with high source levels (around 188 dB re 1 $\mu$Pa at 1 m) (Cummings and Thompson, 1971; Au and Hastings, 2008). Source levels are determined using the above equations. Antarctic blue whales are the loudest blue whale subspecies with a mean source level of 189±3 dB re 1 $\mu$Pa at 1 m over the 25 Hz to 29 Hz range (Širovic et al., 2007). However, there is a spread on the reliability of measurements of the source levels for Antarctic blue whales. Samaran et al. (2010a) reported source levels of 179±5 dB re 1 $\mu$Pa at 1 m over frequencies of 17 Hz to 30 Hz. The most recent preliminary source level measurements by Miller et al. (2014a) are 182 to 185±2 dB re 1 $\mu$Pa over 25 Hz to 29 Hz. Antarctic blue whales produce two types of calls that are both frequency- and amplitude-modulated, namely 'Z' and 'D' calls (Figure 2 and Figure 3). The frequency of frequency-modulated calls changes over time (Frankel, 2002). Individual units of stereotypical patterns of frequency-modulated sounds are called 'calls' and the repetitive sequence of stereotyped three-unit low-frequency calls are called 'songs' (Rankin et al., 2005; McDonald et al., 2006a). The Z call is so named because the shape of the call resembles the English alphabetic letter 'Z' when viewed on the spectrogram (Figure 2b). The Z call is only produced by Antarctic blue whales and is presumably used by males to find mates.

McDonald et al. (2006a) found that these highly vocal cetaceans produce population-specific sounds, and identified nine song types of blue whales from around the world. Subsequently, other blue whale song types have been identified elsewhere in the world since this study (Miller et al., 2014b). Antarctic blue whales' Z calls are characterised by the distinct long-duration (8 to 12 seconds), 28 Hz first tonal sounds (Figure 2b1), followed by a second relatively short-duration (2 to 5 seconds) sound downsweeping from 28 Hz to 19 Hz (Figure 2b2). A third component is an 8- to 12-second (Figure 2b3) slightly frequency-modulated tone between 20 Hz and 18 Hz (Ljungblad et al., 1998; Rankin et al., 2005). This call is also believed to be a contact call usually produced intermittently by a single whale or a pod of travelling whales (Edds-Walton, 1997; McDonald et al., 2006a). The average intercall interval (pause time between calls) in a series of calls is estimated to be 48.5±2.8 seconds for Antarctic blue whales (Stafford et al., 2004). A decline in the tonal frequencies of this Antarctic blue whale song has been observed lately (McDonald et al., 2009).

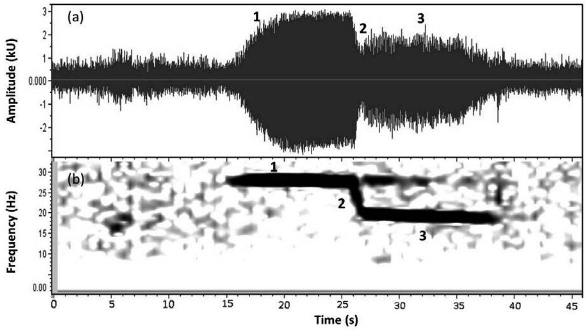


***Figure 2:*** *A typical Antarctic blue whale Z call illustrating the wave form amplitude modulation (a), with the corresponding frequency modulation and duration of each unit of this three-unit call (b). The 28 Hz unit is the high-energy component of the call as it has the highest amplitude compared to the other two components of the call as shown by the amplitude values. The amplitude is presented here in a thousand unit, also known as a kilo unit (kU), of the dimensionless sample values. Data was collected during the 2001/02 IWC SOWER cruise. [See colour figure on page 313.]*

Sound produced at these low frequencies can travel hundreds to thousands of kilometres from the source, but these low-frequency sounds are susceptible to noise due to less target definition and separation (Urick, 1983; Rossing, 2007; Zimmer, 2011; Miller et al., 2012). The frequency range of the signal transmits useful information from the transmitter to the recipient (Tyack and Miller, 2002; Au and Hastings, 2008).

Only male Antarctic blue whales are thought to sing (Z calls) and little is known about female blue whale vocalisation (Tyack, 1998; McDonald et al., 2001; McDonald et al., 2006a; Samaran et al., 2013). However, Oleson et al. (2007) observed that both sexes of northern hemisphere blue whales vocalise during feeding, producing a call more variable in duration and frequency, called the D call. Antarctic blue whales' D calls are shown in Figure 3. This higher-frequency call is likely used for short-distance communication, and could be used to advertise the presence of food to conspecific animals. D calls range in frequency from 22 Hz to 106 Hz (Thompson et al., 1996; Rankin et al., 2005). The D call is a general, worldwide blue whale call that is not population-specific and has been observed from different feeding areas like the gulfs of California and Mexico (Thompson et al., 1996), as well as the Cortez and Tanner Banks and the Southern California Bight (Oleson et al., 2007).

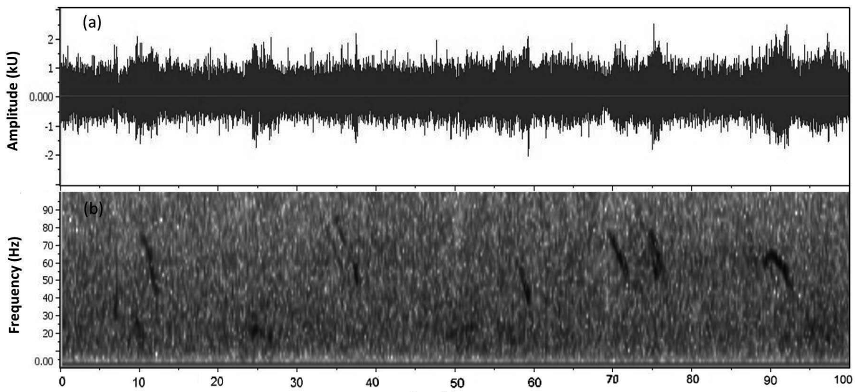


***Figure 3:*** *A spectrogram of the Antarctic blue whale's high-frequency modulated D calls showing the waveform amplitude modulations (a) and frequency modulations (b) over time during the 2001/02 IWC SOWER cruise. [See colour figure on page 313.]*

For Z calls, both the frequency sweeps within a call and the several replications of a call (harmonics) improve long-distance communication by making the call stand out from the ambient noise (Edds-Walton, 1997). McDonald et al. (2009) and Gavrilov et al. (2011) reported a worldwide decrease in the frequency and source levels of blue whales. The reasons for this are not well understood, but factors like depleted/recovering populations, mate selection, animal size, cultural behaviour and ocean ambient noise have been associated with the change. Comparisons of the regional call patterns of blue whales can provide biologists with an understanding and knowledge of the population structure, seasonal relative abundance patterns, migrations and distribution (McDonald et al., 2006a) of the species or populations. Thus, the determination of species identification techniques is important for the effective recognition of a sound producer at a particular location (Tyack, 1998).

## 3.5 Passive acoustic monitoring research on large baleen whales in South Africa – the South African Blue Whale Project

South African cetacean scientists are actively involved in the Southern Ocean Research Partnership (SORP), which is an IWC initiative to enhance cetacean conservation and deliver methods of non-lethal whale research using techniques such as PAM in the Southern Ocean. Prior to the initiation of the SORP, the IWC's IDCR and SOWER cruises were conducted between 1979 and 2010. These cruises utilised PAM stations (1995 to 2009) that deployed sonobuoys. The timing and distribution of the sounds recorded are shown in Figure 4 and Figure 5. However, the main aim of the IWC's IDCR and SOWER circumpolar surveys was to estimate the abundance and distribution of whales using sighting surveys. The acoustic data collected during these surveys is currently being analysed in South Africa to investigate the spatio-temporal distribution patterns of vocalising Antarctic blue whales and to determine the call rates of the observed whale pods. Demultiplexed bearings of vocalising Antarctic blue whales can be estimated from directional DIFAR sonobuoy PAM data to differentiate between vocalising whale pods.

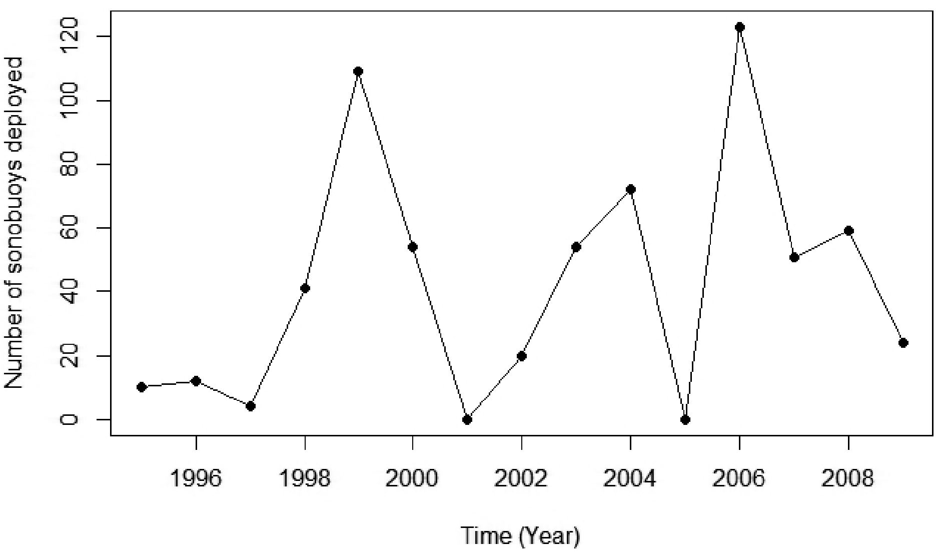


***Figure 4:*** *The IWC's sonobuoy acoustic research effort over time in the Southern Ocean during the IDCR and SOWER cruises, including the 1995 Australia, 1996 Madagascar and 1998 Chile cruises. A total of 633 sonobuoys were deployed over 15 years, which recorded sounds for 1 505 hours. The database that is currently being analysed comprises 93% of the IDCR and SOWER sonobuoy data.*

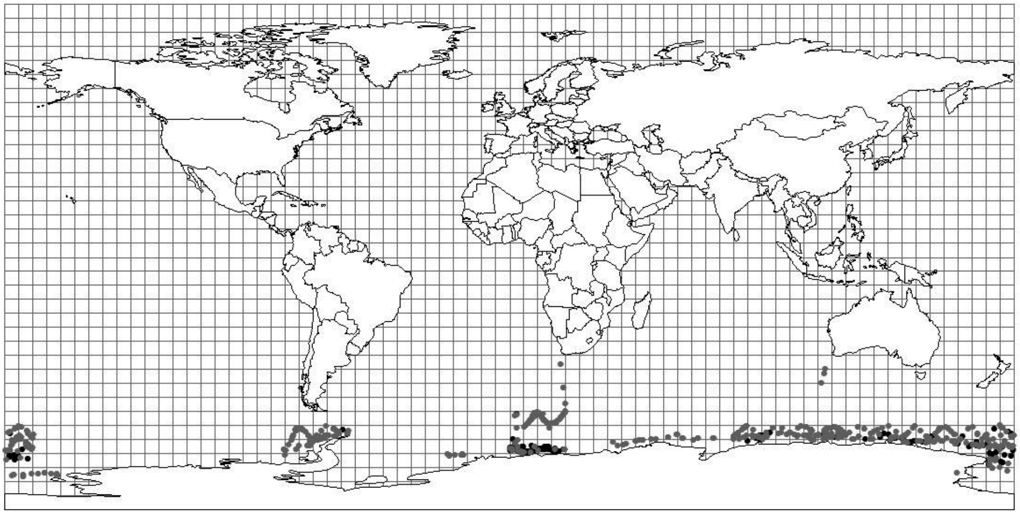

***Figure 5:*** *Detections of blue whales from sonobuoys deployed during the IWC's SOWER voyages, 1999 to 2009. Sonobuoy deployment sites are shown on the map as grey points, while black points show locations at which Antarctic blue whales were heard by acoustic researchers. Each block is 5˚ of latitude and longitude. The data is courtesy of the IWC.*

The SABWP started a long-term passive acoustic programme in 2014 to monitor Antarctic blue whales in the Antarctic sector south of South Africa (000° to 020° E), one of the areas with the highest abundance of the species in terms of calls recorded (Figure 5). An aural M2 autonomous acoustic recorder (AAR) deployed on the Maud Rise (65 00° S; 002 30° E) in water depths of 1 200 m will monitor low-frequency whale calls until February 2015 when the mooring (and the archived acoustic data) will be recovered and most probably redeployed for a further year (Findlay et al., 2014). The recorded PAM data is archived on the recording instrument's hard drive for later analyses once the hydrophone is retrieved. The AAR is operated on batteries for the duration of the deployment and the duty cycle is determined by both battery life and hard drive space.

Such passive acoustic technology is being combined with the conventional sighting survey and mark-recapture methods to study the distribution, abundance and migration of Antarctic blue whales in the South-East Atlantic. The SABWP also deploys AAR moorings off the coast of South Africa and Namibia to monitor and track the abundance, movement and distribution of Antarctic blue whales during their migrations. The seasonal occurrence of other large baleen whales, such as the humpback (*Megaptera novaeangliae*), fin and southern right whale (*Eubalaena australis*) may also be monitored from this passive acoustic system, depending on the target frequencies being recorded (which are obviously a trade-off on battery duration).

The research done by the SABWP contributes important knowledge towards estimating the current population status of Antarctic blue whales, in conjunction with genetic and photographic data collected to help understand the stock structure of the species. The SABWP is also conducting investigations of predator-prey relationships by using active acoustic echo sounders (discussed in Chapter 7) to determine the abundance and distribution of Antarctic krill relative to whales.

# 4. Challenges and the way forward

A number of challenges in PAM methodology need to be addressed in the future.

PAM only detects and records sounds from marine mammals that vocalise, so acoustic studies need to be conducted at times when animals are known to vocalise or throughout the year to determine the times when the animals are vocally active. Thus, sighting surveys combined with PAM using DIFAR sonobuoys can assist in discriminating vocally active whales from non-vocal ones. However, sonobuoys are not easily accessible in South Africa. The presence or absence of a species in a particular area can be derived independently of the acoustic recording instrument from visual sighting surveys and from historic whale catches, assuming those mammals currently utilise the same areas as during whaling (although this can be biased by catch selectivity). The acoustic research effort from the previous IWC programmes is low (Figure 4), varies over the years, and is non-randomly distributed as research was focused in areas with high densities of whales (Figure 5). Consequently, a greater acoustic research effort is required in all the other IWC management areas.

The determination of marine mammal call rates and their variation with age, sex and season are still problematic. The detection range and source levels of many species are unknown and may include considerable variability. Thus, density estimation is difficult to determine from source levels, as they vary considerably between the three currently available Antarctic blue whale studies. Research to determine the vocal behaviour of Antarctic blue whales will answer questions about the diel, seasonal and annual variability of these marine mammals' calls and songs.

Once call rates are determined, the relative amount of calling animals at a given time and location can be determined, as calling animals will be identified to an individual level through concurrent visual observations. The maximum ranges at which a marine mammal call can be detected are estimated based on factors that affect sound propagation, i.e. environmental factors (such as temperature and salinity) and bathymetric data. Therefore, the lack of such data limits such estimations. Oceanographic mooring, as well as conductivity/temperature/depth (CTD) instruments and model data, can be used effectively to provide such environmental data around the South African coast for the duration of acoustic recordings. Positional identification of individual marine mammals requires both source levels and transmission loss to be known to accurately determine the relative density of animals in a given area, as illustrated by the equations in Section 3.2.

The use of DIFAR hydrophones and arrays of hydrophones can enable the estimation of detection range, bearing and source levels of the sounds of marine mammals, although hydrophones must be calibrated regularly. The calibration of hydrophones used for collecting acoustic data is challenging and complicated, as this process cannot be conducted at sea easily, but needs laboratory conditions to produce reliable or robust outcomes. Miller et al. (2014c) present a relatively smooth method of calibrating the magnetic compass of the sonobuoy used for the real-time tracking of Antarctic blue whales *in situ*. The Institute for Maritime Technology (IMT) in South Africa has laboratory facilities for *ex situ* calibrations, and access to such facilities could facilitate an effective calibration process.

Acoustic instruments are expensive as these are usually manufactured overseas, and greater capital investment is required in South Africa to purchase the equipment to conduct this kind of research. Despite the expenses of deployment, the relative cost-effectiveness of AAR systems' long-term monitoring means that such acoustic monitoring is a highly cost-beneficial technique. The use of existing infrastructure may reduce the cost of deployment (Van Opzeeland et al., 2014). For instance, hydrophones can be installed on existing South African oceanographic moorings, and the embargoed acoustic data from the South African Navy's underwater acoustic surveillance hydrophone 'waterbug' can be used effectively for PAM of marine mammals. The deployment of more hydrophones in arrays around the coast of South Africa is recommended, and such deployments need to be aligned with the further development of human capacity in acoustic research in the South African region.

The seas of the world are becoming increasingly noisy as anthropogenic noise at sea is increasing dramatically. Seismic surveys and other anthropogenic activities can result in the masking of sounds from marine mammals (Finneran et al., 2002). In turn, marine mammals may change their behaviour in response to the prevailing noise levels (McDonald et al., 2006b). Stricter marine laws are to be devised and implemented by the United Nations Convention on the Law of the Sea (UNCLOS) to combat the increasing noise levels in the ocean (Reeve, 2012). As AARs record ambient and anthropogenic noise across the frequencies of interest, monitoring such noise levels can provide up-to-date knowledge about the status of background and anthropogenic noise levels around the coast of South Africa.

Collaboration among researchers is fundamental and key to the future success in this field, as exemplified by the SORP Antarctic blue and fin whale Acoustic Trends Working Group (ATW). The ATW aims to establish simultaneous circum-Antarctic acoustic monitoring coverage through a Southern Ocean Hydrophone Network (SOHN) in the next decade, thus effectively reducing acoustic research costs to permit the density estimation of Antarctic blue and fin whales (Van Opzeeland et al., 2014). The PAM component of the SABWP forms an integral regional component of the SOHN.

## Conclusion

The use of bioacoustics to study marine mammals is still in its infancy in South Africa, granting South African researchers an ideal opportunity to develop and apply established methods in South African coastal waters. This acoustic technique has great potential to study vocal marine animals that are difficult to observe or survey visually. More acoustic research on marine mammals is required in South Africa to fully understand the behaviour, distribution and migration of the region's marine mammals. There are opportunities to extend passive acoustic research to other marine taxa to obtain useful data about these animals without disturbing the marine environment and ecosystem.

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# Chapter 9 E-logbook Technology Development in South Africa

*Amos Barkai and Philippe Lallemand*

## 1. Introduction

One of the main hindrances to integrated knowledge management between fishers, managers and scientists is the lack of, and an inability to capture reliable and suitable fishing data. The problem has a number of aspects, not all of which are technical. In many countries around the world, a culture of protecting catch data and disinformation is common among fishers, fishing companies and even official government offices. Significant education is needed to change these mentalities. Although the more industrialised fisheries in South Africa seem well equipped to supply accurate data, there is still a gap between the industry's data collection and its dissemination to the management authorities. Furthermore, the management of the less industrialised sectors of the South African fishing industry has been struggling with a cumbersome data collection system that has been providing inaccurate and untimely data for years. Consequently, there is a significant lack of reliable data to describe fishing operations (catches, duration, gear, locations and relevant environmental conditions), which has been a serious obstacle for advancements in fisheries management, not only in South Africa, but around the world (Barkai and Bergh, 2005).

Another problem that is endemic to imperfect data collection is the ensuing poor quality of historical data found in many fisheries. For example, not all factors related to catch per unit effort (CPUE) data, a key index of trends in resource abundance, have been systematically and/or properly recorded. Consequently, these data are absent from most statistical analyses and resource abundance modelling exercises. Unfortunately, these missing data are often crucial for sound management advice and decisions. This is a global phenomenon and South Africa is certainly no exception. For scientists, unreliable data lead to weak and incomplete stock assessment models and management programmes. For industry, the lack of a comprehensive data collection system significantly reduces its fishing efficiency, since past performance cannot be analysed effectively. As a result, poor management decisions based on unreliable analyses are sometimes made, potentially causing substantial cost and risk to marine resources and the fishing industry (Barkai et al., 2008).

Although there has been a greater awareness of the importance of collecting timely and accurate fishing data among South African scientists and fisheries managers in recent years, there is still some confusion about the data need and how exactly to collect and store them. It is common for skippers to record scientific data on one form, for shore managers to use another for commercial purposes and for skippers to keep separate fishing logbooks. These data are then transferred to different computer systems or complex spreadsheets. Sometimes, they are left in paper format in large, inaccessible books and files. There is degradation in the quality of data because of the multistage process of transcription from handwritten logbook sheets to paper forms and then to electronic databases (Barkai and Bergh, 2005).

A key step in addressing this issue is unifying all parties with regard to data collection and management. Electronic logbook (e-logbook) systems can bridge the data gaps between fishers, managers and scientists. Moreover, when designed with adaptability and flexibility in mind, such systems can be an effective and useful tool for all marine-related stakeholder groups, from the fishers themselves to commercial managers, government agencies and scientists. In fact, e-logbook systems have already been widely implemented and have proven to be an effective data collection tool in fisheries around the world, from Africa to Australasia, North America and Europe.

## 2. The South African experience with the collection and management of fisheries data

The South African fishing industry is a mature industry that, like most fisheries around the industrialised world, is managed to ensure the sustainable use of fisheries as a resource. Law mandates the Department of Agriculture, Forestry and Fisheries (DAFF) to ensure that this resource is not overexploited (RSA, 1998). Any overexploitation of the country's marine resources would not only affect the larger players (such as established fishing companies) and the small-scale subsistence fishers, but the entire South African population.

DAFF relies on scientific advice to manage the fisheries. The quality and accuracy of data used by fisheries scientists is therefore crucial if it is expected to produce accurate information and sound advice.

The transformation of the fishing industry is a constitutional and legislative imperative. The primary vehicle for the promotion of the transformation of the South African fishing industry is the Marine Living Resources Act, Act No 18 of 1998 (MLRA). Another important purpose of the MLRA is to provide for the orderly exploitation of marine living resources, and to exercise control over marine living resources in a fair and equitable manner to the benefit of the citizens of South Africa (RSA, 1998).

### 2.1 Fisheries management responsibilities

The mandate regarding fisheries matters used to reside with the Department of Environmental Affairs and Tourism (DEAT), which became the Department of Environmental Affairs (DEA) in 2009. In April 2010, most of DEA's functions were transferred to DAFF.

Now DAFF, through its Fisheries Management Branch (FMB), is the regulatory authority responsible for managing marine and coastal activities such as the following:

- The allocation and management of fishing rights
- The regulation of recreational fishing
- The management of South Africa's marine protected areas
- The protection and monitoring of South Africa's coastal and estuarine resources
- Researching fish stocks and providing advice on the status of fish stock

However, the FMB has not been fully integrated into DAFF. DEA still manages issues related to marine protected areas (MPAs), which has led to the former being fragmented when executing its mandate.

The process comprises the following directorates that make up the FMB:

- The Directorate: Aquaculture and Economic Development (AED) ensures aquaculture growth and fisheries economic development for sustainable livelihoods by providing public support and an integrated platform for the management of aquaculture.
- The Directorate: Fisheries Research and Development (FRD) ensures the promotion of the sustainable development of fisheries resources and ecosystems by conducting and supporting appropriate research.

- The Directorate: Marine Resources Management (MRM) ensures the sustainable utilisation of, as well as equitable and orderly access to marine living resources through improved management and regulation.
- The Directorate: Monitoring, Control and Surveillance (MCS) ensures the promotion and protection of the sustainable use of marine living resources by intensifying enforcement and compliance.

The FMB employs scientists and technicians who conduct research on more than 200 fish species each year. These data are used to advise the Minister of Agriculture, Forestry and Fisheries and help the FMB to determine the number of fish that may be harvested in each of the 20 commercial fisheries. The FMB relies on the Operational Management Procedures (OMP) database and uses it to manage the major marine fisheries.

The OMP approach is based on the precautionary principle, and derives the total allowable catch (TAC).

## 2.2 Fishing permit conditions

In South Africa, commercial fishing permit conditions define the rules and regulations pertinent to the fishing activity for which the permit has been issued.

There are 28 fishing permit conditions to be met when fishing commercially in South Africa. Some of these permits are sector-specific, depending on the species, area and/or method used (see Table 1).

Each permit condition highlights the various requirements pertaining to the fishing activity for which the permit is to be issued. Under various sections, depending on the permit type, fishers are required to submit catch statistics in a catch return logbook and/or data on landed catch in a landing declaration sheet.

Moreover, for each fishing permit listed in Table 1, fishers are informed under the permit conditions that if their fishing vessel is longer than 6 m, it must be fitted with a functioning Vessel Monitoring System (VMS) approved by DAFF.

Since most vessels are already required by law to be equipped with an onboard VMS, it potentially creates an opportunity to enable the integration of an onboard electronic reporting system.

## 2.3 Fisheries data collection

MRM is responsible for managing the fisheries, allocating fishing rights and setting up permit conditions and regulations. These permit conditions and regulations include exemptions, the allocation of fishing quotas and the maintenance of the rightsholder register. MRM also controls, manages and processes the information collected from all the fisheries. This ranges from socio-economic information to catch effort and landing data.

Currently, there are three main sources of fishing data available to MRM and FRD. The first two are collected systematically and the last one is only collected sporadically:

- Commercial capture fisheries data collection through a vessel logbook: The catch effort and landing data collection is currently initiated and maintained by the FMB through its mandatory logbook programme.

- Scientific data collection through vessel surveys: Programmes run by scientific groups, such as the Marine Resource Assessment and Management Group (MARAM) from the Department of Mathematics and Applied Mathematics at the University of Cape Town, require scientific survey data collected by DAFF.
- Commercial fisheries data collection through observer programmes: Periodically, DAFF also runs ad-hoc observer programmes to gather specific commercial fisheries data to inform management and/or as part of a requirement for a certification process, such as the Marine Stewardship Council (MSC) certification for hake fishery. In compliance with MSC standards, the hake fishing industry has funded an independent observer programme for several years. The programme is run by Capricorn Fisheries Monitoring cc based in Cape Town, which was previously contracted by DAFF.

MCS manages the VMS (see Figure 1), as well as the patrols and inspections of vessels at sea. MCS also manages some 215 fishery control officers (FCOs), who collectively cover some 3 500 km of coastline. There is one FCO for approximately every 17 km. The FCOs are distributed around five major areas grouped into 40 clusters (see Figure 2).

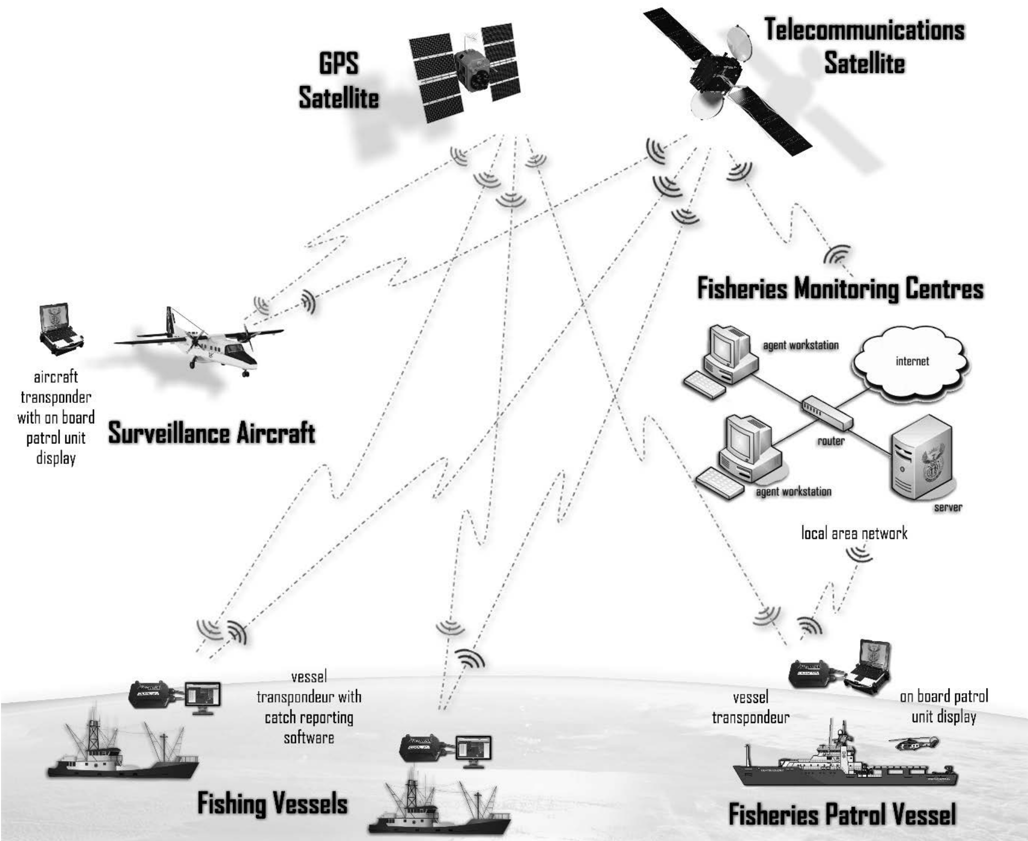


***Figure 1:*** *The Vessel Monitoring System of DAFF's Directorate: Monitoring, Control and Surveillance (based on DAFF 2012a).*

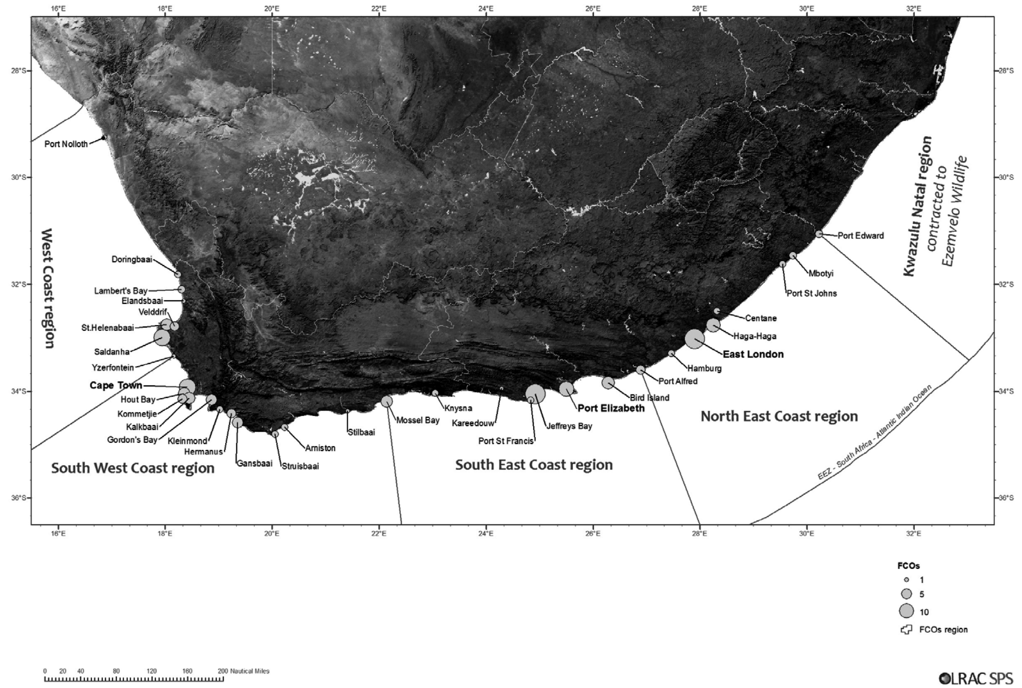


*__Figure 2:__ Coverage of DAFF's Directorate: Monitoring, Control and Surveillance, and the geographic distribution of fishery control officers (based on DAFF, 2012a).*

MCS's key compliance responsibilities include land-based patrol and inspections that monitor 22 consumptive commercial fishing sectors, fish processing establishments (FPEs), landing places and restaurants. It manages an estimated 250 000 recreational fishers, 800 subsistence fishers and 916 interim relief applicants. It also monitors exports and imports of fish at points of entry and exit.

DAFF has been focusing on its restructuring within a new ministry and has also been actively involved in the formulation and implementation of the new Policy for the Small-scale Fisheries Sector in South Africa. All of this was achieved to the detriment of its core function of fisheries management (DAFF, 2012b).

The responsibilities of MRM's operational fisheries/marine resources units include the following:

- Management of fisheries
- Allocation of fishing rights
- Permit conditions
- Permits/exemptions (for example, section 18 and section 81 of the MLRA, imports and exports)
- Rights registers
- Transfer of rights
- Administration
- Constitution and management of sector working groups
- Stakeholder liaison

- Scientific liaison
- Compliance liaison
- Fishing effort and vessel changes
- Recreational fisheries: cross-cutting in a number of sectors
- FPEs: cross-cutting in a number of sectors

Two directorates manage the functions above:

The Directorate: Offshore and High Seas Fisheries Management (OHSFM) is in charge of the following two units:

- The Demersal Fisheries Management Unit, which includes the following fisheries:
  - Hake deep-sea trawling
  - Hake/sole inshore trawling
  - Hake longline fishing
  - Hake handline fishing
  - Horse mackerel fishing
  - Demersal shark fishing
- The Pelagics and High Seas Fisheries Management Unit, which includes the following fisheries:
  - Small pelagics (pilchard and anchovy) fishing
  - Tuna pole fishing
  - Large pelagics (tuna and swordfish) fishing
  - Patagonian toothfish fishing

The Directorate: Inshore Fisheries Management (IFM) is in charge of the following units:

- The Line and Net Fisheries Management Unit, which includes the following fisheries:
  - Traditional line fishing
  - Squid fishing
  - Net fishing (beach seine/trek net and gillnetting)
  - KwaZulu-Natal beach seine fishing
- The Small Invertebrates and Seaweed Management Unit, which includes the following fisheries:
  - Abalone
  - Oysters
  - Seaweed
  - White mussels
  - Bait organisms/small invertebrates
- The Large Crustaceans Management Unit, which includes the following fisheries:
  - West Coast rock lobster (offshore)
  - West Coast rock lobster (nearshore)
  - South Coast rock lobster (SCRL) fishery
  - KwaZulu-Natal deep-sea prawn trawling

## 2.4 Current South African logbook system, issues and limitations

The South African fisheries data collection system was first developed with scientific imperatives in mind. Early on, scientists at government agencies managed the collection and maintenance of the databases. While the scientists continuously improved the system, compliance and enforcement managers saw an opportunity to use the data originally collected for scientific research to meet their requirements and fulfil their purposes.

With the refinement of the South African fishing regulations, accountability, compliance and enforcement needed to be monitored. Very quickly, the compliance and enforcement authorities took custody of the commercial fisheries catch-and-effort database, and government scientists lost most of the control of the database system they had created. Recently, DAFF updated its ageing Sybase database system by developing an alternative data collection system called the Multi-axial Simulation Table (MAST), which is based on Oracle database architecture. However, the newly developed MAST system was found to be harder to implement in all fisheries than previously thought. Today, parallel to the MAST system, a live Sybase database system is still being used for several fisheries, including demersal fisheries.

Only compliance and enforcement agencies have read-and-write access to the database, while scientists only have access to a 'dumped' version of the database, which they can consult for their research. There seems to be a substantial delay (up to two years) between the time the data are submitted by the fishers and the time these data are made available to the scientists. Table 2 shows the data submission schedule requirements for each fishing permit. Depending on the fishing permit, the delay between the discharge following the fishing activity and the data submission can vary from the same day to a month later. The paper logbook is then submitted to the DAFF office where it is processed. Due to the variability between the current data collection systems and the number of steps required, it is hard to estimate the delays between the time DAFF receives the form and the time it is entered into the system. Moreover, depending on the fishing permit, a landing summary must be submitted between 24 hours of discharge and seven months after landing the fish.

This is a good example of an instance where onboard e-logbook systems would dramatically reduce the processing time of the data submitted during and after fishing trips, while increasing the quality and integrity of the information collected at sea. Moreover, such systems would ensure consistency across the collected data, as free-format data entry is limited and data recording is typically done via predefined look-up lists and validation rules that limit the likelihood of recording invalid data. Furthermore, the illegible entries that occur in paper-based logbooks, as well as the errors inherent in the paper-based logbook process where the data are first recorded on paper and then re-entered into a database from the paper logbook, are avoided.

With an e-logbook system, decisions can be made in real time. Faster transmission of information from sea to shore allows for timely responses. As a result, decisions made on a regulatory, managerial, commercial or environmental basis are relevant to what is actually happening at sea. Backlogged, non-electronic reporting, such as that currently implemented in South Africa, means that any event at sea is sometimes only registered onshore up to several weeks after it has occurred. Responding to month-old information, particularly in an ever-dynamic ocean environment, is senseless. Faster transmission will have a substantially more positive effect on, for example, quota management, conservation and even commercial decision-making.

The shoreside reception and centralisation of data also represents a challenge for management authorities. The task of standardising the entire corpus of data so that it is useable for scientific and management purposes is considerable, and is ongoing.

Currently, the SCRL fishery is the only fishery in South Africa that has adopted an e-logbook system solution on all its vessels, although more companies in other fisheries are starting to use such systems for their day-to-day operations. An example of such an organisation is Sea Harvest (Pty) Ltd., which is in the hake-trawling industry.

# 3. An e-logbook solution for South Africa

## 3.1 Benefits of e-logbook technology

An obvious response to the lack of reliable and/or timely data is to use modern information technology (e-logbooks) in the management of living marine resources. Bringing accurate and user-friendly data-logging tools to fishers could potentially transform the entire fishing fleet and the fishing community into the largest group of surveyors in the marine environment. The calibre of data produced through e-logbooks has the potential to benefit all sectors of the fishing industry, from the fishers themselves (fleet deployment and productivity dashboard) to seafood consumers (tracking of fish from catch to end-user), scientists (resource modelling and stock assessment), resource managers (drafting regulations) and government enforcement officials (monitoring and compliance activities). In addition, the international shift towards a greater emphasis on output control measures, such as TACs, requires the implementation of sophisticated catch monitoring tools to allow for a near-real-time auditing of catch versus TAC. (Barkai, 2004; Barkai, 2007; Barkai et al., 2009; Barkai et al., 2010; Barkai et al., 2012).

## 3.2 The South African experience with e-logbook technology

Olrac SPS, a South African-based organisation, was one of the first to offer an e-logbook solution to commercial fisheries. During the last 15 years, the organisation has developed a sophisticated electronic data-recording and reporting system. This system, which was recently re-branded as the Olrac Electronic Logbook Software Solution, was driven by Olrac's consulting experience of the problems that arise when data management is inadequate for scientific research. Today, the main goal of the Olrac software system is to offer a paperless alternative to the present paper-based fisheries data-collection and reporting systems (Barkai, 2004; Barkai, 2007; Barkai et al., 2009; Barkai et al., 2010; Barkai et al., 2012). To this day, Olrac is the only comprehensive commercial e-logbook solution implemented in South Africa. It can be found on every SCRL fishing vessel (Barkai and Flanagan, 2014) and trawlers targeting hake for Sea Harvest (Pty) Ltd., one of the largest South African fishing companies.

Furthermore, the system is now certified by the local authorities for use in the UK and Australia. It is also used in The Netherlands and the USA. Olrac SPS has consulted to the Australian Fisheries Management Authority (AFMA), as well as the Department for Environment, Food and Rural Affairs (DEFRA) in the UK, and the National Oceanic and Atmospheric Administration (NOAA) in the USA with regard to the development of a standardised data format for the centralisation of fisheries data shoreside.

Data that were initially developed for data logging and data management for use in e-logbook technology in the commercial fishing industry has now evolved to provide a complete solution for the collection, management and reporting of other vessel-based activities, such as commercial and recreational fishing trips, oceanographic surveys, marine inspections, cargo and service trips, and surveillance missions.

Ultimately, e-logbook technology should be integrated to include two basic components to cater for the entire data flow, from at-sea collection to the generation and dissemination of reports (see Figure 3).

An onboard data-collection component is a stand-alone data-gathering tool installed on the vessel's computer (desktop, laptop or tablet).

A second shore-based component can be a secured web application (in the internet 'cloud') with the main function to receive, store and disseminate nominal data and summary reports coming from the vessels or, if necessary, other third-party data-logging systems. Such a system should also allow for the direct entry of data via an internet interface in cases where the use of an onboard data-logger is not practical (due to the cost or unsuitable working environment). With the shore or 'cloud' system, the entire fleet of vessels can be managed. It can include a vessel registry, a full quota management system and an elaborate administrative component that allows the user to customise the system to satisfy his or her needs.

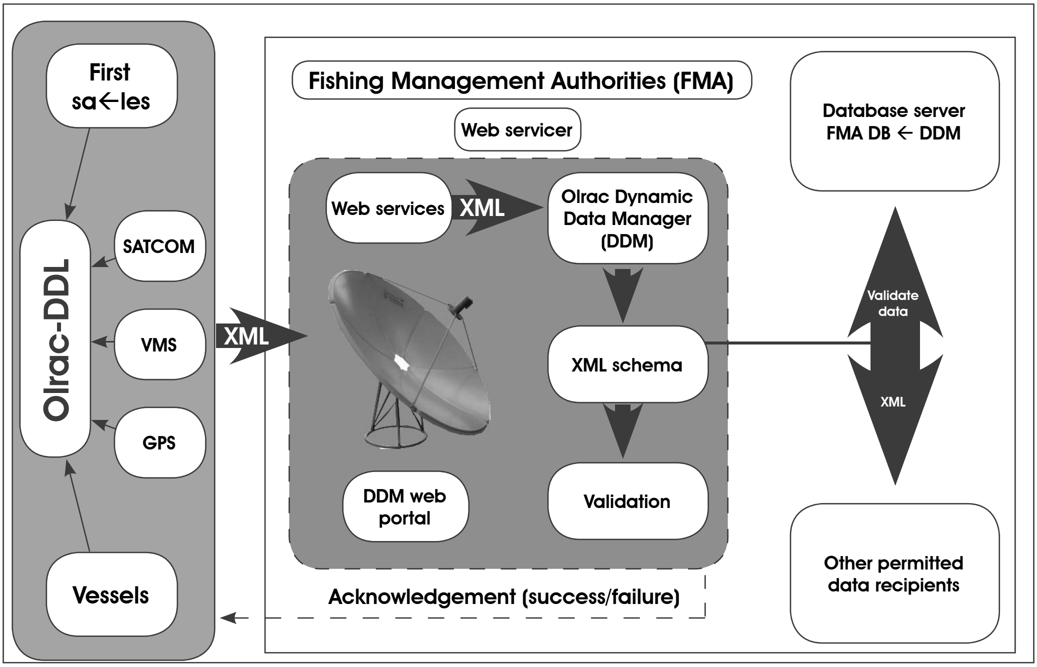


***Figure 3:*** *Example of the general structure of the data-collection and management system.*

## 3.3 Onboard data-logger

### 3.3.1 Basic functionality

With the advance of technology, today's data-logger can make the most of touch-screen capability to capture data in real time and/or after the fishing activity has taken place (see Figure 4). The user can collect any type of data in any form. This includes images, video clips, numerical and alphanumeric fields, free-text comments, date, time and location. Such systems allow data to be inserted from guiding images (infographs) to guide it through complex data-entry needs. Each mode of data entry has its own unique data-entry interface, specifically designed for the type of data recorded.


***Figure 4:*** *Example of a vessel data-logger unit on a tablet PC.*

Ultimately, the system should be highly customised and able to be easily adapted to address different data-recording and reporting needs. It should enable individual users to configure the software to suit their specific requirements. Users should be able to change display labels, field content and look-up values, hide data fields or look-up values, add user-specific fields to the data-capture screens, and decide whether or not certain fields are mandatory. This customisation should be available on every phase of the fishing trip, for example, the trip itself, the start of the trip, and setting the gear. However, under certain circumstances, it is undesirable to allow the user to change the basic configuration and customisation pre-setup. It should therefore be possible to prevent unwanted configuration changes in cases where data definition was strictly controlled by a compliance authority by 'hard' configuring the system and constraining the user's ability to override certain fields.

### 3.3.2 Overall structure

The ultimate onboard system should consist of the following components (see Figure 5):

- Configuration files defining levels, fields and parameters
- Database for working data
- Database for archived data
- User-interface elements: data-entry and browsing facilities, a data-mapping facility, a data centre for maintenance, reporting and querying
- Input/output modules for the following types of data:
  - Reports to specific agencies and third parties
  - Import/export of operational data
  - Backup of the complete system
  - Error/exception-handling reports to software support

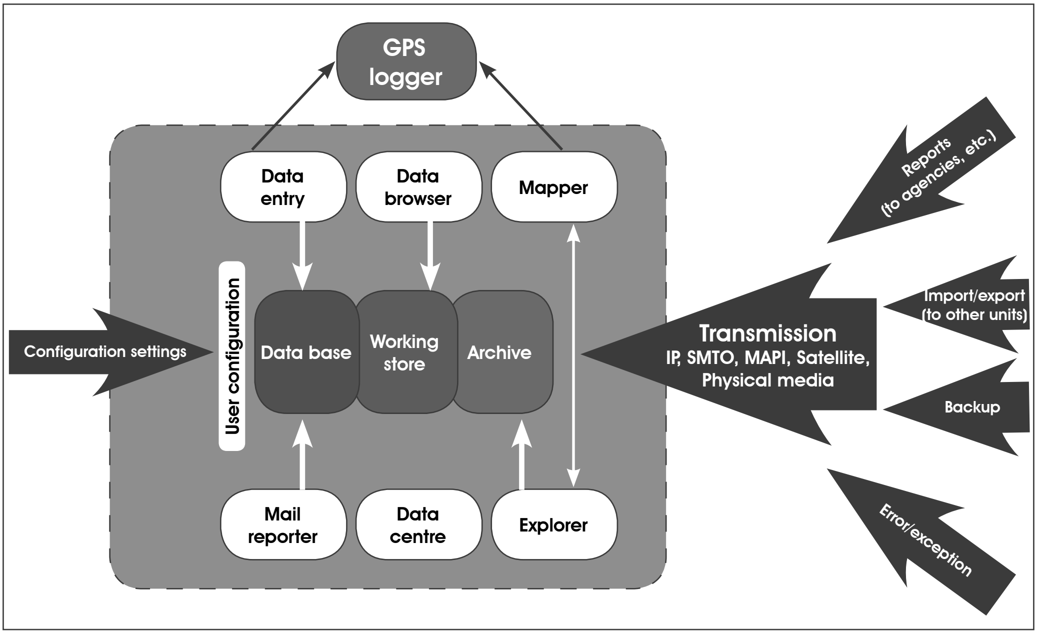


***Figure 5:*** *Example of the basic structure of an onboard system.*

To be fully practical, the onboard system should make extensive use of drop-down lists whenever possible. The use of drop-down lists to enter data helps to maintain data integrity, thus minimising typos and saving time. However, users can add new fields and values if necessary.

A flexible onboard e-logbook system should also be easily configured to fit the 'taste' and needs of different users of the same basic configuration. For example, the user could decide which fields should be visible, compulsory and remembered from previous entries. The user could also decide which data fields should be visible in which phase of the vessel operation (see Figure 6). Examples are 'trip start', 'trip end' and, within a trip activity, 'start' and 'end'. The system should also allow users to set upper and lower limits for any numerical field to reduce the chance of typos.

Another feature of an intelligent versatile e-logbook system is its ability to be dynamically configured to 'intelligently' guide the user during its data-logging activities (see Figure 7). The system can then be configured to reflect data-logging actions of vastly different activities. For example, the same basic underlying user interface can have different settings and can be used to collect data for different forms of fishing (trawling, longlining, purse seine, traps, etc.) or other vessel activities (sea ferry, cargo delivery, coastal guard patrols, oceanographic surveys, etc.).

Data collected by the onboard system should be able to generate any type of report in any format (XML, HTML, CSV, PDF, etc.). These reports can be saved and transferred to other databases (such as a shore version, internet or 'cloud', or other third-party databases) either directly, using portable storage devices or in real time using the onboard VMS or other onboard satellite communication systems.

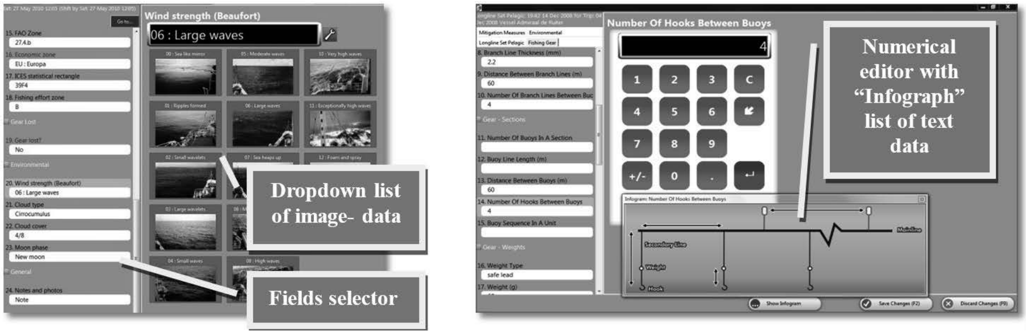


***Figure 6:*** *Example of an e-logbook system data editor.*

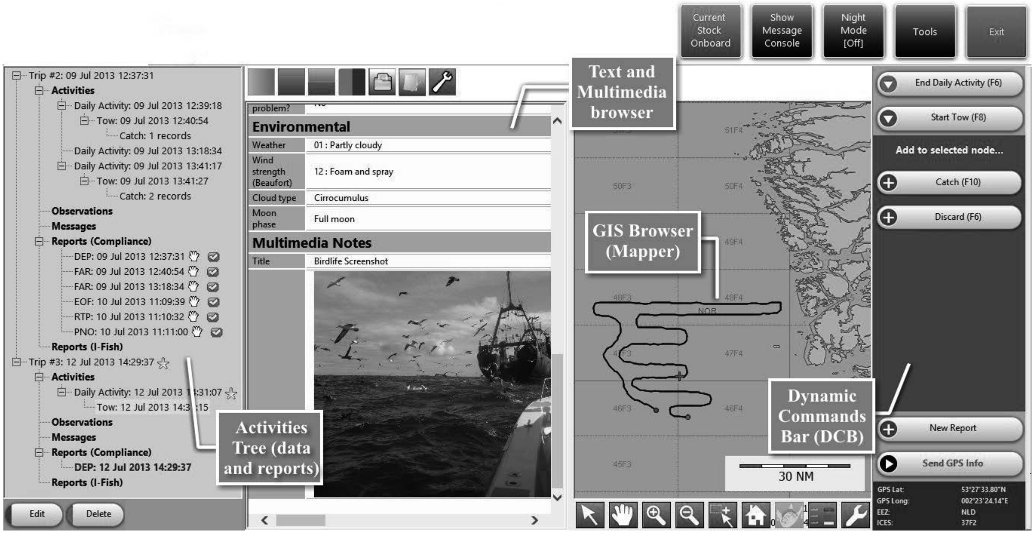


***Figure 7:*** *Example of the main dashboard screen.*

### 3.3.3 Device-logger

Ultimately, one should be able to link the onboard system to any number of analogue or digital sensors (transducers). The device-logger's main function, however, should be to read Global Positioning System (GPS) data and track and plot vessel movements. The device should also track trips, gear setting and hauling. It can fill in the date, time, location and other GPS-related fields if it has access to a GPS unit (see Figure 8). GPS input can come from either a VMS transponder or standard GPS-outputting National Marine Electronics Association (NMEA) strings on a serial or universal serial bus (USB) connection. In fact, in most South African fisheries, vessels of a certain size are required by law to be equipped with a fully functional onboard VMS that would be compatible with such a system.

The device-logger can be a small, 'lightweight', stand-alone application that continually runs on the computer hosting the onboard system, even if the main system unit is not operational. The onboard system should communicate with the device-logger via a simple application programming interface (API), allowing all the low-level interfacing with various sensors to be handled exclusively by the device-logger. This also means that only the device-logger application needs to be compatible with new devices, such as new GPS or VMS units.

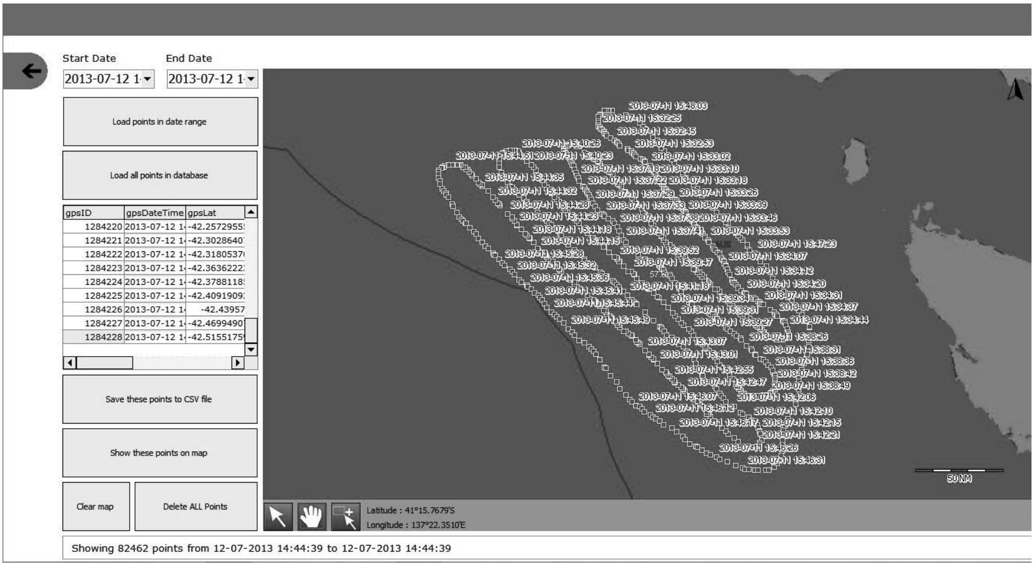


***Figure 8:*** *Example of a GPS reading on a device-logger.*

## 3.4 Shore or internet 'cloud'-based system

The main functionality of the web-based or shore-based system (master system) is to process and report the data received from vessels describing their fishing operations, catch taken, landings, vessel movements, sales and transhipment, and make that data available to the user via a variety of interfaces. The master system could include a vessel registry, a full quota management system and an elaborate administrative component that would allow the system to be customised to satisfy diverse requirements. Such a master system could easily be tailored to meet any future South African electronic data-reporting requirements.

The shore version could be deployed on a server running the necessary components (for example, ASP.NET and SQL server).

Due to its nature, the web-based interface should be securely controlled and access to the data should be limited according to the role of the user (see Figure 9). Typical user roles include the following:

- Administrator, which allows complete control to add, edit or delete data on the system, as well as to view aggregated data.
- Vessel user, which allows the vessel owner or master to view all data submitted by the vessel.
- Fishing authority, which allows the user to view all data received from the various onboard installations, but not to control system configuration data.

## Multiple roles with defined access levels

| | Data entry | Admin | | | Reports |
|---|---|---|---|---|---|
| | | Vessels | Users | Others | |
| Full administrator access | Yes | Yes | Yes | Yes | Yes |
| Query access | No | No | No | No | Yes |
| Data entry and vessel access | Yes | Yes | No | No | No |
| Data entry and vessel access | Yes | No | No | No | No |
| Read only | Browse only | Browse only | Browse only | Browse only | No |
| No login access | No | No | No | No | No |
| System access levels | | | | | |

OLRAC SPS

***Figure 9:*** *Multiple roles with different access levels.*

The master system should also allow the user to enter data directly via the internet interface for cases where the use of an onboard data-logger is not practical (for example, on small vessels where the cost of a logger is not viable or conditions do not permit the installation of a computer).

The master system should allow the user to view reports on an individual level (in their original format), as well as aggregated reports based on imported data. Vessel location and summary data should also be viewed spatially, using any online mapping website, such as Google Maps (see Figure 10). The system should then facilitate data cross-checking, system status and data validation.

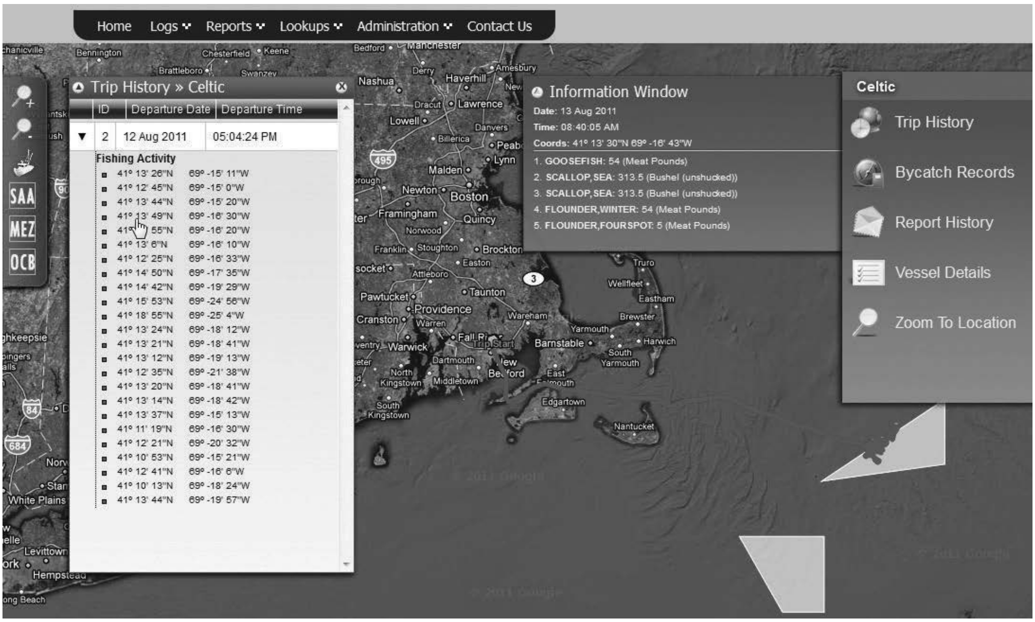


***Figure 10:*** *Example of a web-based system showing vessel location and summary data on Google Maps.*

## 3.5 GIS add-ons

A visual data analysis or Geographic Information System (GIS) module specifically designed to work with the onboard system's main database could be a useful optional add-on. It should allow the user to analyse subsets of data captured by the onboard system. For example, the system might let the user capture information on trips, sets and catches. A trip has, for example, a departure date, departure port and skipper name fields. Possible set fields include start time, start latitude, start longitude and gear used. Possible catch record fields include species and weight. From a selected set, the user could create subsets of data for a particular analysis or presentation. For example, graphs could be drawn showing CPUE as a function of time, moon phase and current strength. Spatial CPUE density distributions could also be plotted on a map, which could then be filtered for various target species or reflect different environmental conditions. Subsets could be swapped to explore different scenarios and data relationships, for example, CPUE at new moon time compared to CPUE at full moon time. A subset of definitions (the list of classes and fields selected for the subset) could be saved to reinvestigate patterns when updating the data.

With the GIS add-on, it should be possible to simulate, for example, the spatial distribution of CPUE by dividing catch weight by fishing duration.

The table created by such an add-on query engine could be shown on a graph (such as a bar graph or a pie chart) or, as in Figure 11, in a density distribution map (if the data contain longitude/latitude information for each row in the table).

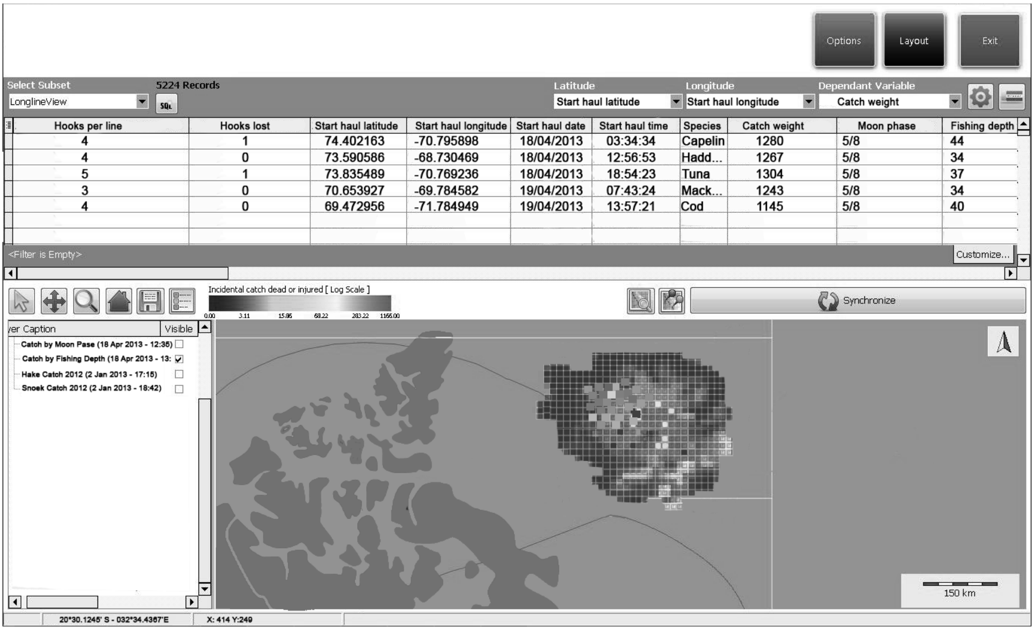


*__Figure 11:__ Example of information displayed by a GIS add-on.*

## Conclusion

Over the past decades, various GIS-based e-logbook systems specifically designed for the commercial fishing industry have been developed around the world with mixed success. Despite many technical and logistical hurdles at first, some systems managed to implement and deploy their technology aboard many vessels around the world. Throughout the years, lessons were learnt and had to be considered before making e-logbook reporting in commercial fishing a global reality. In South Africa, these challenges were met by Olrac SPS during the deployment of the Olrac e-logbook technology onboard trap longline lobster vessels off the South African south coast (Barkai and Flanagan, 2014).

The Olrac e-logbook technology was first installed in 2009 by Ruwekus Fishing (Pty) Ltd., aboard the SCRL fishing vessel, *Rigel 4*. The decision to install the programme was driven by the need to capture real-time fisheries data in an electronic format that can be exported from the vessel and investigated with ease. With the successful implementation of the software aboard the *Rigel 4*, all the other fisheries operators that form part of the South Coast Rock Lobster Industry Association (SCRLIA) adopted the e-logbook.

The deployment of the Olrac e-logbook provided many challenges and continues to be a work in progress. With vessels completing voyages that last 30 to 45 days, software 'bugs' and shortcomings had to be slowly worked out between trips. This required patience and a good working relationship between the vessel officers, shore management and the Olrac software developers.

The officers on the fishing vessels were at first hesitant to adopt the new technology. However, after being educated on the advantages of such a system, they were convinced. The system is now viewed as a tool rather than a burden. Four years later, Ruwekus Fishing (Pty) Ltd., which pioneered this project, is starting to investigate the data to understand the effect of environmental conditions such as wind, moon phase, current and water temperature on their catch rates. The organisation also studies the spatial distribution of the southern spiny lobster *(Palinurus gilchristi)*. It will take some time before meaningful results and patterns emerge from the fisheries data, which will directly influence fishing decisions, but the organisation is making progress. The organisation hopes that the e-logbook will become a crucial source of information, a sort of 'Google' for the SCRL fishery – a search engine of data that answers many relevant, scientific or commercial questions (see Figure 12). As the South African fishing industry slowly moves into the digital age, the Olrac e-logbook has driven Ruwekus Fishing (Pty) Ltd. towards being 'tech-ready' for further developments and requirements.

Experience such as this has consistently highlighted the critical role that fisheries statistics and other data related to fishing have in management and decision-making in South Africa. Where the available data are lacking or have not been properly recorded, various suboptimal decisions have been made. The new data system (MAST), which has been installed at DAFF, has, it would appear, compromised the integrity of the data available for fisheries management. At the moment, in South Africa, fisheries data from the commercial sector are recorded in paper format and digitised later. In some instances, scientists have been forced to de-archive original paper records and embark on a process of re-digitisating the data, a very costly, time-consuming and error-prone task. Furthermore, the lack of consistency with regard to units has rendered years of work obsolete. There can be a substantial time lag between an event and the ability to act on it in an informed manner with all the data available. Shortening this time lag will create additional management options for many South African fisheries. One obvious option for achieving this is to digitally collect data at sea in near real time through the development of an integrated e-logbook system for the various South African fisheries.

For those vessels that cannot use electronic recording tools such as laptops, tablets and mobile phones due to various limitations such as the size of the boat, paper logbooks may still be used. The logbook information can then be captured in an onshore e-logbook system via digital forms set up to match the structure and format of the paper logbook (to ease data entry). This e-logbook system has validation to limit data capture errors. Fishers can also telephone their trip details to a call centre, which will directly capture the details into the onshore digital facilities.

A number of fishing nations are leading or have already led the implementation of e-logbook systems at sea. In the European Union (EU), this approach has been legislated and member countries have responded to this legislation in a variety of ways. In Australia and New Zealand, as well as the USA, similar initiatives are underway.

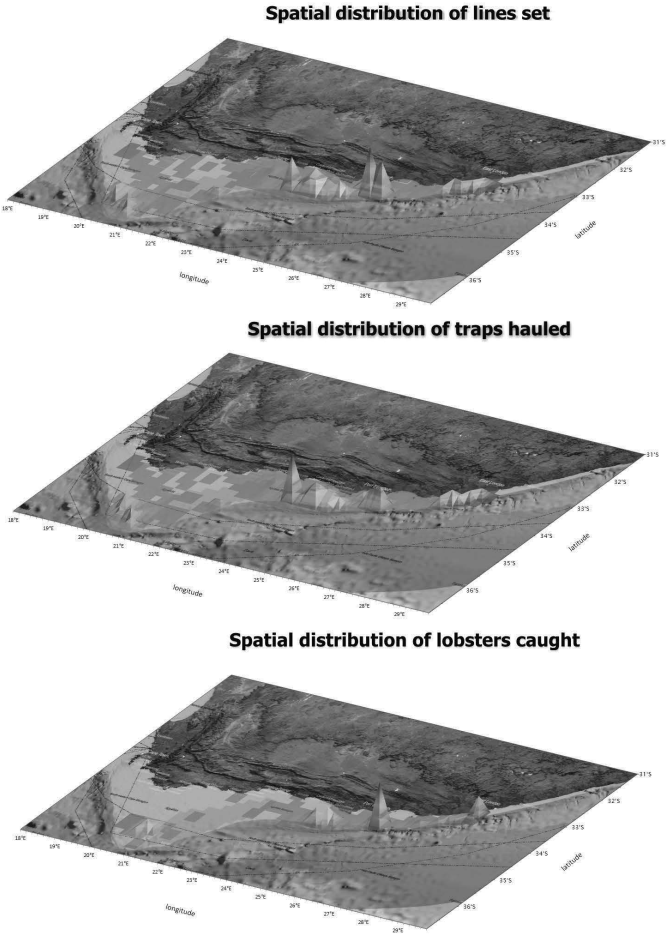


***Figure 12:*** *Example of data generated by e-logbook technology and used for spatial distribution analysis in the SCRL industry.*

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## Tables

***Table 1:*** *List of fishing permit conditions in South Africa*

| Permit condition | Main species | Method |
|---|---|---|
| Abalone fishery | Abalone | Air-assisted diving |
| Pelagic fishery (mainly anchovy and pilchard ) | Anchovy | Purse seine nets |
| Hake deep-sea trawl fishery | Hake | Deep-sea trawl |
| Hake handline fishery | Hake | Handline |
| Hake longline (south coast inshore) fishery | Hake | Longline |
| Hake longline (south coast offshore) fishery | Hake | Longline |
| Hake longline (west coast) fishery | Hake | Longline |
| Hake, sole, horse mackerel and demersal shark fishery | Hake | Trawl, longline or handline |
| Hake/horse mackerel midwater trawl fishery | Hake | Midwater trawl |
| Hake/sole inshore trawl fishery | Hake | Inshore trawl |
| Traditional linefish fishery (Zone A) | Linefish | Line methods |
| Traditional linefish fishery (Zone B) | Linefish | Line methods |
| Traditional linefish fishery (Zone C) | Linefish | Line methods |
| SCRL fishery | Lobster | Traps |
| West Coast rock lobster (nearshore) fishery | Lobster | Ring/hoop nets |
| West Coast rock lobster (offshore) fishery | Lobster | Traps |
| KwaZulu-Natal commercial oyster fishery | Oyster | Hand gathering |
| Southern Cape commercial oyster fishery | Oyster | Hand gathering |
| Patagonian toothfish fishery Prince Edward Islands (South African EEZ) | Patagonian toothfish | Deep-sea longline |
| Pelagic fishery (pilchard/sardine) | Pilchard/sardine | Purse seine nets |
| KwaZulu-Natal prawn trawl fishery | Prawn | Deep-sea trawl |
| Commercial seaweed fishery | Seaweed | Hand gathering |
| Demersal shark longline | Shark | Longline |
| Squid commercial fishery | Squid | Squid jig |
| Swordfish longline fishery | Swordfish | Deep-sea longline |
| Tuna longline fishery | Tuna | Deep-sea longline |
| Tuna pole fishery | Tuna | Pole |
| Commercial white mussel fishery | White mussel | Hand gathering |

***Table 2:*** *Catch and landings current reporting requirements from fishing permit conditions for selected South African commercial fisheries*

| | Catch reporting requirement | | Landing reporting requirement | |
|---|---|---|---|---|
| | Form to be submitted | Submission schedule | Form to be submitted | Submission schedule |
| Hake handline fishery | Commercial linefish catch return (blue book) | As soon as catch is landed | Landing declaration sheet | Before the 15th of the month |
| Tuna longline fishery | Catch return book | By the 15th of each month | Excel spreadsheet with trip summaries to be emailed | Within two weeks after discharge |
| Tuna pole fishery | Catch return book | By the 15th of each month | Landing declaration form as per Annexure 4 of the tuna pole permit conditions | As soon as possible after each trip |
| | | | Updated on an electronic monthly summary in Excel as per Annexure 5 of the tuna pole permit conditions | By the 15th of every month |
| Pelagic fishery (anchovy) | Pelagic catch report (skipper form) | At the end of the trip before offloading | Landing declaration OM/EN 26/7/3 | Weekly summaries of catches |
| Pelagic fishery (pilchard/sardine) | Pelagic catch report (skipper form) | At the end of the trip before offloading | Landing declaration OM/EN 26/7/3 | Weekly summaries of catches |
| Traditional linefish fishery (Zone A, Zone B and Zone C) | Commercial linefish catch return (blue book) | By the 15th of each month | Catch and landing information on the same form (see catch reporting requirements) | |
| Squid fishery | Squid jigging catch book | The last day of the month with respect to the previous month | Electronic summary of landings | By the end of the month following the end of the six-month period (1 January to 30 June and 1 July to 31 December) |

| | **Catch reporting requirement** | | **Landing reporting requirement** | |
|---|---|---|---|---|
| | Form to be submitted | Submission schedule | Form to be submitted | Submission schedule |
| Hake, sole, horse mackerel and demersal shark fishery | Catch-effort data in the fishing logbook (catch discharge sheet) | Sector-specific (in section C of permit condition) | Electronic summary of landings | By the end of the month following the end of the six-month period (1 January to 30 June and 1 July to 31 December) |
| Hake longline (south coast inshore) fishery | Longline daily logsheet (HK/LL 1) | Within 30 days of the date of landing | Landing declaration sheet (HK/LL 2) | On receipt of fish and/or fish product if processed and weighed within 24 hours of discharge |
| Hake longline (south coast offshore) fishery | | | | |
| Hake longline (west coast) fishery | | | | |
| Hake deep-sea trawl fishery | Trawl fishing log (catch discharge sheet) | Before discharg-ing is completed and submitted the last day of the month fol-lowing the month the catch was discharged | Goods received | On receipt of fish and/or fish product if processed and weighed within 24 hours of discharge |
| Hake, horse mackerel midwater trawl fishery | | | | |
| Hake/sole inshore trawl fishery | | | | |
| Abalone fishery | Abalone/ perlemoen catch statistic forms | On landing | Permit holder provides copy of landing slips to a nominated FPE | On landing |
| West Coast rock lobster (nearshore) fishery | West Coast rock lobster landing form (OM/EN 26/12/2) | On landing, once all rock lobsters have been weighed | Catch and landing information on the same form (see catch reporting requirements) | |
| West Coast rock lobster (offshore) fishery | West Coast rock lobster landing form (OM/EN 26/12/3) | On landing once all rock lobsters have been weighed | Catch and landing information on the same form (see catch reporting requirements) | |
| SCRL fishery | V1/3/5/2/1 S daily catch rate – SCRL | Recorded on a daily basis and submitted on landing | Catch and landing information on the same form (see catch reporting requirements) | |

| | Catch reporting requirement | | Landing reporting requirement | |
|---|---|---|---|---|
| | Form to be submitted | Submission schedule | Form to be submitted | Submission schedule |
| KwaZulu-Natal prawn trawl fishery | Drag book OM/ EN 26/6/15 and landing books OM/EN 26/6/13 and 26/6/14 | Submitted on a monthly basis | Landing report OM/EN 26/7/3 | Recorded on completion of the offloading process |
| Patagonian toothfish fishery Prince Edward Islands South African EEZ) | CCAMLR five-day catch-effort report (ref. 23-01) | Every 5 days | Catch and landing information on the same form (see catch reporting requirements) | |
| | CCAMLR monthly fine-scale catch-effort data reporting (ref. 23-04) | Monthly | | |
| | CCAMLR monthly fine-scale biological data reporting (ref. 23-04) | Monthly | | |
| Demersal shark longline fishery | Longline daily logsheet (HK/LL 1) | By the 15th of the following month in which the landings were made | | |
| Swordfish longline | Daily catch return book | By the 15th of the following month in which the landings were made | | |
| Beach seine net fishery | Commercial catch returns for drift and beach seine nets | Before the end of each month in respect of the previous month fished | | |

# Part 4

## Research in the Humanities for the Maritime Sector

# Chapter 10 A Critical Analysis of Research Paradigms in a Subset of Marine and Maritime Scholarly Thought

*Richard Meissner*

## 1. Introduction

The application and applicability of the humanities and social sciences are not always visible in the practical world. This is especially the case in technology-dependent areas like the marine and maritime sectors. In these sectors, control, prediction and recommendations that rely on technologies and their advancement are of the utmost importance. These sectors are, after all, those on which we rely for international trade, defence and security, sources of food and other energy requirements, like oil and gas. At first glance, it would appear that the sectors are devoid of the humanities and social sciences and that these have a minimal, if not marginal role to play. The humanities and social sciences consist of a number of subject fields like anthropology, economics, history, international relations, law, philosophy and sociology. These fields of enquiry are at times service providers to sectors when their services are needed. This relegates the fields to the cupboard of scientific investigation when long-term strategies are developed, which should not be the case. The humanities and social sciences should play a constant role in a human-dominated world. The maritime sector is, after all, human constructed. Trade routes, ports, harbours, warehouses, cranes, rail links and truck routes are not natural occurrences; neither are the technologies that constitute and sustain them. Because of the dominance of the human element, even in the marine environment, the humanities and social sciences can play a more fruitful role in creating opportunities and solving problems. What is more, it is not only the humanities and social sciences that are of importance, but also how humans view the world and react to it either through theoretical or concrete means. Here, paradigms and theories of various kinds from the humanities and social sciences also have their place.

This chapter explores these dimensions in more detail. It starts by presenting a framework, called PULSE$^3$, for analysing the role of the humanities and social sciences in the two sectors. The paradigms of the presentations delivered at the Integrated Marine and Maritime Technologies Workshop in October 2013 are assessed. This chapter reviews the abstracts of the presentations made at the workshop. The review of the abstracts is not representative of the state of research and development in the entire sector. It is only a snapshot of it. However, it provides useful insights into current thinking and practice in the marine and maritime sectors. The purpose of this assessment is to determine the type of paradigm that was dominant. Two paradigms, rationalism and interpretivism, are identified through the assessment. Rationalism views the researcher and reality as separate, with only one reality present. Research is able to control and predict this reality. This means that an objective reality exists beyond the human mind. Interpretivism, however, notes that the researcher and reality are inseparable in that realities are mentally constructed. Multiple realities exist and, as such, knowledge of the world is intentionally constituted through researchers' lived experiences. There is no objective meaning (Wendt, 1999; Weber, 2004; Guba and Lincoln, 2005; Lincoln et al., 2011). An overview of the ethos of analytic eclecticism is provided and how it can aid the marine and maritime sectors. After this, the role of the humanities and social sciences in the public and government policy domain is presented. This is followed by the setting of a number of beacons that the marine and maritime sectors could follow to expand the role of the humanities and social sciences. The repertoire of theories plays a central role in this, the penultimate section of the chapter.

## 2. Framework for analysis

The PULSE[3] framework is used to analyse water governance and politics. This forms the foundation of the chapter. PULSE is an acronym for 'people understanding and living in a sustained environment'. The cube denotes three forces: thinking, shaping and causing change. Individuals think, shape and cause changes in the environments in which they live, be it the natural environment or the working environment (Meissner, 2013). The natural environment shapes and affects changes that impact on human society and the way we live in the environment (Berger and Luckmann, 1966; Giddens, 1984; Meissner, 2003; Kooiman and Bavinck, 2005; Gillings, 2010). Although the framework is geared towards an analysis of water governance and politics (Meissner, 2013), it is equally at home in a review of the marine and maritime technology research landscape. This is because of the framework's ability to analyse issues at a paradigmatic and theoretical level, and not at a macro level. The rationale behind PULSE[3] is that paradigms and/or theories have an impact on how humans act in the world and subsequently the policies, programmes and projects they put in place to resolve problems or create opportunities. A paradigm is a research tradition, which, in turn, is a set of assumptions about how knowledge is produced (Schultz and Hatch, 1996; Sil and Katzenstein, 2010). Stated more formally, a paradigm is a world view that describes – for the person holding that paradigm – the nature of the 'world', his or her place in this world, as well as the range of potential relationships to that world and its parts (Pearse, 1983; Guba and Lincoln, 1994). Considering this definition, it becomes clear that the 'world' of marine and maritime technology has a particular nature with a range of relationships that span individuals, corporates, scientists, government officials, operators and education specialists. If this is the case, it would hold that a certain paradigm is present in the marine and maritime technology landscape that influences how problems are confronted and opportunities created.

PULSE[3] consists of three components or elements. The first is a paradigm assessment index (see Table 1), the second is the ethos of analytic eclecticism, and the third is a repertoire of theories. The paradigm assessment index calculates the nature of the paradigm found in the marine and maritime technology landscape and makes it visible.

### 2.1 Paradigm assessment of the presentations

The difference between rationalism and interpretivism is the foundation of the paradigm assessment. This differentiation can assist with profiling the paradigm of the workshop and the state of research in the two sectors. The paradigm assessment index investigates how knowledge contained in each presentation was generated by the author. In other words, did the author follow a rationalist or interpretivist route to generate his or her knowledge?

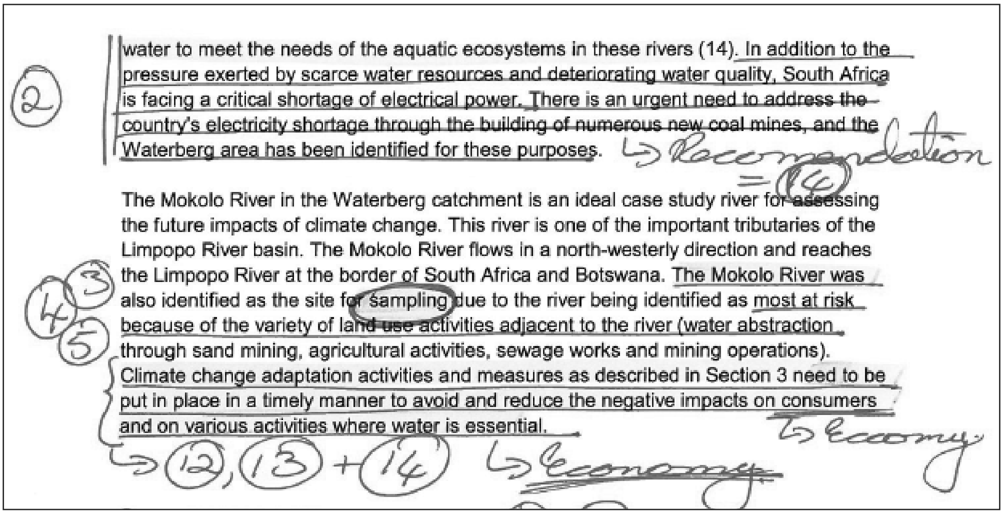
**Table 1:** *Paradigm assessment index*

| | Metatheoretical assumptions about | Rationalism | Score | Score | Interpretivism |
|---|---|---|---|---|---|
| KNOWLEDGE GENERATION | Ontology **(1)** | The researcher and reality are separate. | | | The researcher and reality are inseparable (life-world). **(15)** |
| | Epistemology **(2)** | Objective reality exists beyond the human mind. | | | Knowledge of the world is intentionally constituted through a person's lived experience. **(16)** |
| | Research object **(3)** | The research object has inherent qualities that exist independently of the researcher. | | | The research object is interpreted in light of meaning structured of the researcher's lived experience. **(17)** |
| | Method **(4)** | Statistics, content analysis, laboratory experiments, field experiments and surveys (empirical data gathered and analysed through statistical analyses). | | | Hermeneutics, phenomenographic studies, case studies, ethnographic studies and ethnomethodological studies. **(18)** |
| | Theory of truth **(5)** | Correspondence theory of truth: one-to-one mapping between research statements and reality. | | | Truth as intentional fulfilment: interpretations of the research object match the lived experience of the object. **(19)** |
| | Validity **(6)** | Certainty: data truly measures reality. | | | Defensible knowledge claims. **(20)** |
| | Reliability **(7)** | Replicability: research results can be reproduced. | | | Interpretive awareness: researchers recognise and address implications of their subjectivity. **(21)** |
| | **Total** | | | | |

| | Theoretical assumptions about | Rationalism | Score | Score | Interpretivism |
|---|---|---|---|---|---|
| AGENCY | Organising question **(8)** | Who governs and who benefits? | | | Who acts and what are the consequences of their actions (how are their actions enabling change)? **(22)** |
| | Unit of analysis **(9)** | Hegemons/great powers, international regimes, ideational entrepreneurs, capitalist world economy, structures of rule. | | | Everyday actors interacting with elites and structures. **(23)** |
| | Prime empirical focus **(10)** | The supply of order and welfare maximisation by elites, as well as the maintenance of the powerful and the unequal distribution of benefits. | | | The social transformative and regulatory processes enacted, or informed, by everyday actions of individuals. **(24)** |
| | Locus of agency **(11)** | Top-down. | | | Bottom-up. **(25)** |
| | Level of analysis **(12)** | Systemic. | | | Complex/holistic. **(26)** |
| | Ontology **(13)** | Structuralist. | | | Agential or structurationist. **(27)** |
| | Recommenda-tions based on specific theoretical assumptions **(14)** | Rationalist, positivist or interpretivist. | | | Interpretivist, post-positivist and rationalist. **(28)** |
| | **Total** | | | | |
| | **Grand total** | | | | |

(Weber, 2004; Hobson and Seabrooke, 2007)

The index also indicates to what extent 'agency' is regarded by the author. Agency is defined as any action discussed in a programme, project or policy that involves some form of human action to set in motion general or specific ideas, operations or recommendations. The separation along knowledge generation and agency lines will determine the extent of the landscape's rationalism or interpretivism. There is a simple sorting system to determine the extent of the paradigm backing the policy, programme or project. The paradigm underpinning the action is scored against the presence or absence of rationalist or interpretivist metatheoretical and theoretical elements. A value of 0 = absent, while 1 = present. In a case where both elements are present, a score of 1 is awarded to both the rationalist and interpretivist assumptions. It is possible for both rationalism and interpretivism to exist in one research endeavour. Alexander Wendt (1999), considered to be an interpretivist, says that he is ontologically an interpretivist, while he is epistemologically a rationalist. It is not entirely impossible to come across rationalist elements in his interpretivist work. A combination of the two paradigms in one assumption is also possible, although both will then receive equal weight. The bold number in brackets is there to aid in the analysis of policies, programmes or projects. For instance, should the assumption (whether rationalist or interpretivist) be present in the text, the analyser will mark it with the appropriate bold number to indicate its presence (see Figure 1 for an example of a piece of text marked in this manner) (Meissner, 2013).


water to meet the needs of the aquatic ecosystems in these rivers (14). In addition to the pressure exerted by scarce water resources and deteriorating water quality, South Africa is facing a critical shortage of electrical power. There is an urgent need to address the country's electricity shortage through the building of numerous new coal mines, and the Waterberg area has been identified for these purposes.

The Mokolo River in the Waterberg catchment is an ideal case study river for assessing the future impacts of climate change. This river is one of the important tributaries of the Limpopo River basin. The Mokolo River flows in a north-westerly direction and reaches the Limpopo River at the border of South Africa and Botswana. The Mokolo River was also identified as the site for sampling due to the river being identified as most at risk because of the variety of land use activities adjacent to the river (water abstraction through sand mining, agricultural activities, sewage works and mining operations). Climate change adaptation activities and measures as described in Section 3 need to be put in place in a timely manner to avoid and reduce the negative impacts on consumers and on various activities where water is essential.

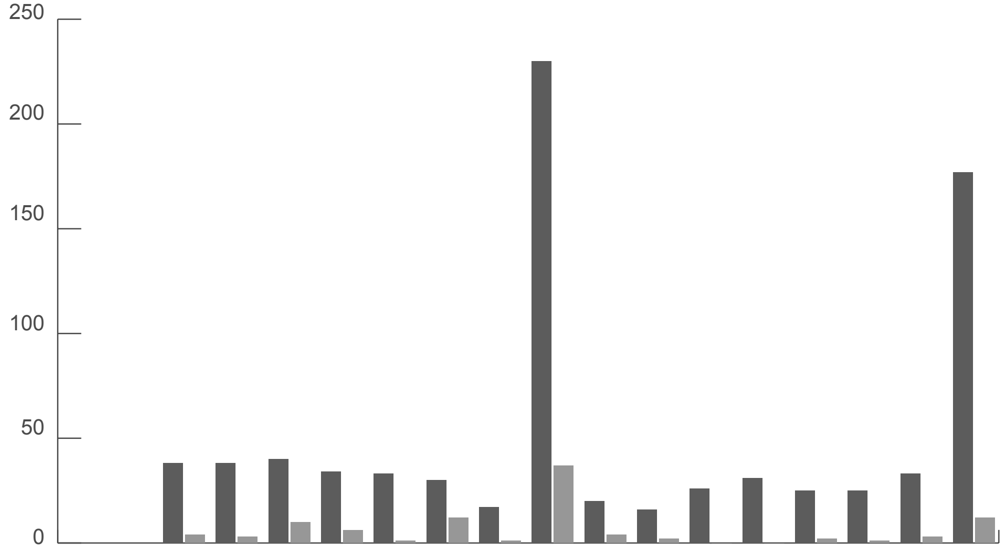
**Figure 1:** *An example of the 'marking' of a text using the numbering system in the paradigm assessment index. The numbers in the circles correspond with those in the paradigm assessment index to indicate the presence of the assumption.*

The methodology used for this chapter was to start with the paradigm assessment of all the abstracts of the presentations delivered at the Integrated Marine and Maritime Technologies Workshop, hosted by the Department of Science and Technology (DST) and the South African Maritime Safety Authority (SAMSA), which was held on 30 October 2013. Each abstract was assessed according to the metatheoretical assumptions present or absent in the text of the abstract. For example, if an author used a rationalist ontology (the study of the general properties of things) (Viotti and Kauppi, 1999) instead of an interpretivist ontology, a score of 1 (present) is accorded to the rationalist ontological assumption and 0 (absent) for the interpretivist ontological assumption. Going through the list of metatheoretical assumptions, and scoring each abstract in that way reveals a paradigm profile for each abstract. This profile indicates to what extent each profile is rationalist or interpretivist. Adding the total rationalist and interpretivist scores for all 43 abstracts reveals an overall paradigm profile for the entire workshop.

The individual and overall assessments can aid in conducting a literature review of the abstracts and the workshop. Such a review reveals the topics and themes under discussion, suggested recommendations, the challenges and constraints facing the marine and maritime technologies landscape and the role-players involved. The paradigm assessment also exposes how people converse over the issue and specifically which world view or paradigm is dominant.

## 3. The marine and maritime research landscape

Having done the paradigm assessment of all 43 abstracts of the workshop's presentations, an overall paradigm assessment was produced (see Figure 2). The dominant paradigm is rationalist.




| | Knowledge generation | | | | | | | | Agency | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rationalism | 38 | 38 | 40 | 34 | 33 | 30 | 17 | 230 | 20 | 26 | 31 | 16 | 25 | 26 | 33 | 177 |
| Interpretivism | 4 | 3 | 10 | 6 | 1 | 12 | 1 | 37 | 4 | 0 | 0 | 2 | 2 | 1 | 3 | 12 |

**Figure 2:** *Overall paradigm assessment of all presentation abstracts delivered at the SAMSA workshop, 30 October 2013.*

This is not surprising, especially considering the topics and themes under discussion, as well as the 'type' of scientist or practitioner making the presentation and the challenges addressed. The purpose of the workshop was to bring together and strengthen relationships between various representatives for various parts of the maritime sector. The workshop also aimed to provide a platform for the participants to share relevant information about the current state of knowledge and technologies in the sector with colleagues. The workshop supported the National Maritime Research and Innovation Agenda. The aim of this Agenda is to enhance and integrate maritime policy, contribute to establishing networks and cross-relations, accelerate knowledge diffusion and innovation, build a long-term sustainable future, identify knowledge to be acquired for the future, and contribute to changing the image of the maritime sector (Nlumayo, 2011).

The main themes under consideration were shipping and transport, marine resources and marine tourism. Under each of the main themes, a number of workshop themes were outlined. Shipping transport was divided into maritime logistics infrastructure, shipping transport and ports, marine services, and coastal. Marine resources was divided into oceanography and environmental, fisheries, pharmaceutical and aquaculture, and offshore energy and mining. Marine tourism was divided into boating and cruising, sports and recreation, and leisure. These subthemes fell under a number of workshop topic areas (see Table 2).

**Table 2**: *Workshop themes and workshop topic areas*

| Workshop themes | Workshop topic areas |
|---|---|
| Maritime logistics infrastructure | Ports, pipelines, roads, rail, maritime logistics hub |
| Shipping transport | Shore-based management, long-haul and short-haul shipping, vessel operations, shipping-generated pollution, cargo |
| Ports, marine services and coastal | Shoreside operations, aids to navigation, offshore operations, ship-to-shore transfer, diving, infrastructure development and maintenance, port and coastal administration |
| Oceanography and environmental | Marine ecosystems, global change, estuaries, inland waters, coastal development, dredging, protected areas, maritime archaeology |
| Fisheries, pharmaceutical and aquaculture | Ocean, tidal and inland water resource management, pharmaceuticals, catching and processing, aquaculture |
| Offshore energy and mining | Minerals mining, oil and gas exploration and production, renewable energy (wind, tides and nuclear) |
| Boating and cruising | Hospitality and entertainment, cruising and ferrying, yachting, inland |
| Sports and recreation | Sailing, swimming, diving, marine activities |
| Leisure | Adventure and views, real estate, ecomarine tourism |

The main topics are predominantly those at home in the natural sciences, except for management, administration, hospitality and entertainment, and tourism. The latter are all social science topics. Even so, it would appear that the marine and maritime technologies landscape is predominantly situated in the natural sciences, with the natural sciences representing and informing the functioning of the marine and maritime environments. Because of the highly technical nature of the landscape, it is natural to have a predominantly rationalist paradigm as the discourse in the marine and maritime industry. The industries look towards the natural sciences to explain, predict and recommend solutions to the problems they face.

Safety in the maritime sector was put forward as one of the most important aspects. Topics under discussion included the surveillance of maritime vessels and the marine environment using satellite technology (Sibiya, 2013; Skoryk, 2013; Van Zyl, 2013), unmanned aircraft (Moore, 2013) and radar technology (Kleynhans, 2013). Management and administration are therefore also viewed in terms of natural-scientific problem-solving technologies. In 40 of the 43 topics, the research object, be it marine, maritime, satellite, navigational, data management or boat-building, was viewed through a rationalist ontological and epistemological lens. This means that the topic under discussion is seen by the researcher or presenter as a reality that is separate from himself or herself and that there is an objective reality to the research object. This means that the research object has inherent qualities that exist independently of the researcher. Because of this, it is possible to control the research object to a certain extent. For example, in a benchmarking study of the shipping, and oil and gas construction industry, Gowans (2013) notes that: "The future requirements of the shipping, and oil and gas industries are specialised ships for Africa, including coastal cargo an[d] gas vessels, and production modules for offshore gas fields." The governance and management of shared resources like the Agulhas and Somali ecosystems are also informed by a rationalist perspective (Stapley, 2013).

There are exceptions to a predominantly rationalist treatment of the research object and its ontology and epistemology. Swanepoel (2013) treats climate change and its impact on search and rescue activities as an uncertainty. For her, the uncertain impact of climate instils scepticism among stakeholders to implement concrete plans and actions. The presentations by Davidson (2013a; 2013b) are good examples of the use of both rationalism and interpretivism. The topics she discusses in her presentations are training and education, subjects at home in the social sciences. Even so, with the technical nature of the boat-building industry, where artisans, architecture and engineering play important roles in the correct functioning of the industry, Davidson (2013a; 2013b) employs a predominantly rationalist perspective in her studies. These studies can be used as good examples of how the rationalist and interpretivist perspectives can work in synergy to explain the intricacies of training, education and innovation in the boat-building industries. She states that: "South Africa is not the only country chasing global opportunities in the boating sector. To remain truly competitive, we need to not only provide innovative market-leading products, but ensure that we continue to develop the skills and technology needed for the long term." Davidson is the chief executive officer of the Marine Industry Association South Africa (MIASA) and therefore has first-hand experience of the challenges facing the industry (MIASA, 2014). Her ontology and epistemology are informed by the boating industry that influences her lived experience. This results in her interpretation of the research object – the boat-building industry – in light of the meaning she structured of it in terms of her lived experience.

Other examples where interpretivism were also used include the presentations by Argawal (2013), Byrnes (2013), Dixon (2013), Ngcobo (2013), Maitland (2013), Vrancken (2013a) and Werz (2013). These presentations do not represent such a strong usage of interpretivism as exhibited in the presentations by Davidson (2013a; 2013b). What is interesting about these presentations, except for the presentation by Ngcobo (2013), is that they all deal with education, training or skills development to some extent.

It is also interesting to note that defensible knowledge claims, as an interpretivist assumption regarding the validity of data, scored the highest (see Figure 2). This is mainly due to aspects such as forecasts (Byrnes, 2013), opportunities (Ngcobo, 2013), climate change uncertainty (Swanepoel, 2013), scenarios (Gowans, 2013) and where the service of one agency has not been fully realised in assisting the marine and maritime industries. An example of the latter is the South African National Space Agency (SANSA) as a potential partner in supporting maritime safety (Avenant, 2013). This means that only where uncertainty is linked to the rationalist project, interpretivism has a tendency to creep in. It does not mean that interpretivism is deliberately used in the utilisation or construction of the data. This is done by default. Under knowledge generation, rationalism had by far the highest score compared to interpretivism (see Figure 2). This is mainly due to the technical nature of the subject matter and the technical background of the presenters. Many were either engineers or artisans or had been involved in the maritime industry either as shiphands or in control of ocean-going vessels. What is more, the majority of researchers from the Council for Scientific and Industrial Research (CSIR) who presented their work are employed in the organisation's Defence, Peace, Stability and Security Unit. They had been trained in science, technology, engineering or mathematics disciplines.

The agency profile of the abstracts paints a different picture. The total score for the rationalist paradigm was 177 and for the interpretivist paradigm it was 12 (see Figure 2). This is much lower than the knowledge-generation component, where rationalism scored 230 and interpretivism scored 37 (see Figure 2). The main reason for this could be the nature of the presentations. Many of the presentations were descriptive analyses of what the scientists or practitioners are researching or practising and how it can aid the marine and maritime sectors (for example, the presentations by Bornman (2013), Chen (2013), Kleynhans (2013), Le Roux (2013), Ngcobo (2013), Sibiya (2013), Skoryk (2013) and Van Zyl (2013)). A number of presentations also considered how research and practices can aid the sectors (for example, the presentations by Awad (2013), Barwell (2013), Bernard (2013), Chilalika (2013), Goschen (2013), Goslett (2013), Grobler (2013), Kramer (2013), Kroese (2013), Otto (2013), Vrancken (2013b) and Wainman (2013)). There were also presenters who are looking at agency from an interpretivist paradigm (for example, Davidson (2013a), Jacobs (2013), Maitland (2013), Stapley (2013) and Swanepoel (2013)). Even so, interpretivism did not score very high in their presentations, except in Maitland's presentation.

Maitland (2013) took a rationalist and interpretivist stance to formulate her organising question and to discuss the locus of agency, level of analysis, ontology and recommendations. Her presentation considers the possibility of making archaeology an attractive career opportunity for school-leavers. According to Bastow et al. (2014), archaeology is situated at the intersection between the humanities and the science, technology, engineering and mathematics disciplines. Archaeology's location in the arrangement of scientific disciplines is the potential reason why Maitland utilises a mixture of rationalism and interpretivism in her presentation. She notes that "archaeology is seen by the youth as an exciting career filled with discovery and adventure." She does not provide concrete proof of this, but as an archaeologist, she is aware of the 'excitement' that goes with making a new 'discovery' or starting a new 'adventure'. Since her research object is painted in such a subjective manner, her agency-organising questions go wide to include a host of stakeholders in archaeological research. She speaks of the involvement of communities as part of South Africa's multicultural heritage. This defines her locus of agency as interpretivist. She also talks of multiple and forgotten histories. Her agenda is not top-down, but rather bottom-up; by involving schoolchildren in archaeology at an early age, the discipline could become a "gateway to the maritime sector" (Maitland, 2013). By talking about 'public archaeology', it would appear that she is taking a complex/holistic view in her level of analysis. Because of this, her ontology around agency is agential and structurationist. For her, archaeology could facilitate the involvement of individuals in the maritime sector. Since archaeology is multidisciplinary for Maitland (2013), she is convinced (in a very rationalist way) that attracting the youth to archaeology will open a myriad of career opportunities for them. This implicit recommendation is also interpretivist, since it is made from a subjective position. It would appear that Maitland is projecting her enthusiasm onto the youth. Her statement also contains empathetic notions of being involved in archaeology.

If the presentations presented at the workshop are overly rationalist in the way they generate knowledge and describe agency, it could possibly be an indication that interpretivism does not play a significant role in the sectors. If this is the case, how can one proceed to indicate how the newer social science thinking, like interpretivism, can play a role in the sectors? The answer lies in analytic eclecticism, which is the second component of PULSE[3].

## 3.1 The ethos of analytic eclecticism

So far, this chapter indicates that the marine and maritime sectors are steeped in the rationalist tradition where natural scientific theories and paradigms play an important role in describing, analysing and recommending how the natural sciences can aid the sectors. This is due to the two sectors' technical functionality in a variety of spheres, ranging from marine pollution to maritime security. This does not mean that the marine and maritime sectors are devoid of issues pertinent to the social sciences. A social scientific subject that is close to the maritime sector is economics. The sessions where presentations with an economics flavour were discussed were supply, manufacturing and construction, shipping and maritime logistics, offshore energy and mining, and water safety, fisheries, pharmaceuticals and aquaculture. Management and business studies were presented in the workshop by Argawal (2013), Dixon (2013), Elfick (2013) Mugumo (2013) and Vrancken (2013b). Their presentations were discussed in the human capital development session. Human capital development also touches on economics. It is therefore not surprising that the workshop presentations were predominantly rationalist because of economics' 'scientific aspirations' (Bastow et al., 2014). The presentation by Vrancken (2013b) was on law, which is a humanities discipline. The representation by Maitland (2013) of the HerBe Programme focuses on a crossover discipline between the humanities and the science, technology, engineering and mathematics disciplines. These are, however, not the only disciplines or subjects that can inform or highlight issues, problems and opportunities in the marine and maritime sectors.

The paradigmatic character of the workshop is the first step in highlighting the role of the social sciences. The social sciences are increasingly taking the improvement of practical problems to heart. This indicates that these sciences have begun to take a pragmatic stance. Should this be the case, the social scientist and the practitioner are now part of the same team and should seamlessly interact to address problems and create opportunities. Paradigmatic limitation can lead to a disjunction between the scientist and what he or she can offer the practitioner. The purpose of analytic eclecticism is to avoid paradigmatic limitations. Arguing from a particular paradigm could become an obstacle, even if it gives powerful insights, especially since clear explanations of complex problems become the victim in an arena where prior assumptions are at the top of the research agenda. The scientist focuses his or her attention on refuting or validating prior assumptions, with pragmatism potentially falling by the wayside (Sil and Katzenstein, 2010). However, analytic eclecticism does not discard established paradigms or research traditions, but tries to discover applicable relationships between seemingly incompatible paradigms like rationalism and interpretivism. After this, invisible connections of perceived mismatched paradigm-bound theoretical elements come to the fore. The objective is to produce novel insights that influence policy debates and practical problems. Achieving this requires alternative thinking about the relationships between assumptions, concepts, theories, research, science and problems (Sil and Katzenstein, 2010).

At this stage, it is important to note that analytic eclecticism is not the same as complexity thinking, transdisciplinarity and theoretical synthesis. Analytic eclecticism is not one theoretical approach to tackle problems, but a diverse convergence of theoretical elements for diverse problems (Sil and Katzenstein, 2010). Problem formulation from a particular paradigm rests on cognitive structures. These constructions are concepts, assumptions and analytical principles. With these, observations are made of complex social and biophysical phenomena. Simplification is unavoidable and a part of reality. Simplification can serve as a sample of the wider scheme of things that are under investigation. How and to what extent we simplify problem formulations have an impact on our understanding of matters and issues. Problems that are stated as different objects of already existing theoretical assumptions may seem inappropriate and misleading to everyone except those adhering to the researcher's assumptions (Shapiro, 2005, cited in Sil and Katzenstein, 2010). Problems formulated in this way can create blind spots for practitioners. Decision-makers are unlikely to consider alternatives on different plains and across paradigmatic borders. It is problematic to coach societal and biophysical phenomena in a specific paradigm or theory. Analytic eclecticism goes beyond such boundaries. Straddling boundaries entails smoothing the progress for open-ended analysis that is able to join the insights from different theories and communicate them to decision-makers in an effective manner (Sil and Katzenstein, 2010).

Analytic eclecticism promises not to slice up complex social phenomena just to make them simple and easy to analyse. This means that reductionism is not an underlying premise. Important substantive questions with relevant real-world application are in the offing by integrating empirical observations and causal stories, which means that rationalism is incorporated into interpretivism and vice versa. This brings about the 'promise of richer explanations' and deeper understandings (Sil and Katzenstein, 2010). It facilitates the quantum leap from singular explanations of real-world problems to fuller clarification, alternatives and solutions to such problems. Paradigms may have blind spots, but at the same time, they also provide useful insight into issues, challenges and opportunities. This inherent paradox of paradigms indicates that there are connections and complementarities between paradigms that can be exploited. Taking advantage of the inherent paradox could lead to a situation where more useful theoretical and empirical insights are generated to service practitioners in a meaningful manner (Sil and Katzenstein, 2010).

A useful distinction in this regard is Robert Cox's dichotomy between problem-solving and critical theory. Problem-solving theories arise from the direct response to problems. This type of theory makes the relationships and institutions that form reality work more smoothly by dealing effectively with particular problems. Critical or opportunity-creation theories are situated apart from the order of the world and investigate how that order came about. These types of theories do not take institutions and social power relations for granted, but question them by looking at their origin and then asking if they are changing. Opportunity-creation theories provide normative choices in favour of the existing social and political order (Cox and Sinclair, 1996). The paradigm assessment indicates that the majority, if not all, of the presentations were written from a problem-solving theory perspective. The presentations deal with a myriad of problems that face the marine and maritime sectors, and suggest ways to improve those problems. Even the presentations of Davidson (2013a; 2013b) and Maitland (2013) are written in the rubric of a problem-solving theory. This is despite the higher incidence of interpretivism found in their presentations.

Thus, the presentations at the workshop fit neatly into the rationalist paradigm and have the characteristics of a problem-solving theory. There is therefore an opportunity for the interpretivist paradigm and opportunity-creation theories to make a contribution in the two sectors. It is in this regard that the social sciences and, more importantly, interpretivism should be brought into view to determine how it can aid the marine and maritime sectors. The next section looks at the role of the humanities and social sciences in society in general. It also highlights the practicalities of these disciplines for society.

## 4. The humanities and social sciences in the policy process

Outside the workshop, the marine and maritime sectors are not devoid of humanities and social science research. Bonnin et al. (2004) investigated training and development in the maritime industry, and identified racial division of labour, a shortage of employment opportunities, and a fragmented training and certification system. However, they also found that training in the sector is of a high quality. To address the shortcomings, they suggested an "overall policy linking initial training with employment opportunities, ongoing skills development and the promotion of greater equality" (Bonnin et al., 2004). Ruggunan (2005) also conducted research on the composition of the maritime labour market in South Africa. He found an occupational differentiation of seafarers that contributes to labour inequality in the sector. In another article, Ruggunan (2011) found that globalisation is not always bad for organised labour's bargaining power in the South African and Filipino maritime sectors, and that globalisation has not led to less seafarers coming from these nations.

Humanities and social science research projects, like those described above, are increasingly focusing on the improvement of critical public problems (Calhoun, 2008; Bastow et al., 2014). This section of the chapter focuses on the relationship between the social sciences and the public policy domain. Because of the increasing emphasis of the humanities and social sciences on the solution of public problems, it is also important to emphasise the other side of the paradigmatic coin: interpretivism. This is not to say that there is a clear categorisation with the natural sciences being rationalist and the social sciences being interpretivist. The social sciences can be just as rationalist as the natural sciences. The reason why interpretivism should also be emphasised is because of the existence or creation of opportunities for better livelihoods. This does not mean that the natural sciences are failing in this regard. Yet, also focusing on the social sciences and their interpretivist contribution can generate a larger pool of opportunities and solutions for the betterment of livelihoods. Thus, the opportunity-creation domain of social sciences also has a critical role to play.

Humanities and social science research have a close relationship with public policy-making. This link comes from academics' strong impulse to help improve policy. Academics in public administration help shape the attitudes of officials through the provision of best practices and trends, and through social science research (Bastow et al., 2014). The recommendations contained in the presentations indicate this shaping of attitudes.

Politicians acknowledge the need for humanities and social science research for the following reasons:

- Policies that work well have a welfare-maximising effect. To accomplish this, policies need to be properly evaluated. At each stage of the policy process, social science knowledge and evidence is indispensable. This means that evidence-based policy formulation and implementation has a tendency to improve policy efficiency (Bastow et al., 2014). The research conducted by Elfick (2013), and presented at the workshop, is a good example of research that could have a positive impact on policy effectiveness. His research indicates that a national maritime institute is required, and that the establishment of such an institute will promote and develop the provision of education for the maritime sector. This will have to happen with the cooperation of partner institutions and the establishment of shared maritime research and education centres. Elfick (2013) made these recommendations instead of promoting the establishment of a separate maritime university that would replace any of the established universities where marine and maritime subjects are taught.

It would be a waste of resources to establish a separate university, since there are already schools, departments and research centres at various South African universities that conduct research on marine and maritime affairs.

- Another reason for politicians to acknowledge the need for humanities and social science research is that political success for government is an outflow of the maximisation of policy effectiveness. Highly effective policies will be chosen by politicians to create an optimal policy mix (Bastow et al., 2014). Here, social sciences can play a pivotal role in gathering qualitative and quantitative evidence to give politicians optimal choices. The paradigm assessment index is a typical example of analysing this mix through both qualitative and quantitative methodologies. As mentioned, the presentations focus predominantly on rationalist problem-solving theories to improve problems. Established institutions should also be looked at to determine how they could be transformed for optimal policy implementation.
- It is not always politicians that make policy decisions. The service can devolve down through the bureaucratic hierarchy or be rendered by service providers (consultants) like Elfick or university-based professionals like Vrancken. Politicians will delegate such tasks for various reasons, because decisions can be complex and costly in terms of time. Politicians also have to abide by the rule of law. Impartial policy delivery systems are needed for this compliance. There are therefore theoretical, empirical, moral and public-interest reasons for politicians to adopt the findings of the humanities and social sciences for policy improvement (Bastow et al., 2014).

Social scientists are also involved in the maintenance of large-scale databases, established through government funding. In addition to this, social scientists are part of a cadre of professionals that construct, improve, interpret and analyse the information in these databases. The databases are important social science resources and have an influence on policy formulation and implementation (Bastow et al., 2014). Examples include economic research on transport costs and logistics, the numerous censuses that are used as baseline information and utilised to indicate the socio-economic transformations of society, qualitative studies in defining long-term strategies for DST and SAMSA's *Research, Innovation and Knowledge Management Road Map for the South African Martime Sector*, and the distribution of research funding by the National Research Foundation (NRF). What is significant about research of this nature is that there is a long-distance link between researchers and public officials, departments and ministries (Bastow et al., 2014). This means that humanities and social science research does not always have an immediate impact on the views and attitudes of public officials; it takes time for such research to filter through and make an impact on decision-makers and, ultimately, policy.

That said, there is also a short-term dimension between the social sciences and government policy. The humanities and social sciences can play an integral part in immediate policy evaluation, how implementation is progressing, how problems are tackled and the handling of crisis events. When politicians need to review options, they might be in direct contact with humanities and social science researchers. Through this direct contact, public officials can also get new ideas from novel research. This is usually the case when humanities and social science research outpaces regulatory structures (Bastow et al., 2014). Public problems can be described as 'wicked problems'. Problems are defined as 'wicked' when they are difficult to distinguish from other problems. Wicked problems do not have permanent solutions, but tend to reappear (Jentoft and Chuenpagdee, 2009). Because of this, wicked problems extend beyond systems (Johnson, 2014) like ports, harbours, logistics hubs and marine environments.

For instance, there is an argument that the maritime sector extends to cargo owners like mining companies extracting coal and iron ore in inland environments (Jones, 2014). This would mean that these companies are at the behest of wicked problems. Here, the humanities and social sciences play a central role regarding government policy, which is to clarify life's complex realities (Caplan et al., 1975; Bastow et al., 2014).

With regard to complexity, the marine and maritime sectors could benefit from the humanities and social sciences. Although presented as fairly straightforward by the presenters at the Integrated Marine and Maritime Technologies Workshop, the marine and maritime sectors are anything but straightforward and simple. Technology plays an important part in both sectors, but as Davidson (2013a; 2013b), Elfick (2013), Maitland (2013) and others indicated, we are not only dealing with a technology-'rich' reality, but also with a healthy dose of human involvement, where human behaviour is not only central to, but constitutive of how the sectors are structured and researched, and how technology is utilised. Where human behaviour is involved, either as a platform for action or in the construction of governance structures, things are bound to become complicated, if not complex.

## *5. Quo Vadis?*

Where to from here? To take forward the agenda of successfully integrating the humanities and social sciences into highly technical domains like the marine and maritime sectors, it is necessary to have alternative theories to those that are rational and problem-solving. With alternative theories in hand, one gets an idea of the type of theories that could aid the marine and maritime sectors to fully integrate the humanities and social sciences. This could help enlarge the small percentage of decision-relevant information at policy-makers' disposal (Bastow et al., 2014). There are three examples of these theories and how they could be applicable in the marine and maritime sectors. These theories are the ambiguity theory of leadership, the everyday international political economy theory and the theory of social learning and policy paradigms.

The ambiguity theory of leadership is relevant to business management. The theory emphasises the role that followers in organisations play in leaders' success and/or failure. The theory notes that leadership varies from person to person, and context to context. Leadership is not easy to define, and is complex and sometimes incoherent. Because people attach different meanings to the concept of 'leadership', it brings forth the potential for ambiguous interpretations, understanding and experiences of leadership. This means that leaders need to cope with ambiguity. The effect of this is that leaders are not always aware of their roles and that followers interpret different acts as leadership. The theory problematises leadership and acknowledges its limitations. Leadership is not a panacea to the problems organisations are facing, which means that everything does not succeed or fail because of good or bad leadership (Alvesson and Spicer, 2011).

The presentations in the human development session placed a lot of emphasis on skills development. Leadership is a skill that is seen as important in any section of society. The ambiguity theory of leadership implies that there are different sets of leadership and that followers also play an important role in leadership. These are aspects that a skills development programme in the marine and maritime sectors should keep in mind. This means that where a lot of faith is placed in leadership to solve problems, the ambiguity theory of leadership represents another side of the leadership coin to remind us that success is not always a straightforward outflow of good leadership.

An international political economy theory that places a lot of emphasis on the individual is the theory of the everyday international political economy. It starts off by asking 'who acts and how do their actions produce and change the world economy in various spatial dimensions?' The theory moves away from the normal 'who governs and who benefits' dichotomy of the international political domain. This question is an outflow of the hierarchical nature of the international political economy, with government entities and large corporations at the top, and everybody else – private citizens included – at the bottom. The question posed by everyday international political economy turns this dichotomy upside down and puts individuals at the top as power-givers instead of power-takers. The bottom-up process is therefore just as important as government processes and regulatory mechanisms. Yet, not all actions that emanate from the bottom-up process affect the world economy. Dominant political elites also play a role, but no longer play an exclusive role. The authority of dominant elites is sometimes rejected through protests and subtle forms of rejection. This does not mean that the rejecters of dominant elite actions can do as they please. Structures are restrictive. Sometimes rejecters are victims, and at other times they could become agents of change. Everyday actions are the acts of agents that play a subordinate role in a power relationship. These acts can take the form of negotiation, resistance or non-resistance, which can occur suddenly or over a period of time. The acts shape, constitute and transform the political and economic environment around and beyond everyday actors (Hobson and Seabrooke, 2007).

In contrast to the ambiguity theory of leadership, everyday international political economy places a lot of attention on ordinary individuals and their interaction with the global economy. The link between this and the marine and maritime sectors is that the two sectors rely on technological advancement for different reasons, which means that the ordinary individual and his or her actions are at times side-lined. By applying everyday international political economy theory, the subtleties of individual actions in the two sectors could become more pronounced. The plea by Maitland (2013) for a 'public archaeology' is a good example of a case where ordinary individuals become the catalysts of a maritime sector stimulated by bottom-up activities like the creation of an interest in marine archaeology among schoolchildren.

For the theory of social learning and policy paradigms, the most important factors that influence policy are past policy and associated practices. In this regard, previous policies are the most important influence in the learning process around policies. The central agents that push for policy change are the experts in a given policy or issue field. They are either advisors in government departments or external consultants. Politicians do not play a central role in social learning. Learning takes place when individuals accumulate new information, which includes past experience. The information is utilised by individuals in their succeeding actions. Social learning is a deliberate process to adjust the goals or techniques of policy in response to past experience and new information. Ideas are therefore central to the policy process. Policies are the products of systems of ideas and standards that are comprehensible to the actors involved in the issue. A framework of ideas and standards specifies the policy's goals. This framework is a policy paradigm. Once ideas associated with some actor or set of actors are adapted to the organisation of a policy issue, the ideas get institutionalised into the procedures of an entity and formalised as a synthesis of some sort in standard texts around the issue. The ideas then specify the nature of the issue's domain, how it needs to be observed, which goals are attainable through policy, and what instruments should be used to attain them. The ideas are the prism through which practitioners see the domain and their role in it (Hall, 1993).

The workshop is a good example of bringing together experts around issues related to marine and maritime technology and the ideas they have about such issues. The presentation of new information, such as that presented by Gowans (2013), is a manifestation of the learning process in the maritime sector. How the various new ideas will be incorporated into practice is up to SAMSA. Even so, the theory of social learning and policy paradigms could become a guide on how to optimally define such a framework.

## Conclusion

Although the integration of marine and maritime technologies is a field where functional technology and natural science expertise play a central role, the two sectors are not devoid of the role and involvement of the humanities and social sciences. The paradigm assessment of the workshop presentations indicates this. Yet, rationalism and problem-solving theories or perspectives are dominant in the presentations. Even where interpretivism is present, it is only applicable to how certain elements of knowledge generation and agency are approached. The paradigm assessment is an indication that the humanities and social sciences can play a more active role in the two sectors. The ethos of analytic eclecticism indicates why the social sciences and, more importantly, interpretivism should play a more active role. The presentation of the three theories and their applicability to the marine and maritime sectors gives an idea of where and how interpretivist perspectives can aid the sectors. Having said that, it is not up to the authorities in the sectors alone to increasingly include the humanities and social sciences and make them applicable. Social scientists have a bigger role to play in this regard. If the theory of social learning and policy paradigms is anything to go by, the more social scientists become involved in the sectors and produce robust research to create opportunities and solve problems, the better the chances for the humanities and social sciences to make a practical impact in the sectors.

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# Chapter 11 The State of Maritime and Underwater Cultural Heritage Research, Legislation and Technology in South Africa

*Jonathan Sharfman, Vanessa Maitland, Sophie Winton and Robert Parthesius*

## 1. Introduction

Waterborne transportation has been a part of the world's cultural heritage for thousands of years. The earliest known boat was found in Pesse in The Netherlands and dates to ca. 9000 BCE (Delgado, 1997). In the South African context, ships have been an integral part of our heritage for the last 500 years (Gribble, 2002). The development of the world until the 20th century has largely been defined by explorers and traders travelling between the continents. Therefore, cultural heritage studies need to take the history of ships and shipping into consideration (Pearson, 1987).

Maritime and underwater cultural heritage (MUCH) was a phrase coined by the Maritime Archaeology Development Programme Working Group of the South African Heritage Resources Agency (SAHRA) in 2010 (SAHRA, 2010a). Maritime archaeology specifically refers to "the study of human interaction with the sea, lakes and rivers through the archaeological study of material manifestations of maritime culture…" (Delgado, 1997). This, however, placed severe restraints on the scope of work within the South African context. The archaeological and palaeontological record in South Africa dates back almost two million years (Pickering et al., 2011) and by concentrating on maritime archaeology, a huge proportion of our history that is underwater due to post-glacial sea-level changes, changing water drainage systems and modern dam construction is ignored.

MUCH is therefore the study of all underwater and maritime cultural archaeological sites, including maritime structures, shipwrecks, survivor camps, Stone Age shell middens and submerged deposits, fish traps and palaeo-landscapes. The scope of MUCH also includes the examination of intangible and living heritage, such as cultural practices, stories, myths and legends related to water.

In order to understand where MUCH studies stand today and how its future is envisioned, this chapter contextualises the subject by first dealing with the difference between treasure hunting or salvage and maritime archaeology, and then tackling the history of MUCH and the theoretical, methodological and technological framework within which the discipline is practiced. An important aspect of MUCH is the legislation that governs how these cultural resources are utilised and understood. This chapter then examines South African maritime archaeological research in the past and present, including the organisation mandated to protect these resources. Finally, by understanding the context of MUCH, it looks to the future and outlines the direction for MUCH and how it forms an important component of the maritime sector.

## 2. Archaeology versus treasure hunting

There is a fundamental difference between archaeology and treasure hunting or salvage: treasure hunting is carried out with the intention to sell objects from shipwreck sites. To treasure hunters, how well a site is mapped, how well objects are catalogued, whether some objects are offered for public display or whether or not archaeological methods are applied in commercial projects, is irrelevant. The sale of archaeological artefacts results in an irretrievable loss of historical data. With this in mind, it is the duty of legislation to distinguish between archaeology and treasure hunting, and to enforce a set of rules that places the enrichment of society as a whole above the enrichment of individuals. The perception of what constitutes 'public good' has played a significant role in the evolution of legislation aimed at the management of the underwater cultural heritage. While archaeologists and heritage managers underline the damage being done by treasure hunting against the potential of scientific research, the public finds it hard to differentiate between treasure hunting and archaeology (McGrail, 1989; Gribble, 2002; Ward, 2003; Bowens, 2009).

Archaeologists themselves are partly to blame for a public assessment of maritime archaeology that has remained relatively static since the 1960s (Gribble, 2002; Sperry, 2008). For most members of the general public, information about activities and projects in the marine environment is provided through popular media (Sperry, 2008). Treasure hunters have successfully publicised their activities by providing the media with stories of their exploits and discoveries. Popular documentaries, books and newspaper reports were almost the exclusive domain of those involved in commercial salvage. Salvors present their work as being maritime archaeology and as contributing to the development of the knowledge base in this research field. Some go as far as to call themselves maritime archaeologists, despite their lack of training (Gribble, 2002). Archaeologists, on the other hand, have failed to capture the public's attention in the same way. Articles in academic publications, although valuable for the advancement of the field, are, for the most part, consumed by academics whose views and opinions of treasure hunting have already been formed and who are in agreement with their fellow scientists. Despite archaeologists working in the same environment and experiencing the same challenges as treasure hunters, they fail to promote the 'adventure' aspects of their work – aspects that might capture the public's attention.

To compound the challenges faced by maritime archaeologists in marketing their discipline, a relatively small number of scientific research projects is being undertaken on submerged sites in South Africa. It is no surprise that the value of archaeological work as an alternative to treasure hunting has not been recognised when specialists in the field have produced little to justify themselves as a viable replacement to current commercial practices.

Legislation has paid a disservice to South African archaeologists in their battle against the looting of shipwreck sites. In the definition of the term 'archaeological', the National Heritage Resources Act (Act 25 of 1999) (NHRA) identifies a range of broad archaeological site types that includes the following:

> "2(ii)(a) material remains resulting from human activity which are in a state of disuse and are in or on land and which are older than 100 years, including artefacts, human and hominid remains and artificial features and structures."

Instead of including shipwrecks within the scope of this site type (e.g. …are in or on land *or in or on the seabed*…), the Act classifies them as a separate entity, implying that they should be treated differently to terrestrial archaeological sites.

> "2(ii)(c) wrecks being any vessel, or aircraft, or any part thereof, which was wrecked in South Africa, whether on land, in the internal waters, the territorial waters or in the maritime cultural zone of the Republic, as defined respectively in sections 3, 4 and 6 of

the Maritime Zones Act 1994 (Act No. 15 of 1994), and any cargo, debris or artefacts found in or associated therewith, which is older than 60 years or which SAHRA considers to be worthy of conservation."

By equating maritime archaeology and underwater cultural heritage exclusively to shipwrecks, legislation that should have encompassed the protection of a variety of locally relevant cultural practices and landscapes has neglected the many other facets of the historical relationship between South Africans and water. Shipwrecks have been isolated as being the single focus of underwater cultural heritage management. Treasure hunters have taken advantage of the division of heritage into 'wrecks' and 'everything else' and encourage the perception of shipwrecks as being representative of the history of the oppressor and the heritage of others in order to downplay their significance to South Africa's development. Because of this, the need for the protection of shipwreck sites has gained little traction in the minds of the majority of South Africans. While it is true that the majority of shipwrecks are European in origin, it is undoubtedly accurate that they were key drivers for a period of South Africa's history, which irrevocably and fundamentally altered the development of southern Africa as a whole and contributed to the rich cultural make-up of modern-day South Africa. Although ships were not the instruments of indigenous people, they carry clues to understanding national identity and progression.

The destruction of archaeological sites that contribute to our understanding of the human past through treasure hunting is not tolerated on land and should not be tolerated underwater. The only solution to this is to increase public awareness and education, bring about changes in legislation to completely protect the country's underwater cultural heritage, and increase scientific excavations to highlight the value of archaeology versus treasure hunting.

## 2.1 Maritime archaeology – theory, methodology and technology

While theoretical and methodological practices for terrestrial archaeological sites developed as early as the 19th century (Renfrew and Bahn, 1991), it was not until the 1960s, when George Bass recognised the historical and archaeological potential of shipwreck sites located off the Aegean coast (Bass, 1968), that the discipline of maritime archaeology gained academic credibility. Bass, who is considered to be the father of maritime archaeology, pioneered methodological approaches that could be applied to archaeological sites underwater and showed that the stringent code of practice that guided excavators on land could be equally applied in the underwater environment. Bass (1968) argues that archaeology underwater should simply be considered as archaeology and that archaeologists who specialise in various subdisciplines of terrestrial archaeology (e.g. Stone Age or Iron Age archaeologists) could apply their expertise to underwater sites that corresponded with their field of specialisation. In other words, he argues that a submerged Iron Age site should be excavated by an Iron Age archaeologist. Unfortunately, few archaeologists were divers and, as a result, those who could dive were given the task of excavating underwater sites regardless of their expertise.

There are a number of reasons why maritime archaeology in South Africa appears to fall behind other subdisciplines of archaeology in terms of theoretical work. Firstly, maritime archaeology became a subdiscipline of archaeology based on environment rather than area of specialisation, and maritime archaeologists were expected to become 'a jack of all trades' (Bass, 1968; Muckelroy, 1978). Because diving archaeologists could not interpret all the site types that they were excavating, they focused their attention on ensuring that their methods and excavation practices were comparable to terrestrial methodologies (Delgado, 2000; Flatman, 2003). This ensured that, even if they themselves could not analyse the archaeological assemblages they were collecting, they could preserve the contextual information of excavated material that would allow other specialists to analyse collections that had been removed from the seafloor. However, this initially caused theoretical concerns to be largely ignored and, despite their best intentions, maritime archaeologists found it difficult to gain acceptance among their terrestrial peers (Muckelroy, 1978).

Secondly, maritime archaeology is widely seen as a form of antiquarianism (Deacon, 1988). It was labelled as a descriptive, rather than an analytical discipline at best, and glorified treasure hunting at worst. The latter categorisation was fuelled by the fact that the collection of artefacts from shipwreck sites was by no means revolutionary. Salvage has existed for as long as there have been shipwrecks, and treasure hunters have taken every opportunity to recover commercially valuable objects from submerged sites. Those who criticised maritime archaeology for focusing more on the collection of artefacts than on the analysis of those objects could see little difference between the actions and products of treasure hunters and maritime archaeologists. Maritime archaeologists continued to practice their discipline despite the reservations of the archaeological community (Muckelroy, 1978), and the field has developed significantly in the past five decades. In addition, maritime archaeologists have become increasingly specialised within the subject. Maritime archaeology has become progressively more directed at shipwrecks, and individuals have dedicated themselves to focusing on narrower research specialisations.

The third reason why maritime archaeology in South Africa is considered 'behind' is that maritime archaeology was often avocational in character (Flatman, 2003). The artefacts were seldom used to interpret and understand the societies from which they came. It is only since the 1980s in South Africa that underwater excavations have been undertaken for purely archaeological reasons by archaeologists in conjunction with amateurs (Gribble, 2002).

Fourthly, in 2003, there were few people working in the field worldwide (Flatman, 2003). Presently, there are seven maritime archaeologists in South Africa, four of whom work for SAHRA and Iziko Museums. In comparison, there are at least 250 registered land archaeologists, who are members of the Association of Southern African Professional Archaeologists (ASAPA, 2012). Finally, maritime archaeology, especially in the perception of the public, is all about treasure, 'cool things' and adventure (Treasure Expeditions, n.d.; McGrail, 1989; Gribble, 2002; Ward, 2003; Sperry, 2008; Bowens, 2009). This perception is intensified by television documentaries and museum exhibits that, of necessity, focus on high-profile artefacts (Flatman, 2003; YouTube, 2013). Maritime archaeologists need to use this publicity to increase awareness of the contributions that the field can make towards a greater understanding of our heritage, beyond the discovery of treasure.

The changes required to make this subdiscipline more theoretically involved are minimal. A post-processual approach will require "an acknowledgement of multiple ways to perceive evidence within more than one possible conclusion" (Flatman, 2003) from practitioners. In Europe, there is an increasing focus on the symbology of the ship – in other words, that it is possible to view depictions of ships from both a functional and a cosmological viewpoint (Ballard et al., 2003; Flatman, 2003). Gibbins and Adams (2001) propose that the unique nature of maritime archaeology, which deals with singular event sites, forces one to approach the data from a wide spectrum of theoretical and methodological arenas as opposed to a single dogma. This, in turn, seeks out multiple contexts and meanings for the data.

Hall and Markell (1993) state that South Africa was a colony and, by definition, an 'outlier' community, whose mode of communication with the founding metropolitan cities was via ships. Therefore, maritime archaeology is vital to understanding the archaeology of colonial settlements, and is thus part of historical or colonial archaeology (Deacon, 1988). Therefore, the theory for both is the same, whether one looks at the data through a structuralist, material culture, processual or cognitive lens (Hall, 1993). However, it has been argued that "certain aspects of the maritime world are so unique to human experiences that even the most radical of existing perspectives are insufficient" (Flatman, 2003). In other words, the 'seascape', which is the focus of maritime archaeology, is fundamentally different from the 'landscape' and therefore requires a completely different theoretical framework (Cooney, 2003). In addition, all theories are biased and intended to deal with land-based archaeological landscapes, and are designed by land-based Western archaeologists, who see the sea as an untamed barrier and only relate it to the land, instead of seeing it as an extension of the land. The sea needs to be seen as part of the landscape within which these older cultures and societies operated (Cooney, 2003; Flatman, 2003). Thus, we need to develop additional theories that deal with these opposed perceptions (Flatman, 2003).

Muckelroy (1978) states that "…to ensure the maximum return from the available material, the researcher must always have in mind the questions outstanding in the current state of his discipline toward which that evidence might be expected to contribute some of the answers. It is only by this steady accretion of data within a systematic framework that any real advances in knowledge or understanding can be made". Within this context, South African maritime archaeology is in its infancy, and the collection and contextualisation of data within a systematic archaeological framework is only just beginning. In conclusion, while theoretical frameworks are being developed in maritime archaeology, this takes place in countries where the research data is far more advanced than in South Africa. Here, we need to build up a solid body of archaeological evidence to begin the process of incorporating particular sites, spatially and temporally, within South Africa's heritage, and to begin asking questions regarding the sites within the larger maritime landscape, regionally and globally. Lawrence (2003) discusses the similarities of colonial assemblages within the British Empire. So, while the South African maritime archaeological data may be limited, one can use comparative analysis with Australian and other colonial maritime sites to better understand the South African context.

## 3. Site surveys

The primary tool in an archaeologist's toolbox is site survey. It is essential to have an accurate site map to recreate the context of the artefacts and to understand the site formation processes. Without an accurate site survey, it would be impossible to interpret the data in any meaningful way. Land archaeologists can use total stations and a number of Geographic Information System (GIS) programs to map their sites to the smallest detail. Maritime archaeology cannot use Global Positioning System (GPS) technology to map a site (GPS does not work underwater). Maritime archaeologists therefore rely on elementary techniques such as trilateration to map sites. It was only in 1997 that Site Recorder (formerly known as the Site Surveyor Program) was developed. This GIS platform for underwater sites gives underwater archaeologists a process whereby simple measurements are used to create accurate three-dimensional coordinates, which can be situated in a real-world coordinate grid. The program checks the trilateration measurements and allows for accurate site plans (Holt, 1997). In 2010, this software was used in South Africa for the first time during the Maritime Archaeology Development Programme (MADP), a SAHRA/Centre for International Heritage Activities (CIE)/ Robben Island Field School. The first accurate site plan was created of the Barrel Wreck in 2011.

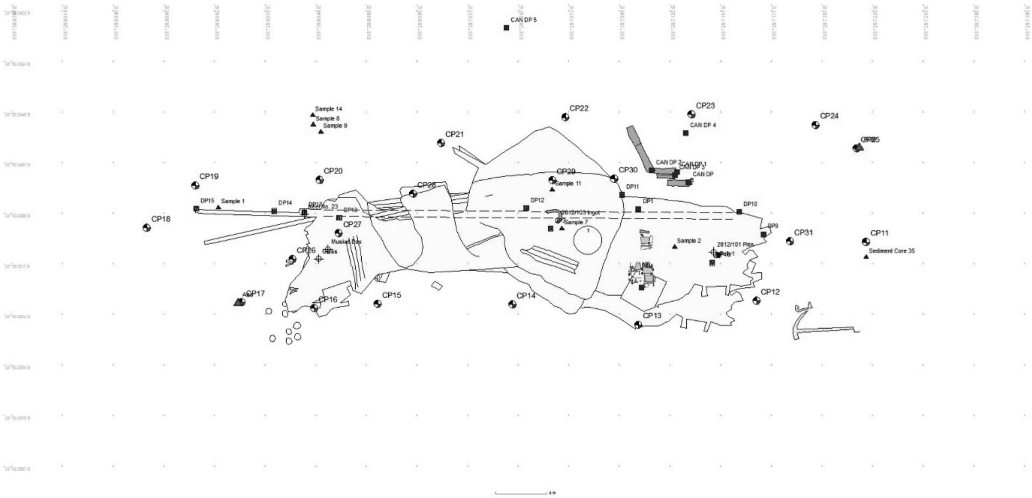


***Figure 1:*** *Site map of the Barrel Wreck created using Site Recorder.*

## 4. Geophysical surveys

The earth has natural magnetic fields. When a ferrous object is deposited onto the seafloor, it creates a magnetic anomaly. This anomaly can be detected using a marine magnetometer. In the past, the only people with magnetometers were treasure hunters. In 2005, SAHRA acquired a Marine Magnetics 'Explorer' Proton Magnetometer with overhauser effect (Berry, 2014), and in 2014, the African Centre for Heritage Activities acquired a G-882 cesium-vapour marine magnetometer that is more sensitive and particularly well suited for detecting and mapping all magnetic anomalies, including anchors, chains, cables, pipelines, ballast stones and other scattered shipwreck debris (Geometrics, n.d.).

Sidescan sonar is widely used in geophysical surveys. This system analyses the intensity of sound bounced back to the equipment from the seabed sediments and exposed objects. Analysts are able to partially differentiate between rock, gravel, wood, metals and sediments. In addition, the sidescan records acoustic shadows on objects that stand above the seabed. This phenomenon creates a three-dimensional image on a two-dimensional scan, and is often more informative than the acoustic returns themselves (Bowens, 2009).

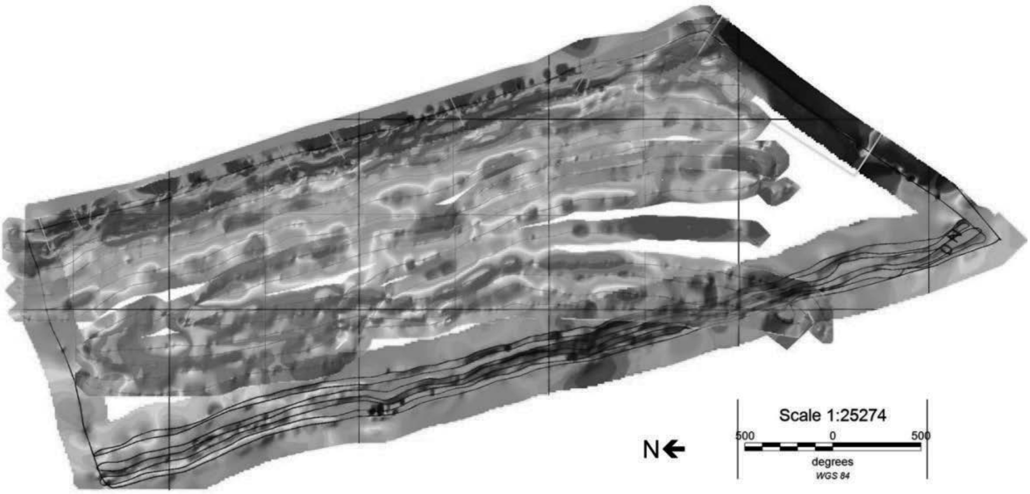


***Figure 2:*** *Magnetometer map off Durban with seabed magnetic anomalies indicated in warmer colours (Maitland, 2012). [See colour figure on page 314.]*

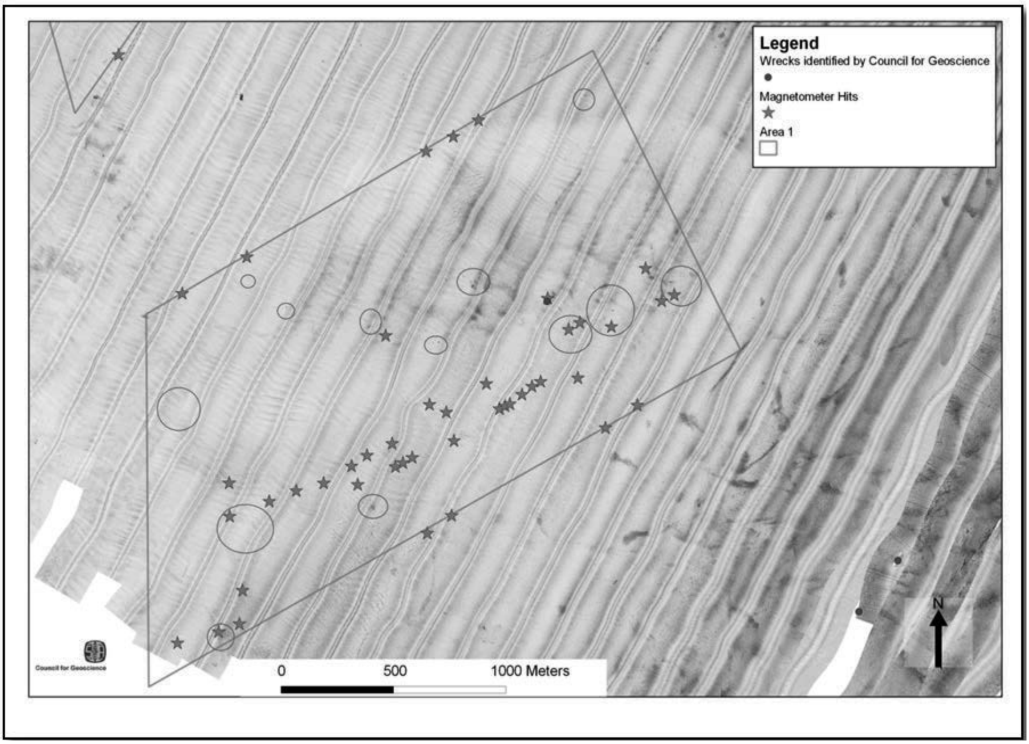


***Figure 3:*** *Sidescan sonar image with magnetic anomalies correlated to identified debris (Adapted from Council for Geoscience map in Maitland, 2012). [See colour figure on page 314.]*

Multibeam bathymetry also uses echo sounder technology, but the returns are denser. In other words, it pings the seabed more often in a given space. This leads to more accurate and detailed data (Bowens, 2009). The images that this technology produces are three-dimensional and can also be 'sliced' (this concept is illustrated in Figure 4, which contains three images; the second image has a rectangle drawn on the wreck; the third image is the 'slice' or profile of the wreck at this point). This technology enables researchers to better understand the site and so produce better research designs.

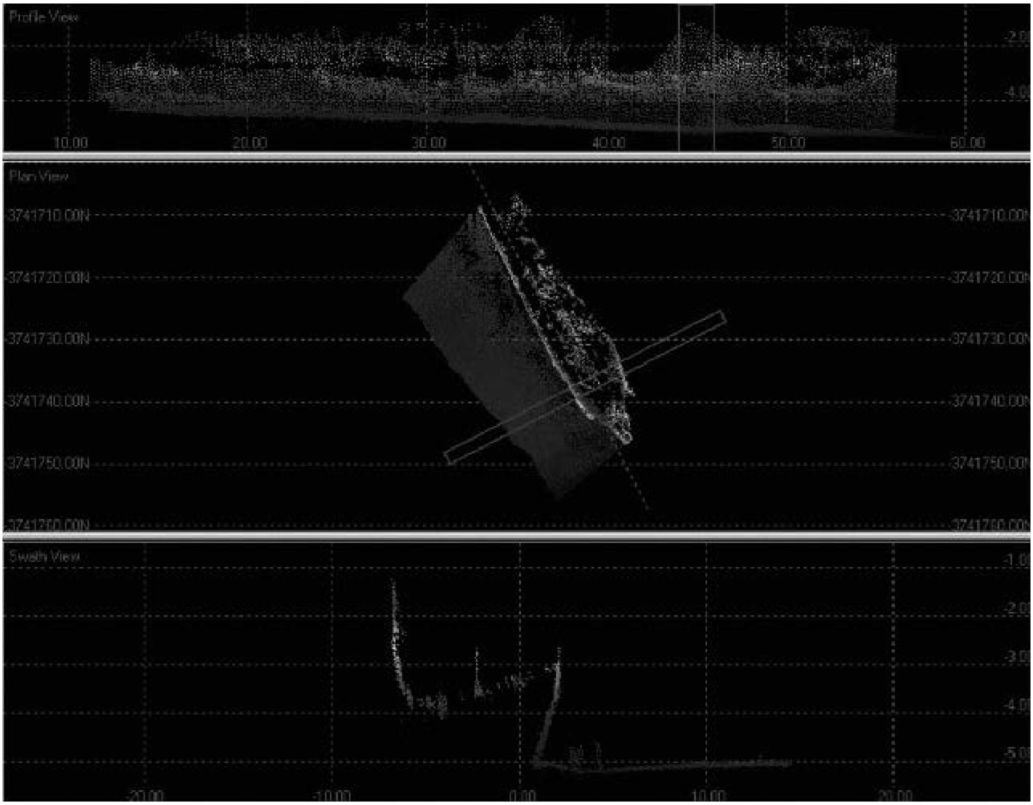


***Figure 4:*** *Three multibeam bathymetry images of the* County of Pembroke *(1903). The top image shows the profile, the middle image is the bird's eye view and the last image is a 'slice' through the wreck (Maitland, 2009).*

New technology that is available, but beyond the budgets of South African maritime archaeologists at the moment, is BlueView's 3D mechanical scanning sonar. This technology can create high-resolution images of underwater areas, structures and objects, even in low-visibility conditions (Teledyne BlueView, n.d.). The use of this technology would significantly increase the accuracy of archaeological site surveys and give archaeologists a greater scope for understanding sites. In addition, the sub-bottom imager (SBI) uses acoustics to view the sub-seabed in full 3D. The SBI delineates discrete objects and stratigraphy (Pangeosubsea, 2014).

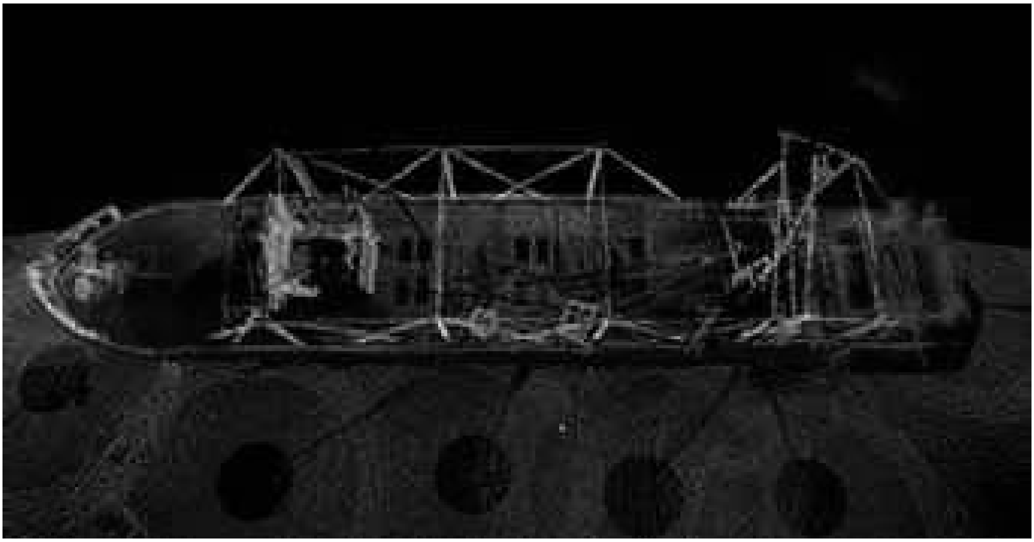

***Figure 5:*** *3D image of the A.J. Goddard (1901) wreck, captured using BlueView technology. This wreck is on the seabed (Dean, 2010).*

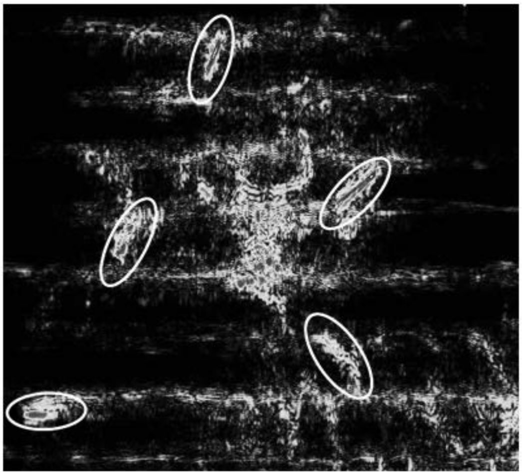

***Figure 6:*** *Mosaic image of a sand-covered shipwreck compiled using SBI (Pangeosubsea, 2014).*

In summary, there is technology available that can increase not only the discovery of 'missing' shipwreck sites, but also improve the mapping of such sites. These technologies can assist in understanding, interpreting and managing these fragile heritage resources.

## 5. Legislative context

South Africa, like many countries around the world, has struggled to develop a strategy and protocol for managing its underwater cultural heritage that is broadly relevant, applicable and implementable within the national context. A number of factors have contributed to this challenge, many of which stem from an uncomfortable failure to define the scope of what constitutes underwater cultural heritage and how this heritage should be accessed, studied, protected and promoted. This has been aggravated by a lack of maritime archaeological capacity, limited academic research and historical baggage. To understand the current trends in South African maritime archaeology and underwater cultural heritage resources management, it is necessary to understand the legislative context in which these fields have developed.

As maritime archaeologists explored their new environment and located increasing numbers of sites, it became imperative that guidelines and legislation be developed to manage a new subsector of heritage. Although terrestrial heritage sites have enjoyed protection for many decades, underwater cultural heritage was given little thought. Like their counterparts in the archaeological fraternity, legislators and heritage managers had little knowledge of underwater cultural heritage resources. To develop policy to protect submerged sites, they needed to define what it was that they were seeking to protect. Therefore, they turned to their maritime archaeologist colleagues for guidance. Since maritime archaeology was focused on shipwrecks, and it was shipwrecks that were being targeted by treasure hunters, salvage companies, looters and souvenir hunters, these were the sites that required immediate protection. Legislators, particularly in developed nations, had drafted and implemented various laws that suited their particular needs and contexts. Nations in the developing world were urged to prepare similar legislation to protect shipwrecks in an effort to safeguard the interests of, primarily, the European nations whose pasts were represented in the shipwreck sites.

## 6. The development of legislation in South Africa

The evolution of a legislative framework that is aimed at protecting underwater heritage sites has been relatively slow in South Africa. Although individuals and companies seeking to profit from artefacts found on the seafloor began targeting historic shipwreck sites in the 1960s, archaeologists and historians saw little value in putting effort into safeguarding these sites until the late 1980s. It was argued that the contents of ships could contribute little to an understanding of the past (Bass, 1968; Muckelroy, 1978), especially in light of the fact that much of their history was documented in archives and other historical records. Nowhere in a review of the archives of the National Monuments Council (NMC) (now SAHRA) is the protection of shipwreck sites found to be desirable (Sharfman et al., 2012). This is not surprising, however. South Africa, at that time, had no trained maritime archaeologists or terrestrial archaeologists with a diving certification. In addition, the media attention given to the 'treasure hauls' and exploits of treasure hunters and salvors meant that they enjoyed public support and the assertion that the goods being salvaged were merely being returned to the stream of commerce, as they had intended to be. This meant that they lost any historical or archaeological significance.

The expertise of archaeologists and other specialists was only called on when treasure hunters or salvors required assistance in the identification of objects or sites (Jobling, 1982; Maggs, 1984). Any public interest in shipwreck objects was satisfied by the donation of small shipwreck collections to museums and other public institutions. Shipwreck displays consisted primarily of historical data illustrated by objects from the shipwreck sites. Treasure hunters promoted their activities as a contribution to the understanding of South Africa's past, but in reality, the objects that they retrieved from the seafloor and displayed were merely an addendum to what was already known from historical records. It is not necessary to recover a cargo of ceramics from a 17th century Dutch East India Company vessel to prove that ceramics were traded in the 17th century.

As a result of projects taking place elsewhere in the world, such as the United Kingdom's *Mary Rose* (1545), the Swedish *Vasa* (1628) and the Yassi Ada wrecks off Turkey (Delgado, 1997), maritime archaeology began to grab headlines. This caused local archaeologists and heritage managers to take a more direct interest in activities on shipwreck sites. Archaeological insights into shipboard life, trade, expansion and maritime culture that could be provided by rigorous archaeological investigation had, in the past, been given little attention, but the recovery of detailed data from wrecks like the *Mary Rose* highlighted the value of applying archaeological methods to underwater sites. The public could no longer be led to believe that the recovery of commercially viable artefacts from a shipwreck site at the expense of the historically significant, non-commercially valuable items and at the expense of contextual archaeological information was an acceptable pursuit. However, the damage was done. "The net result of much of the interest in South Africa's historical shipwrecks between the 1960s and late 1980s was the unquantifiable loss of archaeological and historical material and information as sites fell victim to often indiscriminate commercial salvage" (Gribble and Sharfman, 2012).

Two significant interventions stimulated a major shift in underwater cultural heritage management and maritime archaeological practices in South Africa. In 1989, the services of Bruno Werz, the first trained maritime archaeologist to work in South Africa, were enlisted to assist with the management of historic shipwreck sites (Werz, 1997). This intervention would result in the creation of a teaching post and the development of a maritime archaeological programme at the University of Cape Town (UCT). The university programme produced the first South African maritime archaeology specialists and spurred the growth of maritime archaeology in southern Africa. Shortly after his appointment, the South African Maritime Museum (now part of Iziko Museums) created and filled a maritime archaeologist position and, in 1993, the NMC (now SAHRA) appointed a maritime archaeologist to manage shipwreck permits.

A second important development was the introduction of the Nautical Archaeology Society (NAS) courses in South Africa (Boshoff, 1998). This initiative was jointly coordinated by the NMC (now SAHRA) and the South African Maritime Museum (now part of Iziko Museums). Officials from these institutions conducted training in all the major coastal cities, as well as in Namibia. "The net result of the first course in 1993 was the undertaking of the first vocational project with no commercial incentives, the survey of the British East Indiaman, *Brunswick*, wrecked in 1805 in Simon's Bay" (Sharfman et al., 2012). The project, supervised by museum archaeologist Jaco Boshoff, was the first instance of a purely archaeological, non-commercial venture aimed at a shipwreck site undertaken outside mitigation interventions (Boshoff et al., 1994).

These interventions put professional maritime archaeology onto the heritage radar, and vocational maritime archaeology firmly into the public mindset. Furthermore, they stimulated debate that would result in legislative amendments that would better protect underwater archaeological sites.

Although the challenges of the acceptance of maritime archaeology as a bona fide archaeological subdiscipline, as described above, muddied the waters of submerged site management, some lone voices in museums and universities had raised concerns about the indiscriminate looting of shipwreck sites as far back as the 1960s (Boshoff, 2012). These concerns, together with an increasing awareness of shipwreck history in the 1970s (Bell-Cross, 1980; Gribble, 1998), spurred government to reluctantly enact cursory legislation to protect sites. In 1979, the National Monuments Act (Act 28 of 1969) was amended (Act 35 of 1979) to allow government to declare wrecks over 80 years of age that "were considered to be of aesthetic, historical or scientific value" as protected sites (Deacon, 1993). The NMC, the agency tasked with heritage management, drew up a list of potential sites for protection, but the unwieldy legislation made implementation difficult and no formal protection notice was ever issued (Sharfman et al., 2012).

The prospect that shipwrecks might be out of their reach prompted treasure hunters to lobby for exclusive access rights. They argued, again, that shipwreck sites had no bearing on South

Africa's heritage and should, therefore, not be protected. The NMC tended to agree and conceded that the sites were the heritage of Holland, England and Portugal (Rudner, 1986), and undeserving of undue expenditure of capacity and capital. Despite an absence of state maritime archaeologists with the capacity to assess shipwreck sites, the NMC made sweeping assumptions about the archaeological potential of shipwrecks, including stating that archaeological intervention would be futile and that objects that remained on shipwreck sites should be salvaged as soon as possible to prevent loss through rough seas and looting (Rudner, 1986). The decision of the NMC must, in part, have been based on the conclusions of a 1983 Department of Transport (DoT) investigation into the viability of protecting shipwrecks, which concluded that, in the light of the commercial value of the cargoes of historic wrecks, protection would not only be against the public interest, but 'unacceptable' (DoT, 1983).

Despite the NMC's apparent reluctance to protect shipwreck sites, the National Monuments Act was amended again in 1986. The increasingly vocal opposition to unfettered treasure hunting resulted in the blanket protection of shipwreck sites older than 60 years. Although treasure hunters still enjoyed legal rights to salvage and sell objects from historic wrecks, a permit from the NMC was required and a more scientific approach to excavation was encouraged. Permit applications were more rigorously assessed and the concepts of significance, as applied to terrestrial archaeological sites, were applied to shipwrecks. Although the amended legislation did not provide substantial protection and did not mandate archaeological excavation, it opened the door to the scientific examination of submerged sites.

As South Africa emerged from the apartheid era, new heritage legislation was promulgated to ensure that the past of all strata of South African society received recognition. Redrafting of legislation provided heritage managers and archaeologists with the opportunity to make their voices heard once again and contributions towards redefining the protection of underwater sites were submitted for consideration. The resulting National Heritage Resources Act (Act 25 of 1999) made important advances in the protection of underwater cultural heritage. Most significantly, section 2(2)(c) of the Act defines shipwreck sites 60 years or older lying in South Africa's Territorial Waters and Contiguous Zone (up to 24 nautical miles offshore) as archaeological sites. Shipwrecks older than 60 years became the property of the nation. The intention of including shipwrecks in the definition of what constitutes an archaeological site was to ensure that they would enjoy the same protection as terrestrial sites and that the same ethics and standards would be applied to maritime archaeological sites.

Unfortunately, the NHRA was not explicit in addressing acceptable ethical practices for maritime archaeology. Nowhere does the Act unambiguously outlaw the commercial exploitation of underwater archaeological sites. Maritime archaeologists at SAHRA, the agency established by the Act to manage cultural heritage, drafted a policy that outlined its approach to underwater cultural heritage site management (SAHRA, 2005). In this policy, SAHRA specified that it would not consider permit applications for shipwreck projects that had a commercial component attached to them. In other words, no permits would be issued for projects where objects recovered from the sites were to be sold. In a series of public meetings hosted by the Department of Arts and Culture between 2005 and 2008, treasure hunters argued vociferously that a ban on commercial projects would not only go against their constitutional rights to earn a living, but against a precedent that had been set over several decades. Since the Act did not specifically outlaw the commercial salvage of historic wrecks, they reasoned that a policy that did so would be in conflict with the legislation itself. Legal advice prompted SAHRA to repeal the policy and reinstate a permit system that did not discriminate against commercial interests. A decision to issue a permit could only be based on a set of guidelines contained in the NHRA's Regulations (No. 6820 Notice 548). In addition, SAHRA requested permit applicants to adhere to the principles and spirit of the 1996 International Council on Monuments and Sites (ICOMOS) Charter on the Protection and Management of the Underwater Cultural Heritage as far as it was not in direct conflict with national legislation (SAHRA, 2001).

This is not to say that the NHRA is without merit. The preamble to the Act sums up the spirit in which it was intended to be interpreted:

> "This legislation aims to promote good management of the national estate, and to enable and encourage communities to nurture and conserve their legacy so that it may be bequeathed to future generations. Our heritage is unique and precious and it cannot be renewed. It helps us to define our cultural identity and therefore lies at the heart of our spiritual well-being and has the power to build our nation. It has the potential to affirm our diverse cultures, and in so doing shape our national character.
>
> Our heritage celebrates our achievements and contributes to redressing past inequities. It educates, it deepens our understanding of society and encourages us to empathise with the experience of others. It facilitates healing and material and symbolic restitution and it promotes new and previously neglected research into our rich oral traditions and customs."

It is in the details where the Act has become limited. Currently, SAHRA must assess permit applications within the regulatory framework described above and permits must be issued to individuals who fulfil the requirements. SAHRA is, however, redrafting policy and regulations in an effort to curb the loss of shipwreck objects through the sale and loss of archaeological data from treasure hunting. SAHRA's current activities are discussed in more detail below.

## 7. Maritime archaeology in South Africa

In the 1950s, scuba equipment became readily available and more people began exploiting the underwater environment. As discussed above, commercial salvors have routinely removed artefacts from wrecks without the rigorous and scientific controls of archaeology. In addition, there was an increase in the number of sport divers participating in wreck diving, souveniring and treasure hunting. In South Africa, this interest was fuelled by "the lack of physical and legislative control on wrecks" (Gribble, 2002).

### 7.1 Research: past and present

The shipwreck research that has been published by salvors covers a wide range of material. In terms of general publications, Turner's *Shipwrecks and salvage in Southern Africa* (1988) is an excellent reference source. He attempted to create a database of all the known wrecks. However, it is not complete. He excludes scuttled ships and vessels that were allegedly refloated. Prior to 1988, most of the physical shipwreck work had been undertaken by salvors for commercial gain. These reports have varied from strictly amateur to relatively professional (Allen and Allen, 1978a; Allen and Allen, 1978b; Kayle, 1990; Shapiro, 2012). According to Deacon (1988), maritime archaeology in South Africa owes a significant debt to these salvors. However, Gribble (2002) and Sharfman et al. (2012) argue to the contrary, stating that the widespread publication and promotion of recovered artefacts by treasure hunters have actually helped fuel the public perception that treasure hunters are 'discovering' our past, are protecting our heritage and are the only viable solution to recovering our underwater cultural heritage resources. With regard to the abovementioned publications by salvors, archaeologists have only produced a few publications on South African wrecks. These include Bennie (1998), Burger (2004) and Werz (1997).

Prior to the creation of the first maritime archaeological post at the University of Cape Town (UCT) in 1988, the only maritime archaeological work undertaken was by terrestrial archaeologists in conjunction with sport divers or salvors, with the exception of the excavation by Prof Andrew Smith of UCT of a portion of the survivors' camp of the *São Gonçalo*. During Werz's tenure at UCT between 1988 and 2002, only 10 maritime archaeology projects were undertaken in South Africa (Gribble, 2002). These include Operation Sea Eagle (Werz and Deacon, 1992), a survey of the Robben Island wrecks, the excavation of the *Oosterland* in conjunction with salvors (Werz, 1997), honours and master's degrees that applied GIS to the *Oosterland* wreck site (Sharfman, 1994; Sharfman, 1998), a history master's degree on the washed-up hull segments of the *Amsterdam* (Bennie, 1998), site surveys and limited excavations of the *Brunswick* in conjunction with avocational divers (Gribble, 2002), and Boshoff's work on the sealing and whaling operations on the Prince Edward Islands (Gribble, 2002).

In the last 12 years, only a few projects have been undertaken. Under the NHRA, underwater heritage impact assessments (UHIAs) have to be conducted on areas where there is to be development. Due to the large port developments and expansion in the Port of Ngqura (Coega) and the Port of Durban, two rescue archaeology projects were undertaken where the wrecks were removed. These were the *County of Pembroke* (1903) and the *SS Karin* (1927) (Maitland, 2009; Maitland, 2010a). On the research front, there is the Slave Wreck Project and the search for the slave ship, *Meermin* (Boshoff, 2012), and excavations on the whaling sites on Marion Island (Boshoff, 2014; Van Niekerk, 2014). Boshoff, from Iziko Museums, is leading the South African segment of the African Slave Wrecks Project, a collaboration with the Smithsonian Institute, George Washington University and the United States National Parks Service. The programme works with regional partners in southern Africa, the Caribbean, South America and the United States (Boshoff, 2014).

In 2011 and 2012, SAHRA, in conjunction with the CIE, a European non-profit organisation, held NAS courses off Robben Island. This was the first large-scale awareness and capacity-building programme to be held in South Africa. Training was offered to people from all walks of life, from archaeologists to archaeology students, amateur archaeologists from the now defunct South African Institute of Maritime Archaeology (SAIMA), salvors and sport divers. Non-divers also attended the course and worked on maritime structures on Robben Island (Maitland, 2010b).

The first maritime archaeology project embarked upon solely for the purposes of acquiring an academic degree, without the participation of salvors, is currently being undertaken by Maitland on the Barrel Wreck in Table Bay. In recent years, in underwater archaeology, there has been a trend towards minimal disturbance and *in situ* research and preservation. This is partly due to the huge expense of preserving and curating artefacts from underwater sites, and to the fact that these sites are non-renewable heritage resources (Bowens, 2009; Favis, 2012). The work on the Barrel Wreck employs minimal disturbance techniques to try to identify and contextualise the wreck. It also researches the value and ethics of using salvaged artefacts.

Through a series of projects and programmes, SAHRA aims to expand its coastal network, increase dialogue around MUCH and promote education and job-creation initiatives.

The Underwater Youth Development Programme (UYDP) was launched alongside the MADP in 2009 with the support of the Department of Arts and Culture, as a collaborative effort between SAHRA's MUCH Unit, the Robben Island Museum Education Department and the CIE. The UYDP aims to encourage high-school learners to explore and take ownership of their heritage through annual heritage camps on Robben Island. SAHRA took over the implementation of this programme in 2012 and it has continued successfully, although on a smaller scale. The development of sustainable museum-led educational programmes is underway, providing museum educators with training to ensure a solid understanding of MUCH and a curriculum-based education programme that will be implemented with visiting school groups. The message will reach a far greater number of South Africans and encourage them to interact with their heritage in a meaningful way. Educational material aimed at younger audiences has been developed and social media plays an important role in maintaining contact and interest (SAHRA, 2009; SAHRA, 2010b; SAHRA, 2011; SAHRA, 2012; SAHRA, 2013).

The National Survey of Underwater Heritage was a multiyear development programme, funded by the National Lottery Distribution Trust Fund, which focused on professional skills development in the field and the creation of a comprehensive shipwreck database, listing over 3 000 wrecks along South Africa's coast. The Surveys and Mapping Project continues to identify, record and manage underwater heritage sites. Using the data collected by the National Survey of Underwater Heritage as a basis, the project expands on the research, populating the extensive shipwreck database for use by managers and the public. The project also serves as a monitoring tool for sites that have been assessed in the past and as an oversight tool for sites under permit. Given the small pool of underwater archaeologists working in South Africa, this is one of the essential projects on SAHRA's agenda, as it would be impossible to effectively manage these resources otherwise (SAHRA, 2012).

Marion Island is an island in the Southern Ocean that politically forms part of South Africa's Western Cape. South Africa, together with 11 other countries, is a founding member of the Antarctic Treaty of 1959. Signatories undertake to ensure that the Antarctic region will be used for peaceful and scientific purposes only and to protect and preserve the environment. One of the major current research themes in the region, along with climate variability and biodiversity, is the Archaeologies of Antarctica Project, spearheaded by Iziko Museums and funded by the National Research Foundation (NRF). In the past, research has focused mainly on environmental aspects, and cultural remains were afforded little protection. Based on Iziko Museums' systematic study of the heritage resources and historical archaeology of the island, SAHRA is in the process of grading Marion Island to determine the form of protection that it may require, be it local, provincial or national (SANAP, n.d.).

Along with innovative management strategies, the expanding scope of MUCH requires original recording and presentation methods. The Eastern Cape Oral Histories Project is investigating the lost, forgotten and hidden heritage of rural communities living along the Wild Coast. The scope of the project extended beyond the traditional shipwreck sites to whatever form of maritime and underwater cultural heritage sites local communities consider significant today. The project aims to give a voice to the communities and to enable them to take ownership of their heritage, to determine different levels of relevance of MUCH to different individuals and communities, and to provide a blueprint for future community heritage research projects and management strategies (SAHRA, 2014).

# 8. South African Heritage Resources Agency

## 8.1 The national heritage management mandate

While the term MUCH encompasses a diverse range of heritage sites and ideas, from ancient to modern, it is a relatively young concept. As described above, formal protection for underwater heritage sites in South Africa as we know it now, only came into being with the promulgation of the NHRA. Under the National Monuments Act, as discussed above. Shipwrecks had limited protection and other underwater or water-related sites were not mentioned. The new Act sought to encompass the multitude of South Africa's diverse cultural heritage, establishing the South African Heritage Resources Agency and mandating this agency to identify, manage, protect and promote the national estate for the benefit and enjoyment of current and future generations (RSA, 1999; RSA, n.d.).

The scope of authority that this Act gave managers was greater than ever before and allowed for the broad interpretation of significance and the application of legislation through the propagation of internal policy (Sharfman et al., 2012). However, in terms of MUCH, the language of the legislation focuses on the term 'shipwreck' and does not specifically name site types, thus the focus remains, unintentionally, on shipwrecks. The Act does not specifically outlaw commercial salvage, which leaves loopholes that are exploited. Through scientific research on shipwrecks and on other underwater and maritime heritage sites, it is hoped that the value to our knowledge base will be understood and protective policies enacted. Permit regulations for heritage resources management are currently under review. The approval of these amended regulations will ensure the closure of legal loopholes and, through cooperation with other institutions working in the sector, managers will be better capacitated to enforce the permit system and implement proactive and holistic management strategies that take the substantial variety of MUCH and water-related sites and practices into account.

In September 2012, SAHRA launched the South African Heritage Resources Information System (SAHRIS), an online integrated management system for all heritage authorities in South Africa. As a case management tool, SAHRIS combines GIS planning, electronic case tracking and audited decision-making processes. Ultimately, it will house all the data relating to all heritage sites and objects, and track the movement and impacts of these resources (Wiltshire, 2012). The system revolutionises the way managers interact with developers, scientists and the public through immediate access to heritage reports, impact assessments and decision-making processes.

South Africa is not alone in its heritage management challenges. Many similar issues, such as scarce resource allocation, low capacity and lobby pressure, are experienced elsewhere in the world. It is therefore important to consider international trends. By looking outwards, South African managers can assess the successes and failures of other countries and apply strategies that are appropriate to the uniquely South African context. South Africa's proposed ratification of the 2001 United Nations Educational, Scientific and Cultural Organization (UNESCO) Convention on the Protection of Underwater Heritage, which is currently tabled for approval with the Department of Arts and Culture, would ensure the outlawing of commercial salvage, provide a common base from which to work with other signatories and ensure that managers operate at an international standard. Furthermore, it would cement South Africa's place as a leader in the field in southern Africa.

## 9. The need for capacity

With a coastline of over 3 000 km and numerous inland lakes and rivers, the geographical extent of SAHRA's mandate is enormous. Effective implementation of legislation requires a multifaceted approach to MUCH and significant intervention in capacity, infrastructure and funding structures (SAHRA, 2011). Previous programmes implemented by SAHRA, as discussed earlier, together with partnering institutions, have made significant headway in this regard, but more needs to be done to maintain the momentum created by these programmes.

The MADP showcased the broad scope of South Africa's MUCH sites through the promotion of 'legacy sites'. Representing four perspectives on South Africa's multitudinous MUCH, these sites begin to describe how diverse our cultural relationship with water really is. The first legacy site is the maritime landscape of Robben Island, a world heritage site synonymous with the apartheid struggle. The long history of this island museum is inextricably linked with the sea that surrounds it. Robben Island was used as a political prison for centuries before the rise of the National Party and incarceration of Nelson Mandela. Evidence of the struggle against oppression can be found in the slave gardens on the northern shore, and in the tales of hardship and daring escapes, as well as in the shipwrecks that litter the shore and the surrounding seabed (Robben Island Museum, 2007).

For better or worse, modern-day South Africa owes its existence to the nations that travelled to these shores by ship. The most technologically advanced machines of their day, ships brought people, trade goods, faiths and customs to this country. Thus, the second legacy site is a shipwreck in Table Bay known as the Barrel Wreck because its true identity remains a mystery. This site by no means represents all the wrecks in our waters, but along with only a handful of other true archaeological investigations that have been carried out in South African waters, it represents an example of best practice.

The third legacy site, a sacred lake far from the coast in Limpopo, proved to be an interesting case for heritage managers. Held sacred by the vhaVenda people, local communities believed Lake Fundudzi and its associated waterfall and forest sites to be at risk from development. Lake Fundudzi provides an example of a tangible site that is directly related to the intangible cultural practice of ancestor worship. Declared a national heritage site in February 2014, it could provide a future case study for the role of heritage sites in rural development and social upliftment initiatives (RSA, 2014).

The fourth legacy site is the fish traps in Stilbaai. Used by some of the first colonial farmers in the area over 200 years ago, these stone fish traps are thought by some to date back a lot further to Khoi-San groups who lived in the area long before the settlers arrived (Hine, 2008; Hine et al., 2009). Ownership and access have been challenged since Stilbaai was declared a marine protected area under the Marine Living Resources Act (Act 18 of 1998) and local fishermen have been prevented from removing fish from the fish traps. So, while the physical site is protected, local people's livelihoods are being affected and managers are presented with the challenge of balancing environmental and economic concerns. On the one hand, is the need to prevent the unchecked exploitation of vulnerable fish stocks, and on the other, is the need to maintain and promote the heritage of local people. One does not necessarily need to interfere with the other if managers can reach a compromise.

These four sites provide a starting point for the investigation into South Africa's diverse MUCH. If managers and archaeologists are to successfully engage with communities and encourage citizens to take ownership of their heritage, combat the scourge of the commercial salvage of historic wrecks and negate the public perception that salvage and archaeology are one and the same. The extent of the country's MUCH needs to continue to be assessed and prioritised. As there is currently no university programme in maritime archaeology, training opportunities such as field schools and workshops need to be made more accessible and job opportunities need to be made available in the sector. For this to be achieved, the sector needs to find its relevance in modern-day South Africa and thereby garner greater political support.

## 10. Protecting our maritime and underwater cultural heritage

One of SAHRA's key functions is the grading and declaration of national heritage sites. The NHRA provides blanket protection for all shipwrecks older than 60 years, regardless of location, previous investigation or significance. This means that historical shipwrecks receive automatic protection and do not need to be graded. But what about sites of national significance that are not yet within this time range? Recently, a local historical society and scuba-diving group approached SAHRA with the nomination to declare the *SAS Pietermaritzburg* a national heritage site. Before being bought by the South African Navy as a training vessel, the *PMB* (*SAS Pietermaritzburg*), as she is affectionately known, was a minesweeper called *HMS Pelorus,* which was among the vessels that led the D-Day invasion of Normandy (Van Niekerk, 2012). Amid great fanfare, she was scuttled in 1994 when she became too expensive to maintain – sitting in 30 m of water off Miller's Point in False Bay, she became an artificial reef and one of the Cape's top dive sites, creating significant economic opportunities in terms of recreational dive tourism. Unfortunately, unscrupulous salvors claimed her as their own. This is when the community stepped in. With great support and enthusiasm from the Simonstown community, full protection was granted in December 2012 with the *SAS Pietermaritzburg* being afforded national heritage site status. The site continues to be popular with scuba divers and signage is to be erected on the shore to mark the site.

A similar case has arisen with the *SAS Somerset*, which, after a long and illustrious career, became a financial burden. Previously known as *HMS Barcross*, she is a bar-class boom defence vessel, commissioned in 1941. She was taken over by the South African Navy in 1988 and used for salvage operations. Since then, she has been used as a museum ship as she is the last remaining boom defence vessel in the world. Her fate is yet to be decided, but among the radical management strategies that have been suggested is scuttling her in a manner similar to the *SAS Pietermaritzburg* so that she may be enjoyed by scuba divers and studied by archaeologists and biologists (Boshoff, 2013).

All water-related sites, from sacred lakes to fish traps and intangible oral histories, require innovative management strategies and the personnel with the necessary skills to manage them.

## 11. Challenges for maritime and underwater cultural heritage

MUCH, like many of the sciences in South Africa, faces capacity and funding challenges. Although capacity development programmes have begun to address capacity shortages, there is a need for high-level skills development. Maritime archaeology is not offered as a specialist subject at any university in South Africa and students interested in advancing their education in the discipline must, generally, study abroad. Academic institutions, including the University of South Africa (Unisa) and UCT, have allowed students to enrol in postgraduate programmes and pursue maritime archaeological research projects, but a formal academic programme is essential for the sustained growth of the field.

The heritage sector has always operated within significant budget constraints. As Jamieson (2006) pointed out:

> "The preservation of heritage is a luxury many developing countries are simply unable to afford. Administrators must maintain and enhance their heritage resources within a legislative and political environment that, in most cases, places low priority on heritage preservation. This is clearly a political issue to be resolved at the local level..."

The development of strategies that promote heritage protection and research as a means to achieve economic benefits may alleviate some of the funding burden. By engaging at a community level to identify opportunities for businesses, such as tourism and its associated industries, strategies can be developed that are mutually beneficial.

## 12. The future of maritime and underwater cultural heritage

MUCH finds itself at a crossroads. Recent archaeological programmes and management interventions have established a framework around which the discipline can be built. Although these have been discussed elsewhere, it is perhaps relevant to examine the future implications and potential of some of these projects.

Although SAHRA's maritime archaeologists, in conjunction with the CIE in The Netherlands, devised their MADP as a tool for increasing capacity and awareness through training initiatives, there were important spin-offs that will impact on South Africa and the southern African region. Firstly, as mentioned above, the programme coined the phrase 'maritime and underwater cultural heritage' in an effort to broaden the scope of the discipline. The term intended to be inclusive and connective by linking terrestrial sites associated with water to submerged sites. This was an important step, making maritime archaeology and submerged heritage accessible and relevant in the African context. Secondly, the MADP provided the platform for a regional MUCH management meeting held on Robben Island in 2010 (SAHRA, 2010a). Representatives of government institutions in Mozambique, Namibia, South Africa and Tanzania formulated a joint strategy document stating key areas of collaboration and a commitment to the development of MUCH in the region. High on the agenda was the need for ratification of the 2001 UNESCO Convention on the Protection of Underwater Cultural Heritage, 2001, the need for information, resource- and capacity-sharing, and the need to encourage archaeological research and excavation projects. Significantly, the delegates committed themselves to acknowledging the role that communities at heritage sites play in their protection, and recognised the need for management strategies to include community input and involvement (SAHRA, 2010a).

The range of local and international experts that was invited to contribute to MADP training in 2010, 2011 and 2012 provided participants with access to an extensive multidisciplinary network of professionals committed to sharing skills and knowledge (SAHRA 2010a).

The MADP contributed meaningfully to the development of maritime archaeological capacity in South Africa. Although the programme did not strive to certify maritime archaeologists, it empowered a wide variety of individuals to become actively involved in maritime archaeology and MUCH management. This has notable implications for the future of MUCH in South Africa in that a pool of trained individuals can support archaeologists in their research efforts (SAHRA, 2010a).

Finally, the capacity-building efforts of the MADP resulted in the establishment of a new non-government organisation, the African Centre for Heritage Activities, whose mission includes the further development of capacity in the heritage-related sectors throughout Africa (SAHRA 2010a).

The implementation of new archaeological projects in the underwater environment has important implications for the future. The projects have already begun to produce exciting data that has broad public appeal. This will contribute to allowing archaeologists to present the discipline as a viable and necessary alternative to treasure hunting. Furthermore, the projects have been specifically designed to incorporate local and international partners whose expertise and exposure will further promote archaeological efforts. High-profile institutions, such as the Smithsonian, will bring much-needed attention to the challenges and outcomes of the programmes. The increase in archaeological projects provides researchers and archaeologists with better opportunities to work increasingly on non-commercial projects. This has facilitated a move away from archaeological collaboration on treasure-hunting projects, which, in turn, has resulted in fewer treasure hunters being able to satisfy the requirement set out in SAHRA's regulations for archaeological support in recovery projects. The accessibility of archaeology for archaeologists is, therefore, contributing to the abolition of treasure hunting (SAHRA, 2009; SAHRA, 2010b; SAHRA, 2011; SAHRA, 2012; SAHRA, 2013; SAHRA, 2014).

Access to technology, such as magnetometers, GIS and other tools, has opened new frontiers to maritime archaeologists. Where archaeologists used to rely on finds being reported to heritage agencies, museums or dive clubs to gain access to sites, they can now actively locate sites and design activities that contribute to answering specific archaeological questions that redress the imbalance of knowledge created by treasure hunters concentrating on 'treasure' ships.

The Eastern Cape Oral History Project is a primary example of a future approach to MUCH that is gaining support throughout southern Africa. The project recognises the fact that heritage is an important component in identity and culture. As such, it is not enough to memorialise only those sites that encompass global values or showcase national historical highlights. The project acknowledges that heritage must be understood and celebrated on an individual, community and local level. To promote the protection of heritage, it is important that the citizens who are asked to protect it on behalf of the nation feel that their own heritage contributes to the national identity. The Oral History Project is a test case to commence collecting the smaller maritime heritage of communities along the Wild Coast, the outcome of which will be the development of a revised heritage map of South Africa that will allow everyone's voice to be heard and provide a true understanding of the many heritage narratives that have contributed to the evolution of South African society. The project has also recognised the challenges in developing sustainable strategies for protecting our heritage in areas where economic survival is of primary concern and heritage is low on the agenda. The programme is striving to create community-driven strategies for heritage management that are economically viable, beneficial and sustainable (SAHRA, 2014).

Legislative revisions that will have widespread implications for MUCH have been mooted by the Department of Arts and Culture. Following public consultations surrounding the development of a national Policy for Underwater Cultural Heritage and the ratification of the 2001 UNESCO Convention on the Protection of Underwater Cultural Heritage (UNESCO, 2001), the Department is in the process of approving a substantive policy and has recommended that South Africa ratify the Convention. The implementation of these legislative interventions will support archaeological endeavours and promote unambiguous guidelines for the management of underwater cultural heritage.

## 13. Conclusion

South Africa has an embedded culture of salvage and treasure hunting. The history of this mindset was explained in this chapter, as well as the steps that have and are being taken to change this, through changes to legislation and public awareness programmes and courses. The discipline of maritime and underwater archaeology has changed dramatically in the last 50 years. This chapter also enumerated the need for rigorous scientific excavations to contextualise the cultural data on a national and global scale. Furthermore, the technological innovations that could be used to better understand the maritime and underwater cultural heritage resources were outlined.

In conclusion, we can look at MUCH within the analogy of a ship. The ship has to be seaworthy in order to sail. The hull of the vessel is the discipline of archaeology and specifically the development of maritime archaeology. The masts are the theoretical and methodological framework within which the discipline is practiced. The rudder is the legislation that protects and guides the heritage resources. All that is needed for our ship to sail is the wind – this is capacity-building and funding. If the vessel is not sound, it will founder on the challenges, but if it can set sail, it will reap benefits for South Africa as a maritime nation. It can create employment opportunities through heritage tourism and research positions. It can help us understand our history as a maritime nation and create national pride in our brave seafarers throughout time and across cultures. As Sir Seretse Khama, the first president of an independent Botswana, said:

> "It should now be our intention to try to retrieve what we can of our past. We should write our own history books to prove that we did have a past, and that it was a past that was just as worth writing and learning about as any other. We must do this for the simple reason that a nation without a past is a lost nation, and a people without a past is a people without a soul."

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# Chapter 12 Southern African Maritime Archaeological Research and the Development of the African Institute for Marine and Underwater Research, Exploration and Education

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## 1. Introduction

When seen from a global perspective, Africa's contributions to date to marine and maritime research in their broadest sense are only marginal. South Africa is currently the forerunner in the development and application of technologies and is the hub for related research on the continent. Nevertheless, local work is limited to specific sectors. Although there are different institutions that provide facilities and training for these individual sectors, a more unified approach seems to be lacking. Recognising the value of a more integrated intra- and interdisciplinary model, the African Institute for Marine and Underwater Research, Exploration and Education (AIMURE) was established in October 2012. This non-governmental organisation (NGO) advocates a broader viewpoint by uniting different fields of study related to the marine, maritime and underwater spheres under one interdisciplinary umbrella. This is in line with current efforts by the South African Maritime Safety Authority (SAMSA) to engage different stakeholders in an effort to create a broader national approach.

In this chapter, more attention will be given to the development of maritime archaeological research in southern Africa and the future role of AIMURE.

Due to its recent establishment and the absence of financial and infrastructural government support, AIMURE has not yet achieved the same status as other well-established institutions. Nevertheless, AIMURE strives to actively develop and pursue projects that focus on research, exploration and education related to the marine, maritime and underwater environments. By doing so, it also stimulates closer cooperation between different parties. As some of AIMURE's board members have an academic background in the field of maritime archaeology, its scientific base rests on this research specialisation.

## 2. What is maritime archaeology?

Before giving a general overview of the development of maritime archaeology in southern Africa, it is necessary to briefly indicate what the field is about. In essence, maritime archaeology is a specialisation of archaeology that focuses specifically on people's relations to the sea in the past. These relations are diverse and include the role the sea has played for millennia as a provider of food and a medium of contact, communication, exchange and interaction between different groups of people (Muckelroy, 1978). Juxtaposed to this is the role it sometimes played as a protective barrier against foreign influences. Many examples of these various roles can be given and it may suffice to point out that these resulted in the exploitation of new food sources, resulting in varied diets, the exchange of knowledge and ideas, cultural achievements, technological developments and material wealth. It also resulted in aggression, the spread of diseases, slavery and colonialism (Werz, 2009c).

There are different ways of obtaining more data regarding the abovementioned aspects. As archaeology is emphasised here, the most important bearers of information are objects, specifically man-made objects or artefacts, and the context in which these are found. This context includes the spatial relationships between objects, but also site evidence provided by soil discolorations and other less tangible traces. Nevertheless, additional data can be provided by other disciplines, such as history. Thus, the field of maritime archaeology can be defined as a scientific approach that attempts to study people's past relations with the sea through surviving material evidence and all available additional evidence of whatever nature (Werz, 1999b).

Archaeological sites contain material evidence and related site information that not only provide valuable information on past human activities at specific locations, but also on environmental conditions during different time periods. It is therefore essential that any excavation takes the potential presence of such traces into account. This is even more important, as excavation, however carefully undertaken, is inherently a destructive activity. There are, of course, different types of maritime archaeological sites and these can be classified on the basis of their functional characteristics and physical appearance. An example in this context is the natural static sites that can be described as immobile shelters, living and working places, places of deposition and obstructions formed by natural processes. These processes may include erosion, volcanic activity, movement of the earth's crust or changing sea levels. Sites resulting from these processes are presently located in the same geographic position where they were originally formed. Examples of natural static sites are coastal caves that were occupied by prehistoric people. Only some time after their formation, often millions of years, did they become hiding, living or working places (Werz, 1999b).

***Plate 1:*** *A submerged rock near Oranjemund, Namibia, that caused the sinking of sub-Saharan Africa's oldest discovered ship. This vessel was probably the Portuguese merchant ship* Bom Jesus *that was lost in 1533. Part of a cargo of copper ingots is deposited at the base of the rock. The site is under sea level and was temporarily pumped dry to allow for the recovery of diamonds (image by Bruno Werz©/AIMURE) (Werz, 2009a; Werz, 2009b; Werz, 2010b).*

The majority of site types that are of interest to maritime archaeologists can be described as artificial dynamic sites. Artificial dynamic sites are mobile structures that were built by people with a specific purpose in mind. These are presently situated in a different location to where they were originally constructed. They started fulfilling the role for which they were built immediately after completion. This category includes all types of rafts, vessels, boats and ships. Due to their nature, it can be said that ships have multifunctional characters. They were, and still are, used for fishing, whaling and sealing activities, and are thus aimed at enabling subsistence. As means for the transportation of people, animals and goods, they played a role as elements in economic systems (Plate 1). As military platforms, ships served offensive and defensive roles to realise political and economic purposes. Ships were also used for exploration, thereby contributing to more knowledge about other territories and opening these areas for further political and socio-economic development. This resulted in improved and extended communication and interaction between different societies, which resulted in the exchange of ideas, language and other cultural achievements, as well as intermarriage. Further political and socio-economic development also resulted in the spread of disease, disruption or the suppression of other societies.

Generally speaking, ships form the main body of research subjects for maritime archaeologists, not only because of the large number of wrecks of different types and over different time periods, but also because most maritime archaeological research involves questions that are in some way or another connected to the roles ships played in the past (Muckelroy, 1978; Gould, 2011).

Although maritime archaeology is essentially a specialisation of the discipline of archaeology and thus focuses on material culture, the field also provides ample opportunities for multidisciplinary approaches. Especially because the excavation part of the data-collecting process is destructive, as much information as possible needs to be secured to interpret past events. This information is partially contained in the artefacts themselves. Artefacts often reflect temporal changes and their development in time can be recorded through absolute dating methods, as well as typology, which is a typical archaeological technique (Muckelroy, 1978; Dean et al., 1992; Werz and Klose, 1994). Typology enables the relative dating of sites and their contents.

Detailed information on the physical or chemical make-up of artefacts, which may allow for absolute dating, can only be established by applying other specialisations, such as chemistry or materials science (Werz et al., 1991). The same applies to the technique of excavation that often involves well-established surveying methods (Werz, 1992b; Werz, 1993b). Analyses of a variety of fieldwork data are often enhanced by applying statistical methods, Geographic Information System (GIS) instruments and other computer-based techniques (Werz and Martin, 1994; Martin and Werz, 1999). When dealing with sites that were created during historical periods, other disciplines, such as history, history of art and numismatics, also come into play (Werz, 2007; Werz, 2009c). Information on the environment in which maritime archaeological sites were deposited can be obtained from hydrographic and oceanographic studies, including marine geoscience and bathymetry, but also meteorology (Werz and Martin, 1994; Martin and Werz, 1999). This interplay between different research specialisations represents one of the big attractions of undertaking maritime archaeology, and that makes it an excellent multidisciplinary pursuit (Dean et al., 1992) (Plate 2).

***Plate 2:*** *The author surveying an anchor on the shipwreck of the* Oosterland *(1697) in Table Bay. This wreck of a Dutch East India vessel is one of many examples worldwide of an artificial dynamic site. The excavation of the* Oosterland *and its sister ship, the* Waddinxveen, *during the 1990s set a benchmark for scientific maritime archaeological research in southern Africa at the time (image by Bruno Werz©/AIMURE).*

## 3. The development of maritime archaeology in southern Africa

Maritime archaeology was formally introduced in southern Africa in 1988 with the establishment of an academic position in the discipline at the University of Cape Town (UCT). The main reasons for creating this position were as follows:

- Growing concern regarding the ongoing disturbance and destruction of submerged archaeological sites through salvage, treasure hunting and development
- Belated realisation of the importance of such sites
- Unsatisfactory cultural resource management practices

Various attempts to rectify this situation have been undertaken since 1988. These include the following:

- The introduction of a formal academic teaching and research programme, as well as public education programmes
- The publishing of scientific and popular articles
- The rendering of specialist advice to institutions, such as the National Monuments Council (NMC), now the South African Heritage Resources Agency (SAHRA), the South African Maritime Museum and the Namibian National Monuments Council, from 1988 until 2012
- Extensive public relations

Unfortunately, the academic position was prematurely disbanded due to a combination of factors in 1996. This happened in a year when half of the master's degree students in UCT's Department of Archaeology were specialising in maritime archaeology. Although the author has continued to research, publish, promote public education and render advice since, the opportunity for formal education in this discipline in Africa has been restricted for now. As a result, some students have moved abroad to study in countries like the UK, Australia and the USA (Werz, 1999a; Werz, 1999b; Werz, 2003). This situation should be redressed because maritime archaeology plays an important role in the study of aspects of the history of (southern) Africa (Werz, 1990b; Werz, 1993a; Werz, 1993d; Werz, 1994a; Werz, 1994b; Werz, 1996; Werz, 1997; Werz, 2006; Werz, 2007).

Due to the long human presence, as well as their geographic position and environmental circumstances, southern African coastal waters and adjacent shores have become a major repository for maritime archaeological sites. These include an unknown number of camp sites and shelters used by prehistoric hunter-gatherers (Werz et al., 2014). Later historical developments, which included commercially motivated expansionism by European nations since the late 15th century, followed by colonialism from the 16th century onwards, resulted in the establishment of camps that were occupied by shipwrecked mariners, whalers and sealers, as well as lighthouses, jetties and harbour works, and, of course, shipwrecks (Werz, 2011). A preliminary survey, based on incomplete historical data, indicated that a minimum of 1 506 vessels foundered around South Africa from 1550 to 1984. These vessels, which are of at least 17 different types ranging from exploration vessels to oil tankers and originating from at least 27 different nations, indicate the diversity and international importance of South Africa's underwater heritage (Werz, 1999b). However, these figures represent the minimum numbers and can only serve as indicators of the shipwreck potential that, as more recent studies indicate, might well be twice as great as and more diverse than previously assumed (Gribble, 2002; Werz, 2011).

Although shipwrecks can be found at many locations along the nearly 3 000 km of the South African coastline, the section between the Orange River mouth and Cape Agulhas shows a significant concentration of wrecks. This is partly due to geographic and environmental factors where submerged obstacles and weather conditions, such as adverse winds and the occurrence of fog, have played an important role. In addition, historical factors also contributed to the foundering of ships in this region. Table Bay's most important role since the Early Modern Era (1500 to 1800) was that of a place of refuge for passing ships. It was also the place from where expansionism into the interior started and can partly be used to explain this phenomenon (Werz, 1999b; Werz, 2011).

Historic shipwrecks are important to modern society. Their value is diverse and ranges from being of educational, research-focused, cultural, memorial, recreational and even aesthetic value. Nevertheless, many sites are threatened by human interference. Such actions can be motivated by development, for example, when a natural place of refuge is changed into a harbour or when parts of an old roadstead become reclaimed land. The Port of Cape Town is a prime example of this. Wrecks may also be destroyed when they pose a threat to navigation. However, in the South African context, illegal exploitation of the cargo and contents of older shipwrecks for private gain seems to be the most important motivation for interference with such sites. To control and curb these combined activities, various statutes have been introduced over the years. These include the National Heritage Resources Act, 1999 (Act 25 of 1999), which classifies wrecks older than 60 years as archaeological sites, the Merchant Shipping Act, 1951 (Act 57 of 1951) (as amended), and the Customs and Excise Act, 1964 (Act 91 of 1964). The last two acts pertain to salvaging in general (Werz, 1999b).

The responsibility to manage, control and enforce regulations contained in the various statutes and their amendments is shared by different authorities, including the Minister of Transport, the Controller of Customs and Excise and SAHRA. Unfortunately, insufficient monitoring and control, as well as the attitude of profit-motivated divers, did not contribute to the adequate protection of the underwater cultural resource over the years (Werz, 1999b). Fortunately, this situation changed recently with the introduction of the National Heritage Resources Act (Act 25 of 1999), as well as public information and education campaigns that were developed by SAHRA. These campaigns are mainly sponsored by the Dutch government (SAHRA, 2014). Nevertheless, historic wrecks are still vulnerable to human interference. This is a matter of concern, bearing in mind the international importance of shipwrecks in South African waters and their status as limited, non-renewable cultural resources that make unique contributions to a better understanding of aspects of people's history on a national and international level (Werz, 2003; Werz, 2006; Werz, 2011).

Formal efforts to protect and manage the underwater cultural resources in South Africa have intensified during the last 25 years and are ongoing. In this context, it should be realised that public interest in maritime archaeology is considerable. This seems to be mainly due to attitudes becoming more focused on conservation during the last decade. If the current situation in South Africa is to be improved, the assistance of interested people, such as sport divers, is essential. One way of stimulating this interest is by providing practical examples, where members of the public are allowed to participate in research projects. Experiences elsewhere in the world, such as the *Mary Rose* (1545) excavations in the UK, have shown that this approach is beneficial to specific projects, while the educational, recreational and public relations role that maritime archaeological projects play is enhanced (Rule, 1983; Dean et al., 1992). Private initiatives, such as AIMURE, represent another way in which the situation can be improved. Although advocating a comprehensive general and multidisciplinary approach to marine and underwater studies, one of AIMURE's specific aims is to stimulate the proper development and management of the underwater cultural resource by furthering scientific research, providing advice, and offering practical and theoretical courses to interested parties. It is hoped that, through the practical examples provided by the research projects that will be briefly discussed hereafter and AIMURE's related activities, the current situation in (South) Africa can be further improved (AIMURE, 2014).

## 4. The African Institute for Marine and Underwater Research, Exploration and Education

The South African Department of Social Development formally registered AIMURE as a non-profit organisation (NPO) under the Non-profit Organisations Act, 1997 (Act 71 of 1997), on 8 October 2012. The establishment's motivation is to stimulate research and education in aspects related to the marine, maritime and underwater environments, as well as the further exploration of these environments. Therefore, its main objective is to actively develop and pursue projects that promote research, exploration and education.

***Figure 1:*** *AIMURE's logo.*

According to its website, AIMURE's secondary objectives are as follows:

- Establish a group of volunteers that support the organisation in its activities.
- Liaise with other organisations and professionals that can assist in furthering AIMURE's objectives.
- Create a base that students of various disciplines can use as a launchpad to further their studies of the marine, maritime and underwater environments.
- Reach a point where such studies can be coordinated and international cooperation achieved.
- Provide specialist training, specifically aimed at young people from previously disadvantaged communities.
- Inform and educate the general public through public lectures, publications, documentaries and other forms of information.
- Establish a suitable infrastructure that, inter alia, consists of premises, staff and equipment.
- Acquire funding for the ongoing financing of equipment, projects, publications, training, salaries and other expenses

These goals can partly be achieved by formulating and establishing different research projects, undertaking (underwater) fieldwork, documenting and analysing research results, incorporating these results in academic publications and a public education programme, as well as establishing a Social Development Programme (SDP) (AIMURE, 2014).

Since the introduction of maritime archaeology as an academic specialisation in southern Africa in 1988, a number of projects have been undertaken. In the section that follows, some old and new projects, which are now being undertaken under AIMURE's guidance, will be briefly discussed. These illustrate the diversity of the (southern) African maritime and underwater heritage, its international importance, as well as the opportunities that are provided for multidisciplinary research, public information and education, as well as international cooperation.

Research involving the Dutch East India Company (VOC) ships the *Oosterland* and the *Waddinxveen* serves as a prime example in this context. Less than 50 years after a refreshment station for passing ships at the Cape of Good Hope was officially established, both vessels sank during a violent storm in Table Bay between 13:00 and 15:00 on Friday, 24 May 1697. This disaster claimed the lives of some 140 people. As both ships and their valuable cargoes of Asiatic export products perished, the incident also resulted in a substantial financial loss for the VOC (Plate 3). Both vessels thus provide links to aspects of the history of Europe, Asia and Africa (Werz, 1989; Werz, 1992a; Werz, 1996; Werz, 1997; Werz, 1999b; Werz, 2004a; Werz, 2004b; Werz, 2009c). Sport divers found their remains during the late 1980s and this discovery was reported without the sites being pilfered. This resulted in a cooperation agreement between the divers, the erstwhile NMC (now SAHRA) and the Department of Archaeology at UCT. The agreement stipulated that the author would be responsible for the project and cooperate with the discoverers. Fieldwork expenses were to be financed by the discoverers, who in return received up to 50% of the recovered material, according to shipwreck legislation of the time (Werz, 1990a). The South African government received the remainder of the materials that were housed at the South African Maritime Museum. After the artefacts were adequately recorded and studied, they were divided and the state had the first option of securing items of extraordinary importance.

***Plate 3:*** *Three porcelain statuettes of the Chinese god of prosperity and wealth, Liu Hai, that were excavated from the* Oosterland. *The god is often depicted with a raised right leg, a toad and a belt with gold coins. The statuettes served as incense burners, as indicated by the cylinder next to the left foot. Height: 70 mm (image by Bruno Werz©/AIMURE).*

Although this agreement was not ideal, as it allowed for the dispersal of archaeological material into private hands, it was the best option at the time. If nothing had been done, both wreck sites would have disintegrated because of prevailing natural conditions (McLachlan, 1991) and the actions of treasure-seeking divers, while more information and material would be lost. Although a clause in the agreement forced the discoverers of the wrecks to part with their share if the state offered them reasonable compensation, the South African government did not subsidise the project in any way, thus missing the chance of full ownership of a rather unique collection (Werz, 2011).

The results of the *Oosterland* and *Waddinxveen* projects were diverse. Interested divers, students and volunteers were given an opportunity to participate. Using the wrecks as field schools, some people were trained in standard underwater recording and excavation techniques (Plate 4). Recovered materials were used during lectures and practicals, where first-hand experience was gained in artefact recording, material analyses and conservation techniques. A number of students from different academic departments also produced theses on different aspects of the project, including underwater surveying and post-excavation analyses of a variety of artefact groups (e.g. Breitenmoser, 1991; Hampshire, 1991; McLachlan, 1991; Sharfman, 1994; Sharfman, 1998). Research results were incorporated into academic and public lectures and all of the collected scientific data was stored and made available to other researchers, as well as SAHRA and the museum where the state's share of artefacts is kept. Public information benefitted from the substantial media coverage that the project enjoyed, whereas scientific data was published in a variety of peer-reviewed articles and books (Werz, 1991; Werz et al., 1991; Werz, 1992b; Werz and Seemann, 1993; Werz, 1993a; Werz, 1993b; Werz, 1994a; Werz, 1994b; Werz and Klose, 1994; Werz and Martin, 1994; Martin and Werz, 1999; Werz, 2004a; Werz, 2009c; Werz, 2010a). Due to its strict adherence to accepted scientific methods and techniques, this is the first project of its kind in the southern African region. Envisaged future work includes the compilation of an extensive catalogue on the material culture that has been recovered from both wrecks and possible continuation of excavations (AIMURE, 2014).

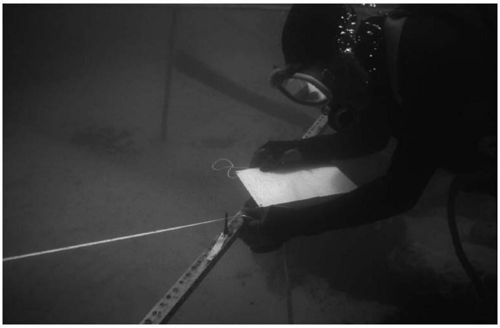

***Plate 4:*** *A diver on the wreck of the VOC ship,* Oosterland, *recording the position of an artefact by applying the direct survey method (DSM). This basic technique was developed on the Mary Rose Project during the 1970s and 1980s and proved to be the fastest and most accurate measuring technique in conditions with low underwater visibility (image by Bruno Werz©/AIMURE).*

Research involving the *Oosterland* and the *Waddinxveen* resulted in another project, Operation Zembe, which is of global significance. This project was launched in 2002 in recognition of the importance of further searches for inundated prehistoric sites. *Zembe* means 'axe' in the Nguni languages of southern Africa. The project is open ended and has already enjoyed much cooperation and support from organisations such as the South African Museum and the South African Navy (SAN). Internationally, the project is supported by the Southampton Oceanography Centre and the Scientific Exploration Society in the UK. It is currently managed by AIMURE and, in years to come, regular expeditions to systematically search areas of the seabed around Cape Town for prehistoric occupation sites will be organised. Fieldwork is supported by teams of local and international volunteers (Werz, 1999b; Werz, 2003; Werz, 2004a; Werz, 2009c; Werz et al., 2014; AIMURE, 2014).

***Plate 5:*** *The three Acheulean hand axes that were excavated close to the wrecks of the* Oosterland *and the* Waddinxveen*. They date back to between 1.5 million and 300 000 years ago and are the oldest artefacts ever found underwater in the world. Hand axes were the most versatile tools used during the Early Stone Age and were used for butchering carcasses and digging up bulbs and roots (image by Bruno Werz©/AIMURE).*

During the course of excavations, some stone implements were discovered that could be identified as Acheulean hand axes that date back to between 1.5 million and 300 000 years ago (Plate 5). These artefacts were located in sediments underlying the wreck sites and at least one of them was found *in situ* and was covered by a palaeosol that indicated an old land surface. It was confirmed internationally that these finds represent the oldest artefacts ever recovered from the underwater environment in the world to date (Flemming, 1998).

More importantly, they provide conclusive evidence of the possibility of finding more such materials on the continental shelf, even in areas that have experienced multiple sea-level transgressions and regressions over the years. Previously, it had been suggested that prehistoric people may have used the current continental shelf to find marine foods in the intertidal zone, as a hunting ground, and as a portal through which migration took place along the African coast. Many archaeologists rejected the possibility of finding prehistoric material dating back hundreds of thousands of years *in situ*, until the discovery in Table Bay (Flemming, 1998; Werz and Flemming, 2001; Werz et al., 2014). Another interesting point is that the underwater environment preserves many materials much better than sites on land due to the lower oxygen levels and relatively low and stable temperatures. This is especially the case with organic substances. Recognising that the bottom 'archive' of prehistoric finds excavated from land sites is far from complete, as it contains mainly stone objects, charcoal, pottery and sometimes bone, the underwater environment offers a challenging alternative. Thus, it may be possible to find other items that could have been used, such as leather sandals, parts of skin clothing, wooden carvings, spears and other tools, rope and maybe even the remains of food reserves, in future. Another exciting perspective is that the underwater environment can reveal more data on past climates and the environment through remains such as seeds, pollen and other biological materials. This, of course, will contribute to a better understanding of issues like climate change and global warming in the past.

***Plate 6:*** *The most recent wreck around Robben Island is that of the* Sea Challenger*. This 30-m long tug was pushed onto the rocks by strong winds and a stormy sea during the morning of Saturday, 9 May 1998. The incident occurred while the tug was engaged in efforts to refloat the Taiwanese long-line tuna catcher* Han Cheng 2 *that had grounded in thick fog some days earlier. The* Sea Challenger *was owned by Sealink and was being used at the time by the Cape Town-based salvage organisation Pentow Marine (image by Bruno Werz©/AIMURE).*

Operation Sea Eagle is a project that is involved with the underwater heritage around Robben Island in Table Bay and was undertaken during the period 1991 to 1992 on direct order of the South African Cabinet. The mandate of this project was to locate and identify the maritime archaeological potential within a one-mile security zone of the island. The reason for this was to assist in the formulation of a heritage management policy, as the island was destined to become a United Nations Educational, Scientific and Cultural Organization (UNESCO) world heritage site (Werz and Deacon, 1992).

During two field seasons, the author, with the support of SAN divers, searched the seabed around the island. This resulted in the location of 15 shipwrecks. Surveys were also undertaken in the harbour and around the old jetty. Parallel to underwater searches, archival research has established that at least 22 vessels had foundered near the island between 1694 and 1976. The records indicated that these ships originated from eight different nations and were of 14 different types, ranging from a VOC yacht that sank in 1694 to the Korean ore-carrier *Daeyang Family* that ran aground in 1986 (Werz, 1999b; Werz, 2001; Werz, 2003). Since then, other incidents have taken place, including the foundering of the Taiwanese fishing vessel *Han Cheng 2* and the local tug *Sea Challenger* in 1998 (Werz, 2011) (Plate 6).

As a result of Operation Sea Eagle, a reasonable impression could be formed of the potential that the Robben Island shipwrecks represent. Although the condition of most wrecks is not what was expected, it has become clear that the potential for detailed studies of a scientific nature is considerable. Research has indicated that reasons for maritime accidents varied and depended in most cases on environmental and human factors. The state of individual wrecks ranges from reasonably coherent and well-preserved structures to sites that are completely dispersed. Factors that dictated the level of preservation on individual sites include the type and age of the shipwreck and its place of foundering (Werz, 1999b).

The objectives of the first phase of Operation Sea Eagle were satisfactorily met, given the available time and resources. The extreme natural conditions on and below the water surface constrained the fieldwork. Operation Sea Eagle has been the first large-scale project in Africa where attention was devoted to the underwater cultural heritage (Werz, 1993c; Werz, 1994c). It proved the following:

- Cooperation between relevant government departments can promote the study and management of this heritage.
- South Africa has the infrastructure and expertise to undertake such a survey.
- The outcome of the survey, which was undertaken under extremely difficult circumstances, can meet any international standard.
- The costs can be kept relatively low.

(Werz and Martin, 1994; Martin and Werz, 1999)

The historical research into the backgrounds of individual ships, the shipwreck site inventory, as well as the assessment of their state of preservation and the contents that resulted from Operation Sea Eagle, provided a basis for a management policy. In this context, it should be recognised that the underwater cultural resource in the waters surrounding Robben Island has diverse values that are related to history, culture, recreation and education. Besides that, some wrecks have economic value if they are to be salvaged. There is tension between profit-orientated motives and the other values mentioned above. Treasure hunting and salvaging are the biggest threats to which the wrecks around Robben Island are exposed and there are indications that these still continue (SAPS Western Cape Diving Unit, 2014). An argument that is often used by commercially motivated operators is that many sites around the island have been broken up by the action of the sea, thus limiting their archaeological and educational value. Still, historic shipwrecks represent a non-renewable and limited resource that should be used for the benefit of society. Salvage results in the irreversible destruction of such sites and the information contained in them, as well as a limited financial return for the very few people involved in such operations.

***Plate 7:*** *A South African Police Service (SAPS) member from the Western Cape Diving Unit inspects the wreck of the* Rangatira *off Robben Island. The* Rangatira *was a British steamliner that ran on the rocks on 31 March 1916 in dense fog en route from London to New Zealand (image by Bruno Werz©/AIMURE).*

Operation Sea Eagle has shown that the coastal waters of Robben Island contain a diverse collection of historic wrecks that could be maintained as a maritime archaeological reserve. Such a reserve would enhance the educational, recreational, cultural and scientific value of shipwrecks. To achieve this, public interest and further research must be promoted. Access to the resource should be controlled so that no material is removed for purposes other than research and public display. This could be combined with an underwater shipwreck trail that would allow visitors to dive on selected wrecks under supervision. If these suggestions can be realised, Operation Sea Eagle will have proven to be of even greater relevance to cultural resource management (Werz, 2006). At the moment, AIMURE is cooperating with the SAPS's Western Cape Diving Unit to record the current state of the maritime archaeological resources around the island (Plate 7). These non-intrusive surveys will be compared with previous results obtained during the first phase of Operation Sea Eagle to establish how the resource has been affected during the last 25 years.

In addition to the projects described above, AIMURE intends to expand its research programme in the future. More involvement from other academic disciplines and increased international involvement from other African states, as well as on an intercontinental level, will be emphasised. Public information and educational activities, such as lectures, courses and media coverage, will also be expanded. AIMURE's SDP will play a crucial role in these activities. Since the inception of AIMURE, it was decided to put an SDP that represents its formal outreach programme to society in place. To be in line with AIMURE's general objectives, the SDP focuses on skills development related to water and diving (Plate 8). It will serve members from previously disadvantaged communities and contribute to people's careers in the formative years.

For the abovementioned reasons, a three-tier approach consisting of swimming courses, sport diving courses and commercial diving courses (level 4) will be followed. Ideally, suitable candidates will start by being taught to swim. They will then proceed to the sport diving level and end with a commercial diver's certification. This is, however, not realistic for every candidate. For various reasons, such as aptitude, motivation or circumstances at home, it can be expected that most candidates will not be able to follow the complete track. From various discussions with educators and other professionals, the following prognosis emerged. It is likely that out of ten candidates who finish the swimming course, approximately half will continue with the sport diving course and probably only one of those divers will complete the commercial diver's course. It is therefore essential to only allow candidates to the swimming course after they have given sufficient proof of motivation and drive. Technical schools in Cape Town's poorer areas will be approached first to determine if there are willing and suitable candidates for the SDP. One of the reasons for this is that learners in a technical field, such as construction or welding, can benefit from becoming commercial divers. Unfortunately, the majority of these learners are male. Female learners should also be encouraged to take part, as they may ultimately find a job in the sport diving industry as instructors, dive guides or professional divers in research organisations, such as universities, aquaria or commercial companies.

Due to the limited time available and the limited availability of suitably qualified AIMURE members, the three components will be outsourced. An advantage is that formal certificates from recognised training institutions will be issued upon successful completion of each component. This also directly benefits participants. The swimming courses will be offered by registered swimming instructors or swimming schools up to a level where participants have acquired sufficient skills to take to the water safely. The sport diving course will be provided by a reputable diving school up to an open-water level, while the commercial diving course will be provided by a training institution that is approved by the Department of Labour. Although AIMURE can only start with the SDP once sufficient sponsorship has been procured, any partial repayment at a later stage will be regarded as income for AIMURE, which will be used to finance the programme in future (AIMURE, 2014).


***Plate 8:*** *A professionally qualified AIMURE diver during a training exercise. The diver is wearing a dry suit that protects him against cold and pollution. He is supplied with a gas mixture for breathing through an umbilical hose (background) and carries an emergency supply on his back. Communication with the surface is maintained through the helmet and full-face mask (image by Bruno Werz©/AIMURE).*

## Conclusion

Maritime archaeology plays an important role in the study of aspects of human history, as the sea has played a major role in the progression of our species. Before the advent of flight, contact between different continents was only possible through maritime traffic, which contributed greatly to the process of cultural development and globalisation. Maritime archaeology is especially important to the history of southern Africa because there would not be the diversity of people of different backgrounds, races and creeds that make up modern society in these parts without past maritime traffic.

Marine, maritime and underwater research in Africa is only undertaken on a limited scale and a few specialisations are emphasised. In an attempt to offer an alternative to this prevailing particularistic condition, AIMURE advocates a more comprehensive and multidisciplinary approach. Nevertheless, as the background of some AIMURE members is strongly rooted in maritime archaeology, one of the specific aims of this private initiative is to stimulate the proper development and study of the underwater cultural resource.

AIMURE attempts to be as inclusive as possible. Its geographical focus is primarily, but not exclusively on the African continent as a whole, and its interest sphere includes all research of a marine, maritime or underwater nature. This can range from oceanography, marine biology and limnology to underwater archaeology. AIMURE intends to forge working relationships with different governments, institutes, organisations, industry and people from all over Africa and beyond. Its international outlook is partly reflected in the composition of the management committee that includes representatives from Africa, as well as the Americas and Europe.

In order to function, AIMURE needs material and financial support. As it is an NGO, AIMURE cannot rely on government funding. Although some limited state funds may be available for specific projects in the future, the greater part of the organisation's financial means will have to be obtained from the private sector initially. Nevertheless, AIMURE fully intends to become a self-funding organisation in due time. This can be done by charging for its expertise, through contract work or by designing certain projects, including its SDP, in such a way that they become self-sufficient in time.

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# Part 5

## Infrastructure and Technology Developments for the Maritime Sector

# Chapter 13 Port Infrastructure: A Holistic Framework for Adaptation to Climate Change[1]

*Kana Mutombo*

## 1. An overview of the maritime industry

The world economy is becoming more and more interrelated as a result of increasing trade and the movement towards globalisation of production. This is mainly attributed to the fact that modern organisations tend to opt for the international fragmentation of their operations by allocating different stages of production to different countries, depending on the availability and cost of resources and the socio-political environment prevailing in the host country. This trend has resulted in increased trade between producers in one country and consumers in another country. Over the past half a century, there has been a steep increase in import and export activities as a result of the vertical specialisation of world trade. In addition, there have been major structural changes in the world economy as a result of globalisation. Raw materials sourced in one part of the world are often shipped over long distances to different locations for development into finished products (The World Bank, 2007). This 'open market' situation has intensified world trade competition, thereby forcing various role-players to continuously search for creative ways of maintaining a competitive advantage.

Seaborne transportation is characterised by low energy consumption, resulting in a small carbon footprint. Its climate-friendly image makes it attractive for shippers of cargo (Bonnerjee et al., 2009) For instance, carbon dioxide ($CO_2$) emissions per ton per kilometre for road and rail transportation respectively are about six times and twice the amount of $CO_2$ emissions generated by seaborne transportation. Airborne transportation emits far more $CO_2$ than rail transportation (UNFCCC, 2013). Global trade is largely seaborne (91%), with cargo ships carrying approximately 50 000 billion tonne-miles (UNFCCC, 2013). This means that all this trade has to move through ports to reach consumers (SAMSA, 2013). The development of maritime transportation infrastructure has therefore become a key enabler of and catalyst for the competitiveness and development of any regional economy.

As a result, developments taking place in international logistics, shipping technology, industry consolidation and environmental regulations (especially in respect of climate change) are driving major changes in the way ports will operate in the 21st century. As distances are shortened by globalisation, the economies of the world become more interdependent and the role of ports is gradually shifting from a set of complex infrastructures to a major player in national supply chain management. Technology, mergers and acquisitions in the shipping sector are changing the image of ports into that of an active, highly competitive and productive industry. In order to achieve better efficiency and gain a competitive advantage, public-private partnership models have been developed with some level of success in

1 This chapter forms part of a PhD research project in progress at the World Maritime University in Malmö, Sweden. The PhD programme is sponsored by the South African Maritime Safety Authority (SAMSA) with the support of Transnet National Ports Authority. The research project is supervised by Dr Aykut Olcer (World Maritime University) and co-supervised by Prof Winston Shakantu (Nelson Mandela Metropolitan University).

countries like Belgium, Singapore and The Netherlands. In South Africa, for instance, Transnet National Ports Authority has widely recognised the spin-off benefits of public-private partnerships and is currently in the process of exploring the implementation of such a model at selected ports (Durban, Ngqura, Richards Bay and Saldanha). Mergers, acquisitions and private sector involvement have substantially fuelled further competition between ports. Furthermore, players who could not come up with innovative strategies to cope with the change in the industry were progressively absorbed, while a few surviving players have strengthened their influence to become major players who change the way port services are bought and sold (The World Bank, 2007).

Because of these developments and changes in the international and national ports sectors, South Africa is making major capital investments to meet long-term market demand (see Figure 1). For instance, the total number of containers handled nationally by Transnet National Ports Authority during the 2012/13 financial year was 4 million twenty-foot equivalent units (TEUs). The seven-year forecast predicts 6.3 million TEUs and the 30-year forecast predicts 17 million TEUs.

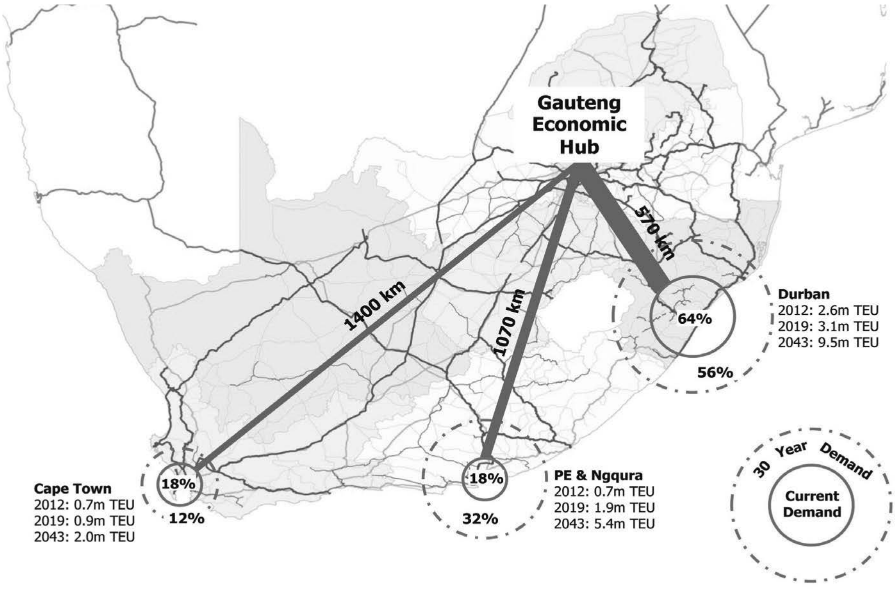


***Figure 1:*** *An indicative figure of growth in container market demand in South Africa over the short and the long term.*

There are currently 117 berths across the port system in South Africa. This is equivalent to 30 400 m of berth length. Most berths are used for break bulk operations (41 berths), followed by dry bulk operations (21 berths), containers (20 berths) and liquid bulk operations (19 berths). Taking a future demand forecast into consideration, this capacity should be increased fourfold within the next 30 years to match demand requirements.

In South Africa, there are a number of common trends and issues that play a role in long-term port planning.

Demand from emerging economies has led to an increase in international seaborne trade. In an effort to achieve a competitive advantage, players opt for greater specialisation, centralisation and economy of scale. As a result, there is increased competition for skills and a subsequent slowdown of resources in developed economies. There is also an exponential increase in vessel and parcel sizes due to favourable economies of scale in cargo transportation. As a result of this, there has been an emergence of innovative regional and global port operational models, such as hub and spoke systems.

The industry is experiencing a restructuring of logistics networks and an improvement in processes dealing with hinterland congestion and intermodal transportation links. Great efforts are being made towards moving cargo from road to rail as a more competitive and sustainable mode of transportation. Port reforms due to high costs and constraints on port infrastructure are a regular occurrence. This results from port governance restructuring and de-regulation, as well as the awarding of concessions to global terminal operators to improve the productivity, efficiency and profitability of ports. This trend has emerged through attempts to achieve advanced port operational systems and develop more efficient cargo-handling equipment. Transportation and the handling of alternative forms of energy, such as liquefied petroleum gas (LPG) and liquefied natural gas (LNG) are currently being investigated as major market opportunities. As such, the need for sustainability in infrastructure solutions, as well as increased stakeholder engagement on issues such as the carbon footprint, cleaner technologies, green and ecoports, health and safety, and end-user costs, has become a serious consideration.

The aforementioned trends and issues do not include the consideration of global climate change and its negative impact on shipping and infrastructure. While port infrastructure generally has a long lifespan, and is expected to remain in operation for many decades, it remains vulnerable to climate change. This is usually because seaports are located on coasts that are susceptible to a rise in sea level and storms, or in the mouths of rivers that are susceptible to flooding (Becker et al., 2011). The majority of coastal/port infrastructure was built on the assumption of a static climate (Stockholm Environment Institute, 2010). Although there is evidence that investment decisions are beginning to take potential climate change adaptation measures into account (PricewaterhouseCoopers, 2010), the extent to which climate change adaptation is considered across the entire sector still remains unclear. Much infrastructure built today will withstand changes in climatic conditions over the course of the century, but in most cases the changing climate was not considered in the design phase of port infrastructure development. A holistic model for adaptation is necessary to serve as a benchmark for future infrastructure planning, decision-making and investment strategies in the industry.

This chapter aims to raise the necessary awareness of the need for a three-tier port infrastructure adaptation framework in South Africa's maritime industry. It attempts to recognise that climate change is not a constraint, but rather an essential underpinning of port infrastructure development in the maritime industry. The chapter is divided into sections that address climate change, the knowledge gaps and port response to climate change. It ends with a conclusion.

## 2. Climate change

Scientific evidence obtained through ice-core drilling indicates that the world's temperature is gradually increasing. This was established through an examination of the correlation between the $CO_2$ content trapped in ice masses and the temperature. Furthermore, records of temperatures and a rise in the sea level over the past century have confirmed that the earth is getting progressively warmer (Gore, 2006).

Scientists attribute an increase in the concentration of greenhouse gases ($CO_2$, methane, water vapour, nitrous oxide and ozone) to the current global warming phenomenon (Lisa et al., 2009). Meanwhile, the resolutions of the Intergovernmental Panel on Climate Change (IPCC), dated 27 September 2013, concluded that the warming of the climate system is unequivocal and that, since the 1950s, many of the observed changes are unprecedented over decades to millennia. The IPCC further stated that human influence has been detected in the warming of the atmosphere and the oceans, the change in the water cycle, the reduction in snow and ice, the rise in the global mean sea level and changes in some climate extremes. It is extremely likely that human influence has been the dominant cause of the observed global warming since the mid-20th century (IPCC, 2013).

Nevertheless, in spite of an increasing number of mixed tendencies of scepticism, denial, uncertainty and activism in the scientific domain (Vey, 2013; Foucart, 2014a; Foucart, 2014b), climate change has successfully entered public consciousness, thereby leading to a string of organised initiatives – the most significant of which are the following:

- The IPCC is a leading international body established by the United Nations Environment Programme (UNEP) and the World Meteorological Organisation in 1988 to provide the world with a clear scientific view on the current state of knowledge on climate change and its potential environmental and socio-economic impacts.
- The United Nations Framework Convention on Climate Change (UNFCCC) is an international treaty joined by various countries in 1992 that aims to recognise that there is a problem, set goals, encourage developed countries to lead the way, direct new funds to climate change activities, monitor progress, strike a balance and take considerations on climate change adaptation into account.
- The Kyoto Protocol (11 December 1997) is an international agreement that commits parties to set binding emission reduction targets.
- The Bali Action Plan (December 2007) is a comprehensive process that aims to enable the full, effective and sustained implementation of the UNFCC through long-term cooperative action, now, up to and beyond 2012 (UNFCC, 2013).
- The Cancun Agreements (2010), the United Nations Climate Change Conference in Durban (2011), The Doha Climate Gateway (2012) and the United Nations Climate Change Conference in Warsaw (2013) are all corresponding initiatives that seek to address the pressing demand to act against climate change.

These initiatives have recognised the need to act against climate change and have developed strategies aimed principally at reducing $CO_2$ emissions. However, considering that a reduction in $CO_2$ emissions will not immediately reverse current climate trends, a need for adaptation has gradually emerged. This reinforces the need to build climate resilience at ports and on ships in the context of the maritime supply chain industry.

## 2.1 Climate change indicators

The IPCC has holistically identified the following indicators of climate change (IPCC, 2013):

- World oceans are warming.
- The mean global sea level is rising (see Figure 2).
- The salinity of oceans is changing.
- There is an increased acidification of oceans.
- There are more frequent warm days and nights, and fewer cold days and nights.
- There is a decrease in snow cover in most regions.

- Degrading permafrost in real extent and thickness has been observed over the past few decades.
- There are large-scale precipitation changes.
- An increase in the number of heavy precipitation events has been experienced in different parts of the globe.
- The Arctic sea ice is shrinking.
- There are widespread glacier retreats.
- Changes in ice sheets in Greenland and Antarctica have been quite visible recently.
- The average global temperature is rising.
- There is an increase in the earth's surface humidity.

These indicators will have a direct or indirect impact on any large-scale engineering projects that are designed to exhibit socio-economic benefits and last for decades into the future to some extent.

To illustrate this impact, consider the following scenarios. Any submerged steelwork (or reinforced concrete) infrastructure in ports will react to an increased salinity or acidification of the water. An increase in the water level will increase wave overtopping on structures. The design of the stormwater networks of existing port infrastructure is based on most prevailing rainfall patterns on record. Increased rainfall could therefore lead to more flooding in the port as a result of the inability of existing networks to absorb the increased flow of stormwater. This situation may, in turn, create further cascade failures like damages to roads or power stations.

In addition, there is evidence that a complete melting of the ice of Greenland and Antarctica has the potential to raise the global sea level by approximately 60 m. This indicates how ports will be progressively affected by the continued melting of the ice. Furthermore, while the current cause of the rise in sea level is principally attributed to thermal expansion and ice melting at a ratio of 60:40, this is expected to shift and the ice-sheet disintegration will become the principal contributing factor for the rise in the sea level in the next decade. As a result of the complex interface between sea and atmospheric conditions, extreme weather events (for example, tornados) will also be generated with devastating impacts on ports.

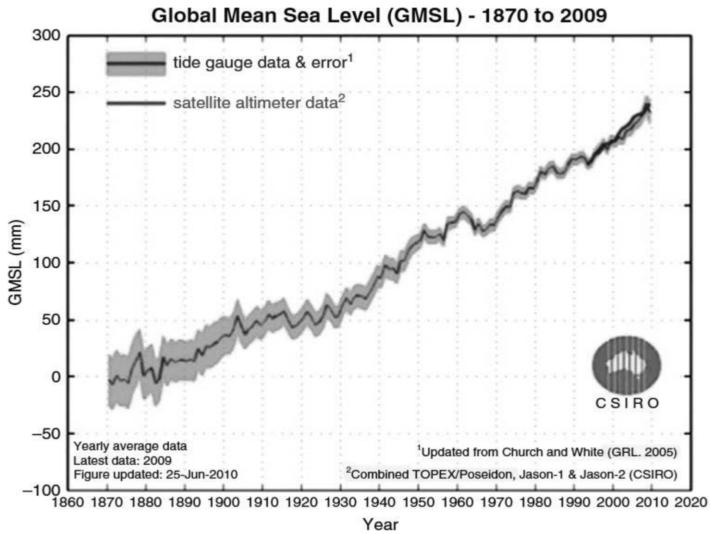


***Figure 2:*** *The trend of the sea level rise from 1870 to 2009 (Farmer and Cook, 2013).*

## 2.2 Impact of climate change on port infrastructure

A study conducted by the Royal Melbourne Institute of Technology (RMIT) University (2013a) concluded that the following major climate variables would influence port infrastructure resilience: sea level, precipitation, wave conditions and temperature. The study argues that climate variables that would affect the long-term performance of the port infrastructure are a rise in sea level, the water table, temperature, rainfall/runoff, waves, wind, salinity and humidity.

Historically, climate change was not deemed an important consideration in the design of port structures (RMIT University, 2013a) since most infrastructure was built on the assumption of a static climate. Furthermore, the impact of climate factors differs very much between geographical locations, and a climate change assessment would therefore require a more detailed analysis of the particular network. The need to factor climate change considerations into the planning stage is becoming increasingly imperative. This is because, under normal circumstances, the adaptation of existing infrastructure to increase its resilience costs more than factoring in adaptation strategies at an early stage during infrastructure development. Adapting features on existing infrastructure is a sensitive process and may require demolition or rebuilding to ensure that the structure is consistent. A holistic approach adopted by the RMIT University (2013b) summarises the most well-known and obvious components of port infrastructure on which climate change has a direct impact. These are berthing structure, protection barriers, port superstructures, channels and harbour basins, road infrastructure and rail infrastructure.

Visible impacts on berthing structures include damage and deterioration resulting from heavy storm activity, inundation and the shifting tidal and splash zone level. In many instances, ports have experienced a steady increase in their maintenance budgets as a result of an increasing maintenance cycle aimed at mitigating further damages and deterioration. It is anticipated that this increase in maintenance budgets will translate into an increase in port fees, which, in turn, will affect the cost of seaborne transportation.

Increased wave overtopping of protection barriers (see Plate 1) is occurring in many ports across the globe. Furthermore, there have been numerous occurrences of barrier material displacement and fracture, and the erosion of barriers as a result of the increasing forces exerted on these structures.

The most common impact of climate change on port infrastructure is the failure of foundations, the degradation of superstructure material, increased storm and flood damage and the failure of roofs and cladding. This is mainly attributed to extreme weather events that, in many instances, may not have been factored into the design process during the planning stage of the infrastructure development project.

Depending on geographical locations, most South African ports have experienced a gradual increase in annual dredging costs (as a share of total port maintenance costs) over the past decade as a result of the increased presence of sediments in channels and along berths. Furthermore, changes in water depth, water flow and the timing of seasonal high and low water have also contributed to the exacerbation of sediment inflow, thereby impacting on the maintenance regime cycle.

Road infrastructure is mainly affected by flooding as a result of the inability of the stormwater system to cope with excess rain. Major common failures on roads include embrittlement and the cracking of bitumen, potholes, the submergence of roads and, in some cases, the damage to road foundations as a result of prolonged drought and low rainfall.

Rail infrastructure is mainly affected by flooding and a change in temperature. Major common failures includes the buckling of tracks, the submergence of low-lying rail tracks, and damage to signals, rail foundations and other railway installations.

The above direct climate change impacts on port infrastructure are not exhaustive. Through a proposed climate risk-based approach for assessing the impact of climate change on port infrastructure, additional direct impacts will be discovered as improved understanding of climate risks comes about. It is anticipated that a comprehensive risk-based approach will be used during the research to highlight all possible climate risks to port infrastructure with the goal of developing a holistic port infrastructure adaptation model to climate change.

***Plate 1:*** *Port of Port Elizabeth, South Africa, 2008: the result of an extreme weather event.*

## 3. The knowledge gaps

Literature generally views the adequate supply of infrastructure as an essential activity for economic development and poverty reduction (National Planning Commission, 2011). In many instances, it is suggested that infrastructure development can play a major role in promoting growth and equity, and to help reduce poverty (PricewaterhouseCoopers, 2010; National Planning Commission, 2011). The meaning of infrastructure has shifted from one focusing on physical fixed assets to one embodying notions of softer types of infrastructure, such as systems, procedures, policy and knowledge (UN Habitat, 2011; Taneja, 2013).

Although an outright denial of global warming is progressively proving to be unviable, literature suggests that there is still the persistent power of lobbyists and special interest groups attempting to stall climate adaptation policies. Despite this, there is an acknowledgement of the need for robust interventions to climate change. Physical port infrastructure is being altered to improve resilience and reduce vulnerability to climate change in some ports in developed countries (Dawson, 2012; EC, 2013), while opportunities and risks caused by climate change to port infrastructure are currently being addressed in ports in other developed countries (HM Government, 2011; EC, 2013). A need for conservative design specifications has already been emphasised through various studies. Adaptive change recommendations to support construction activities, land use planning and land protection have also been developed in the industry on a small scale (Lewsey et al., 2004).

However, initiatives in this regard have thus far been fragmented and poorly coordinated with industry process owners, thereby yielding insignificant outcomes (Natural England, 2009). In many instances, ports have opted for mitigation strategies (a quick fix) rather than adaptation. It is widely speculated that this is due to the perceived short-term cost-saving benefits associated with mitigation as opposed to the huge long-term investment required by adaptation strategies (Mills-Knapp et al., 2011). An additional reason attributed to this slow pace in decision-making on adaptation strategies is the uncertainty and controversial nature surrounding climate change issues.

Environmental engineer, Kristin Lemaster, argues that adaptation and short-term mitigation are two topics competing for resources (Mills-Knapp et al., 2011): mitigation often wins because the results are associated with saving money. Adaptation is also a more difficult issue to address since it involves planning on a long-term basis and the risks are not always easily identifiable. Becker et al. (2011) echo the fact that, while current operational challenges may make it difficult for individual companies to devote resources to this long-term issue, the implications of climate change impacts on many industries, including dredging, will be quite profound.

Nevertheless, the extent to which a port is affected by climate change is dependent on whether the port is exposed or sheltered (Australian Government, 2012). As such, some ports may not perceive climate change as a pressing matter, while other ports may feel directly threatened by it. This results in different levels of response among ports worldwide.

## 3.1 Infrastructure adaptation models

Many authors present a strong case for incorporating risk management into adaptation initiatives models (HM Government, 2011; The Royal Academy of Engineering, 2011; Beckers et al., 2013; Chapman et al., 2013; O'har, 2013; RMIT University, 2013b). A study by the Organisation for Economic Cooperation and Development (OECD) ranked the top 10 port cities with high exposure and vulnerability to climate extremes as Miami, Greater New York, New Orleans, Osaka-Kobe, Tokyo, Amsterdam, Rotterdam, Nagoya, Tampa-St Petersburg and Virginia Beach (Nicholls et al., 2008). Various climate change initiatives have been implemented in these port cities, and countries like Australia, Canada, Japan, The Netherlands, the UK and the USA have taken the lead by passing infrastructure adaptation to climate change models into legislations (Hernan, 2009; HM Government, 2011; O'har, 2013).

It is speculated that, since South African ports record a low-to-moderate vulnerability to climate change (when compared to the top 10 ranked ports), adaptation of port infrastructure is still perceived to be a lesser priority considering other pressing socio-economic challenges that require immediate short-term attention from stakeholders. However, although many developed countries with maritime activities have recognised the need for adaptation and have implemented different strategies and adaptation models, these models are very shallow in that they often provide high-level directives and are very broad in that their scope covers the complete transportation infrastructure system (road, rail, airports, pipelines, etc.). These models often cover generic infrastructure adaptation guidelines, which encompass the following steps: identification of current and future context, identification of vulnerabilities and risks, an analysis and evaluation of risks and vulnerabilities, and an identification and assessment of adaptation options.

The subjective nature of the steps of the adaptation process mentioned above remains a bone of contention. This weakens the case for adaption and compromises the ability to secure the necessary funding to implement adaptive initiatives. It is also fuelled by a vague understanding of risk: one port could be prepared to live with some amount of 'acceptable' climate change risks, while this may not necessarily be acceptable to another port in similar conditions.

More importantly, although it is practically impossible to eradicate subjectivity in the port infrastructure adaptation process altogether, it is possible to minimise subjectivity substantially by using complex non-linear tools in assessing risks.

## 4. Port response to climate change

Ports not only play a role in the chain of transportation for interchange. They function as self-sustaining industries linked to domestic and international trade (Gaur, 2006). They often play major contributing roles in local, regional and national economies. The nature of port activities is such that they generate substantial multiplier effects. Climate change risks to ports therefore present devastating threats to these economies as ports act as earners of foreign exchange, not only in the form of transhipment or hub ports, but as part of national supply chain management through their provision of logistics services to the industry.

Responding to climate change requires two kinds of action (HM Government, 2011):

- Mitigation: Seeking to reduce the concentration of greenhouse gases
- Adaptation: Seeking to create a climate change resilience environment

At port level, mitigation actions cannot be controlled entirely. Although ports should be encouraged to develop mitigation policies, the effect of such policies on the reduction of greenhouse gas emissions will be insignificant, particularly considering the broader nature and complexity of greenhouse gas-emitting industries that fall outside port-controlled environments. Effective mitigation strategies ideally require a worldwide approach by intergovernmental agencies with enough power and authority to enforce compliance. Mitigation, as a response to climate change, is therefore omitted from this research.

Adaptation, however, seeks to lower the risks brought about by the consequences of climate change (Fisk, 2014). Schipper and Burton (2009) argue the need of adaptation while stating that adaptation used to be largely associated with Darwin's theory of evolution and the process of natural selection, which is mainly embedded in the 'survival of the fittest' principle. Evidence suggests that climate change is a human-induced process rather than a natural process (Bonnerjee et al., 2009). Human counteractions are therefore required to mitigate further damage and build resilience. Schipper and Burton (2009) further recognise the increasing need to estimate the impact of climate change for two reasons: to provide a basis for assessing the overall severity of the problem and to provide a benchmark (the 'do-nothing' option) for evaluating the pros and cons of potential response strategies.

## 4.1 The way forward: a risk management approach for port infrastructure adaptation to climate change

Taneja (2013) defines port infrastructure as a system that includes physical elements (such as the breakwater, access channel, berths, equipment, and road and rail connections) in addition to the operating procedures, management practices and development policies that interact with societal demand and the physical world to facilitate its function. The potential impacts of each climate change indicator need to be assessed through sensitivity and risk analyses to identify critical thresholds and quantify risks and threats that may require a response. Thresholds for damaging impacts will, in fact, be raised by adaptation (Schipper and Burton, 2009).

As the sea level increases, the probability of the overtopping of coastal structures increases (Dawson, 2012). The IPCC (2013) predicts a rise in sea level of between 52 cm and 98 cm by 2100. Even with aggressive emission reduction strategies, a rise of between 28 cm and 61 cm is still predicted (UNFCC, 2013). Moreover, a new study surveys 90 sea level experts who warn against the conservative approach of the IPCC by arguing that the rise in sea level in 2100 will far exceed the IPCC's projections (Abraham and Nuccitelli, 2013). Furthermore, it is estimated that a complete melting of the Greenland and Antarctica ice sheets will result in a global rise in sea level of 57 m (Pilkey and Young, 2009). While the melting of ice (see Figure 4) currently contributes 30% to 40% of the rise in sea level, it is anticipated that this contribution will significantly increase in future. Unfortunately, the melting of ice sheets is a non-linear function. This makes prediction extremely difficult, since the tipping of ice disintegration remains unknown. Rippeth and Scourse (2009) have released a contentious report undermining alerts associated with the a rise in sea level by stating that it should, in fact, come to an equilibrium as the expansion of the continental sea shelf will generate an increased growth of plankton, which will, in turn, absorb more $CO_2$, ultimately reducing warming and the threat of any further rise in the sea level.

Furthermore, scientific evidence indicates a gradual increase in the occurrence of human-induced extreme weather events over the past decade. These events are generally far more damaging to port infrastructure and the maritime sector in general than the rise in sea level (in the foreseeable future). It is estimated that annual losses generated by these events over the past decade have reached the US$200 billion mark (IPCC, 2013).

Nonetheless, climate change has clearly brought new risks for humanity (Shaw et al., 2010; Chapman et al., 2013). It is important to understand the nature of these risks in order to understand where port infrastructure systems are most vulnerable. Considering ports as a critical element of the maritime supply chain and understanding the risks brought about by climate change will provide a better understanding of the influence that these risks may have on the maritime industry in general.

The vulnerability of existing port infrastructure will be very difficult to assess since most of the elements of such infrastructure were built decades ago and have already undergone deterioration, damage and possibly repairs that are very difficult to assess with any degree of certainty. For the purpose of this research, adaptation will therefore be limited to new infrastructure in the developmental stage.

An important element of climate change risks to port infrastructure systems is the fact that some of these can be controlled within certain port boundaries, while events outside the controlled port environment often have the potential of cascading into failures in the port environment.

The subject must, however, be approached carefully as maladaptation may, in some cases, present a greater risk to the functionality of the port infrastructure when infrastructure is adapted, based on a flawed understanding of climate change predictions. These predictions remain uncertain and highly contested.

### 4.2 A proposed three-tier approach for adaptation

A three-tier approach to port infrastructure systems can be considered when assessing the risks to the smooth functioning of port infrastructure systems and when developing relevant adaptation strategies (see Figure 3).

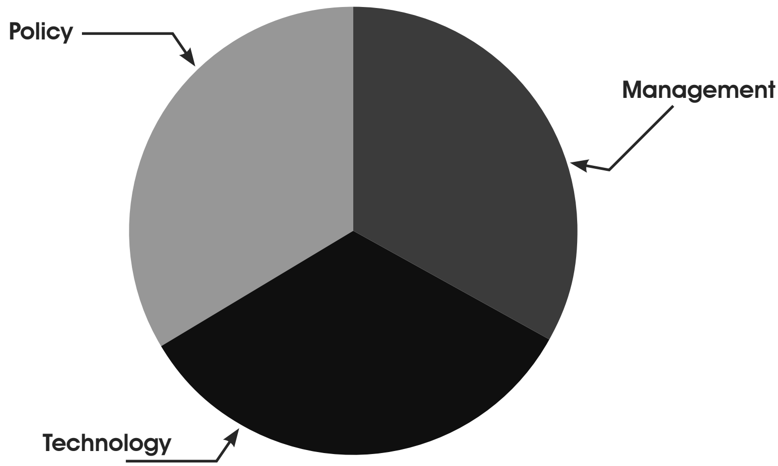


***Figure 3:*** *Three-tier model for port infrastructure adaptation to climate change.*

A holistic adaptive response to climate change indicators will take into consideration the three-tier model of port infrastructure systems. Subsequently, policies and management interventions must be developed in respect of the risk index for each climate variable. Considering that this approach aims to prioritise risks based on severity in a cost-effective manner, climate variables with a low risk index that do not present any threat to port infrastructure will therefore not be taken into consideration when developing an adaptation framework. Depending on the location of the physical infrastructure and the nature of the port, a climate variable risk index may vary substantially from port to port, and a proper analysis of specific trends will be necessary to classify results into groups based on various observed common factors (e.g. geographical, commodity handling or the nature of ports). For instance, while the global rise in sea level is widely recognised as a threat, there are still certain parts of the world (e.g. Scandinavia and Alaska) where the sea level is, in fact, dropping (Pilkey and Young, 2009). This is attributed to the isotactic rebound effect and the sea level may therefore not necessarily present any risk or may present a totally different type of risk associated with the dropping of the sea level. Hence, a holistic approach to the climate change risk assessment and adaptation process is needed.

## 4.3 Technology

There are three strategies to make physical infrastructure resilient to climate change: retreat, accommodate and protect.

Site-specific investigations are required to select the best practice. As a general rule, the review of infrastructure design codes to include climate change variables and improve construction techniques is essential if one wants to guarantee the resilience of the infrastructure. Constant trade-offs between conservative design and costs remain a matter of great concern in the industry. The need for a guideline that will provide a framework of possible interventions required at technological, management and policy levels has proven to be essential in the industry in order to maintain consistency and reliability.

## 4.4 Management practices (policy and management)

An important element in climate change adaptation is the appetite of risk, which remains vastly subjective and often has fatal consequences. Climate change risks have the potential to generate broad social externalities that the private sector may not always fully take into account. In the absence of legislative or regulatory intervention, companies in the private sector may be prepared to live with a level of climate change risk that is unacceptable to the society in which they operate (PricewaterhouseCoopers, 2010). As such, defined acceptable risk within the framework of port infrastructure operation is critical during policy development.

It has been found that regulators face two key difficulties (National Planning Commission, 2011). Firstly, because regulators are responsible for ensuring that consumers have access to reliable and quality infrastructure, they are required to play a proactive role in guaranteeing that infrastructure consistently promotes adequate levels of investment. Secondly, because infrastructure investments tend to be capital-intensive and require large chunks of investment, there is a need for economically viable pricing levels.

At the heart of this 'policy' category will be discussions of six generic risk treatment classifications in accordance with the AS/NZS ISO 31000[2] Standard lists (RMIT University, 2013b):

- Avoiding the risk
- Accepting the risk
- Removing the source of the risk
- Changing the likelihood of the risk
- Changing the consequences of the risk
- Retaining the risk

There are three fundamental tools that management may use to prioritise adaptation options:

- Cost-benefit analysis
- Multi-criteria analysis
- Cost-effectiveness analysis

2 AS/NZS ISO 31000: ISO 31000 is a family of standards relating to risk management codified by the International Organisation for Standardisation. The joint Australian/New Zealand Standards (AS/NZS) was reviewed with the focus on international standards to form the AS/NZS ISO 31000 in 2009. Significant changes achieved with AS/NZS ISO 31000 include a change to the definition of risk, the introduction of eleven principles for the management of risk, five attributes of an enhanced risk management framework and a recommended approach to developing an enterprise-wide risk management framework (Australian Government, 2010).

The cost-benefit analysis consists of an assessment of the costs of each decision against its benefits and an evaluation of whether the benefits outweigh the costs. In South Africa, during the decision-making process, the benefits of port infrastructure investments are traditionally evaluated in the port-controlled environment. Yet, the maritime industry generates far broader spin-off benefits at local and regional levels than ports are currently able to quantify. This is partly attributed to the emergence of an informal economy that is very difficult to control and regulate.

The multi-criteria analysis explicitly considers multiple criteria in the decision-making process and has proved to be effective for complex assessment. According to Taneja (2013), port development needs to be based on a balanced view of numerous rationalities. It needs to ensure economic development (return on investment), social progress (employment) and the protection of the environment (viable territory). Climate variability has now proven to be an essential component to be factored in at an early stage of port development in order to maximise return on investment, secure employment and ensure environmental protection. In addition, the traditional approach to assessing an infrastructure development project on cost, time and quality is progressively phasing out as ports now face an increasingly heterogeneous stakeholder group with divergent perceptions, values and interests. Management is therefore compelled to place additional emphasis on soft issues associated with corporate social investment, stakeholder satisfaction, ethical and legal acceptability, flexibility and long-term sustainability.

The decision to cater for and prioritise adaptation features during infrastructure development will principally be informed by risk severity assessments. However, when assessing adaptation options, management must take cognisance of additional essential factors, such as effectiveness, efficiency, equitability, costs, co-benefits and the danger of maladaptation. Furthermore, management may consider categorising options according to whether the decision outcome offers any of the following: no regrets, low regrets, win-win, once-off adaptation or flexible adaptive management.

The cost-effectiveness analysis consists of a comparison of the relative costs of a decision or actions and its outcomes in order to evaluate the effectiveness of such an action. Like the cost-benefit analysis, it is very difficult to estimate with precision the outcome effects of a port investment considering the complex nature of the maritime industry, which often generates a lot of externalities that are difficult to quantify.

It is therefore paramount to strengthen governance mechanisms to reduce the risk of corruption and make climate change initiatives more effective and successful. Central to this process will be the recognition that responding to climate change is not a constraint, but rather an essential underpinning of infrastructure development (Transparency International, 2011).

## Conclusion

The complex nature of climate change risks present major difficulties in developing a one-size-fits-all solution for port infrastructure adaptation, considering that exposure to climate change risks differs substantially between geographical locations, the nature and the strategic objectives of ports. As port infrastructure is defined as a complex interactive system, the traditional adaptive approach based on linear risk assessment is inappropriate. In many instances, adaptation is left to the individual prerogatives of engineers or line management. A need for complex non-linear tools to assess the severity of risk and develop a holistic three-tier (policy-management-technology) port infrastructure adaptation framework is essential to minimise subjectivity and ensure reliability, accuracy and consistency throughout the port system globally.

Unfortunately, no provision is made in the maritime industry for a port-wide approach or methodology to assess and incorporate risks at present. However, there appears to be adequate scientific and technical data available in the industry to allow design engineers to assess climate risks to port infrastructure and to incorporate adaptation measures into the design of port development. It remains the primary responsibility of design engineers to properly evaluate this and incorporate these risks into design parameters, making such critical decisions an individual prerogative.

Furthermore, many authors suggest that, despite awareness raised with regard to risks posed on port infrastructure by climate change, there is a persistent trend towards adaptation decisions that are still driven by affordability rather than risk. This could easily be attributed to a lack of reliable tools that will serve to sensitise, quantify and highlight the cost of risk, which in many cases is far greater than the cost of adaptation. Many ports have, in some instances, opted for 'affordable' adaptation, but again, there are no studies that have highlighted the cost of maladaptation, which may sometimes be far greater than the cost of proper adaptation. On the other hand, in the modern risk society where there is a rising tide of cultural anxiety towards risk, Mythen (2004) warns society of the danger of becoming less concerned with 'social goods' and more concerned with 'social bads'.

An important element regarding the necessity of adapting port infrastructure to climate change remains the fact that non-adaptation has proven to be more ineffective and costly to ports and to the maritime industry in general in the long term. This is the result of the increased occurrence of a maintenance regime that will translate into a rise in port fees and ultimately impact on the cost of seaborne transportation at some point.

Nonetheless, it is largely recognised that port infrastructure adaptation to climate change is compelling. Becker et al. (2011) conclude that planning for climate change demands a rethinking of a variety of paradigms: impacts will occur beyond the infrastructure design life and beyond the length of the average port administrator's career. Furthermore, the World Association for Waterborne Transport Infrastructure established that portfolio management of adaptation and mitigation options are useful in prioritising investment strategies to encourage sustainable development (Stocker et al., 2013).

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# Chapter 14 Maritime Technology Support to the South African Navy

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## 1. Introduction

The Institute for Maritime Technology (IMT) is a division of Armscor, which is a state-owned organisation. The Institute is a multidisciplinary organisation that specialises in techno-military research and development, as well as specialised products and services.

The organisation provides science, engineering and technology assistance to the South African National Defence Force (SANDF) in support of its national maritime security role. It is conveniently situated in Simonstown, alongside its primary client, the South African Navy (SAN).

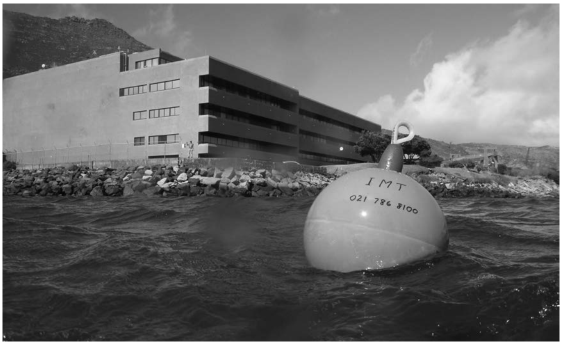



***Plate 1:*** *Aerial and side views of IMT in Simonstown.*

While providing technological guidance and support to the SAN, the organisation also strives to conduct research in support of the SANDF's maritime operational requirements. It strives to be a national resource for development and a maritime technology centre of excellence. This unique home-grown capability helps the SAN to patrol, watch and care for South Africa's sea routes and Exclusive Economic Zone (EEZ). The tasks are divided into the following seven focus areas or domains: Underwater Security (USEC), Naval Systems Subsurface (NSS), Naval Systems Above-water (NSAW) (surface warfare), Underwater Sensors and Signatures (UWSS), Above-water Sensors and Signatures (AWSS), Environmental Characterisation (ENCH) and Maritime Decision Support (MDS). Each of these focus areas is discussed in the following sections of this chapter.

IMT's facilities include the following:

- Two large indoor acoustics tanks (for underwater sensor testing and experimental trials)
- Underwater acoustic and magnetic measurement facilities (for measuring and managing underwater ship signatures)
- Radar and infrared evaluation facilities (for above-water sensing and surveillance trials and tests)
- Small survey vessels (for sea trials)
- Mechanical and electronic workshops (to develop test equipment as required)
- Geographic Information System (GIS) instruments for spatial data management and decision-making purposes

A scientific seagoing and small dive team supports underwater work, such as underwater installation inspections, experiments, cabling, instrument deployments and sampling.


***Plate 2:*** *IMT's technology research vessel.*

## 2. Underwater Security

Protection against underwater threats is one of the SA Navy's important functions. During peaceful times, this ensures unhindered legitimate maritime traffic, while countering illegitimate activities. In times of war, it ensures the free movement of naval vessels and allows the supply of materials and goods. These inshore activities are grouped as underwater security and include mine warfare (the use and countering of sea mines) and underwater waterside security (protection of vessels and infrastructure). Since its establishment over 30 years ago, IMT has provided the SA Navy with scientific and technical support in these areas.

Knowledge and technologies are maintained through a structured approach, which is based on three central areas of expertise: sea mines, mine countermeasures and underwater waterside security. Together with their related higher and lower system levels, they are represented in Figure 1. Associated capability areas are shown alongside the structure in the figure. Activity areas are determined by close interaction with the SAN representatives through a managed process. Examples that demonstrate some of the technology capabilities in the domain are given below.

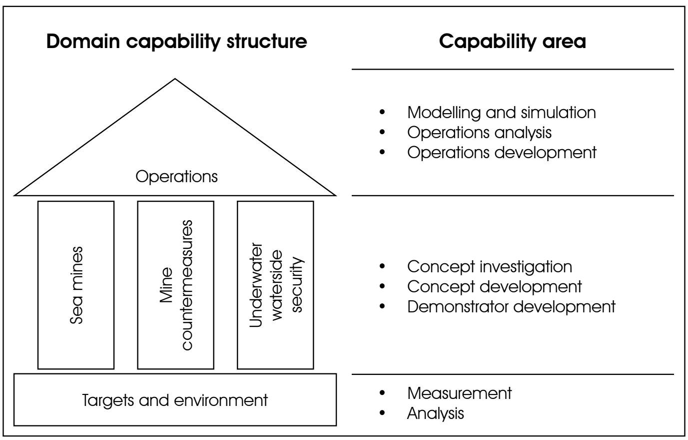



***Figure 1:*** *USEC domain capability structure and areas.*

## 2.1 Modelling and simulation

Extensive emphasis has been placed on building a capability that makes it possible to model and simulate the operational processes that are required in different application areas of underwater security. One such example is the optimisation of safe routes through mapped minefields, as well as the optimised removal of mines to ensure safe passage. Processes such as evolutionary optimisation and route optimisation algorithms are used. A fictitious example of route optimisation, which considers sea mines and environmental risks, is shown in Figure 2. Other modelling applications concentrate more on operational issues, such as the interaction between sea mines and ships, and the investigation of the operational implications of using autonomous underwater vehicles (AUVs) for mine detection and classification, a trend that is becoming more accepted internationally.

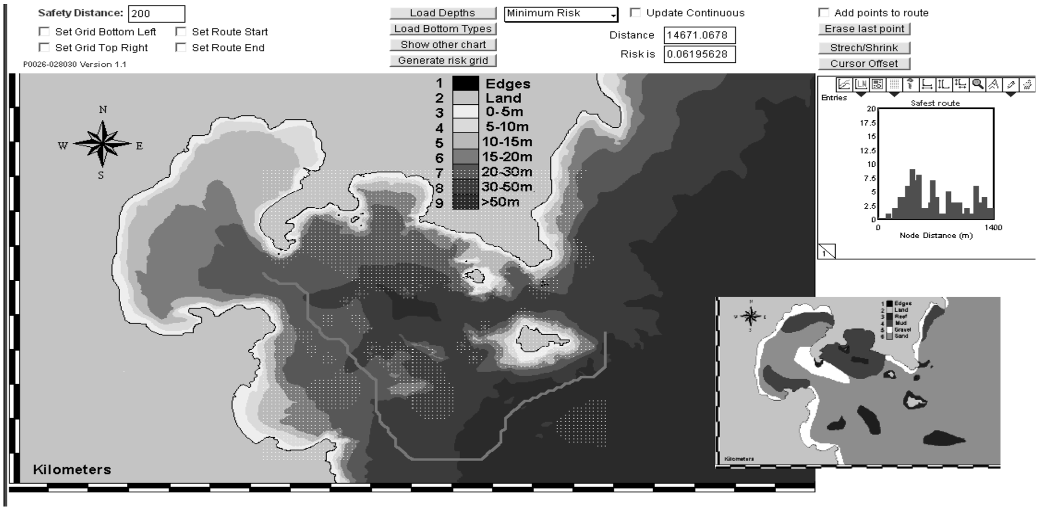
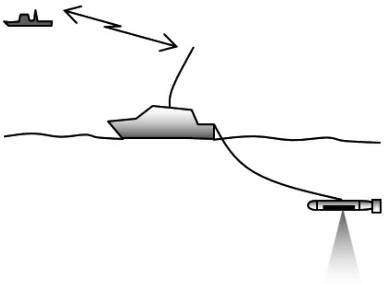



***Figure 2:*** *Route optimisation through a shallow-water minefield. [See colour figure on page 315.]*

## 2.2 Concept development

Countering sea mines with conventional methods holds risks for personnel who operate in the minefield. Consequently, IMT started developing a mine-hunting system that can be remotely operated from a surface craft, with all survey information available to the shore or a mother ship. With these capabilities, sea mines can be detected and classified from a safe distance, so that they can be avoided or destroyed. IMT has developed a demonstrator controllable vehicle that is towed underwater to perform side-scan sonar surveys to detect mines. This forms part of an ongoing development path leading to a remote mine-hunting demonstrator.



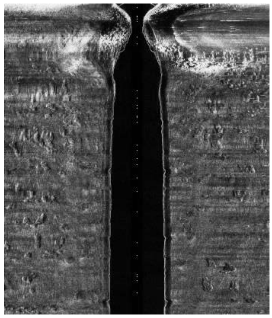


***Figure 3:*** *Conceptual system schematic.*

***Plate 3:*** *IMT towed vehicle.*

***Plate 4:*** *Seafloor sonar image.*

It is essential that the SA Navy maintains a capability to exercise with sea mines so that it has a better understanding of the threat posed by such weapons. This knowledge can be used to counter sea mines and understand the deployment of such systems, should the tactical need arise. To assist with this, IMT has developed a sea mine technology demonstrator. This exercise mine system is used for sea trials to build knowledge and understanding in IMT and the SA Navy. An example of this hardware is shown in Plate 5. These exercises allow the SA Navy to investigate how mine settings and surface ship signatures interact to result in mine actuations that could cause damage to ships. These systems contain no explosives, but record target data and mine reactions to target influences for later analysis.


***Plate 5:*** *IMT-developed exercise-mine demonstrators.*

## 3. Naval Systems Subsurface

The NSS domain focuses on the application of technology for submarine warfare and underwater naval systems. This technology assists the SAN in maintaining the security of our maritime domain. Weapon and countermeasure systems, communication systems, and escape and rescue systems are the primary areas of submarine system expertise. A range of autonomous and tethered underwater vehicles are deployed as platforms for the evaluation of underwater technologies.

## 3.1 Submarine system expertise

A modelling environment, which includes a SAN submarine with its sensor systems, weapons systems and countermeasures, was developed. The primary use of the model is to simulate a torpedo attack on the submarine to evaluate the submarine's countermeasure tactics. This has resulted in improved offensive and defensive tactics. The SAN has received assistance in the form of evaluation of and specialist maintenance on torpedo systems for the last 20 years. This includes the re-engineering of electronic units and the development of test equipment. IMT has also assisted with the integration and operation of the torpedo countermeasure system onboard submarines to defend the submarine against attacking torpedoes. This includes building an evaluation launch facility and test equipment, as well as a practice round for system evaluation.

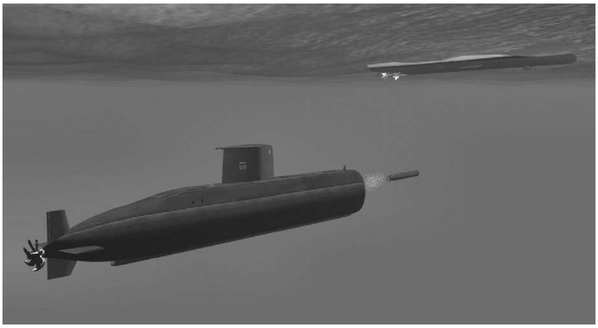


***Figure 4:*** *Torpedo tactics.*

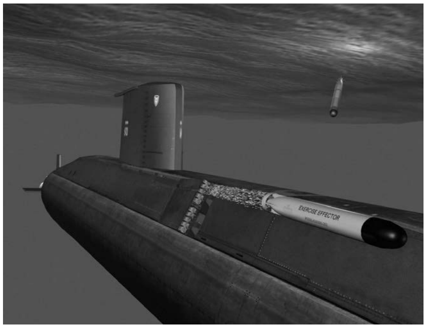


***Figure 5:*** *Torpedo countermeasures.*

Through its Submarine System Technology Support (SSTS) programme, IMT is continuously developing new technology to assist the SAN's submarine flotilla to improve the operational capability. This includes the enhancement of the communications capability of a submersed submarine. For this, IMT developed a submarine-deployable communications device, where a communications buoy is deployed en route. On reaching the surface, an above-water communications link is established to a land-based command centre via satellite. This creates a quasi-underwater telephone.

***Plate 6:*** *Low-frequency radio transmitter.*

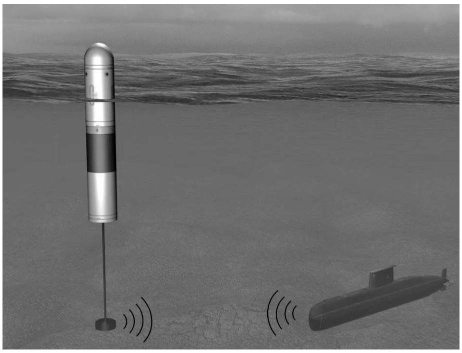


***Figure 6:*** *Communications buoy.*

New technology developmental examples include a land-based low-frequency submarine communications system that operates at periscope depth, as well as a portable waterproof submarine navigation display that is linked to the ship's combat system via Wi-Fi.

In an effort to improve the safety of the personnel aboard a submarine, special technologies for escape and rescue operations have been developed for the SAN's submarines. This includes the evaluation of air-quality monitoring equipment and new technology escape suits. This equipment is vital for rescuing the crew from a bottomed submarine.

***Plate 7:*** *Submarine navigation display.*

***Plate 8:*** *Submarine escape and rescue.*

### 3.2 Underwater vehicles

A range of autonomous and tethered underwater vehicle platforms for the evaluation of underwater technologies and naval tactics is employed. This includes an AUV with payload options for evaluation purposes, which was developed in-house, as well as a remotely operated vehicle (ROV).


***Plate 9:*** *Remotely operated vehicle.*


***Plate 10:*** *Autonomous underwater vehicle.*

These were developed to illustrate the use of technologies, such as ethernet cameras and real-time video processing. Such ROVs can be used for ship-hull security applications. An ROV can automatically scan the hull for defects or limpet mines, while a ship is docked in a foreign harbour, and makes a dive team on the ship redundant.

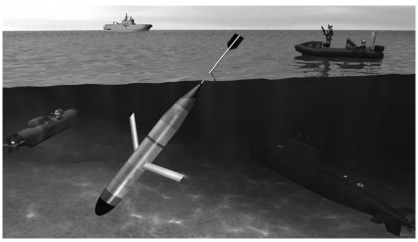


***Figure 7:*** *Underwater glider.*

A small research ocean glider was developed to investigate military applications for this technology, such as patrol perimeter surveillance. A glider can patrol a large area of the ocean and stay at sea for a few weeks at a time, only surfacing to report back via a satellite link. This makes it ideal for patrol areas where ships cannot be stationed for long periods.

## 4. Surface warfare

The unique nature of modern surface warfare, the combatants and the wide range of evolving technologies that need to be integrated constitute important aspects of a relevant field of expertise.

The NSAW domain focuses on the technological insight that will allow the SAN to fully exploit the potential of its surface warfare systems. The multidimensional complexity of maritime warfare, where surface assets may face threats from land, sea (underwater and on the surface), air, space and the cyber domain, is recognised.

In recent years, navies around the world have had to adapt to accommodate littoral[1] and asymmetric[2] threats, in addition to the classic 'blue water' threats. Littoral and asymmetric threats include terrorism, piracy, trafficking, smuggling and poaching. In support of this additional responsibility, the SAN must have asymmetric defence capabilities, as well as a maritime domain awareness (MDA) profile, which means persistent surveillance of the South African coastline.

The domain's overall strategic focus is to develop the expertise, tools and facilities to support the SAN's present and future requirements in above-water naval systems. This includes demonstrating new technologies to the SAN, feasibility studies for system upgrades, investigating problems and providing systems engineering support.

***Figure 8:*** *Sources of an integrated maritime picture.*

Current domain activity is primarily aimed at assisting the SAN with the following:

- Developing an integrated maritime picture (IMP) (both regional and expeditionary)
- Requirement formulation for upgrades or new acquisitions
- Improving combat system efficiency
- Developing countermeasures and tactics against air and submarine threats for the surface combatants

1 In oceanography and marine biology, the idea of the Littoral Zone is extended roughly to the edge of the continental shelf.

2 An asymmetric attack is an attack between belligerents whose relative power, or strategy or tactics, differs significantly. Put simply, asymmetric threats or techniques are versions of not 'fighting fair'. This can include the use of surprise in all its operational and strategic dimensions, and the use of weapons in ways unplanned by the opponent.

- Improving the distribution and communication of operational data
- Addressing issues of interoperability
- Researching concepts relevant to naval command and control


***Plate 11:*** *Surface-to-air missile trials.*

Many of the above activities also have a wider application in marine and maritime safety. The IMP is vital for various government organisations, such as the South African Police Service (SAPS), South African Customs, the National Sea Rescue Institute (NSRI), Marine and Coastal Management (MCM), and the South African Maritime Safety Association (SAMSA). These organisations perform functions such as anti-trafficking, anti-smuggling, anti-poaching, search and rescue, and vessel safety monitoring.

The domain can provide the following services:

- Translation of operational and user requirements into system design requirements and specifications. This requires a sound understanding of and insight in the performance and design of surveillance sensors, tracking systems, electronic warfare systems, naval weapon systems, navigation systems, communications systems and combat system integration.
- Analyses, developmental and operational tests and evaluations.
- Trade-off analyses, the identification of conceptual solutions, and making scientific and technological recommendations. This is supported by a thorough systems engineering capability with integration knowledge and insight.
- Engineering support to combat systems acquisitions or upgrades. This is supported by experience in the acquisition and management of complex military systems and, in particular, naval systems.

- Development of conceptual solutions and managing the research and development effort to provide such solutions.
- Simulation of surface combatant effectiveness utilising the Ship Air Defence Model (SADM). This is supported by experience in the development and use of performance prediction models, simulations and mathematical techniques to evaluate complex problems. This mainly applies to offensive and defensive warfare simulations, but can be applied to find the best sites for coastal radar systems that monitor shipping lanes.

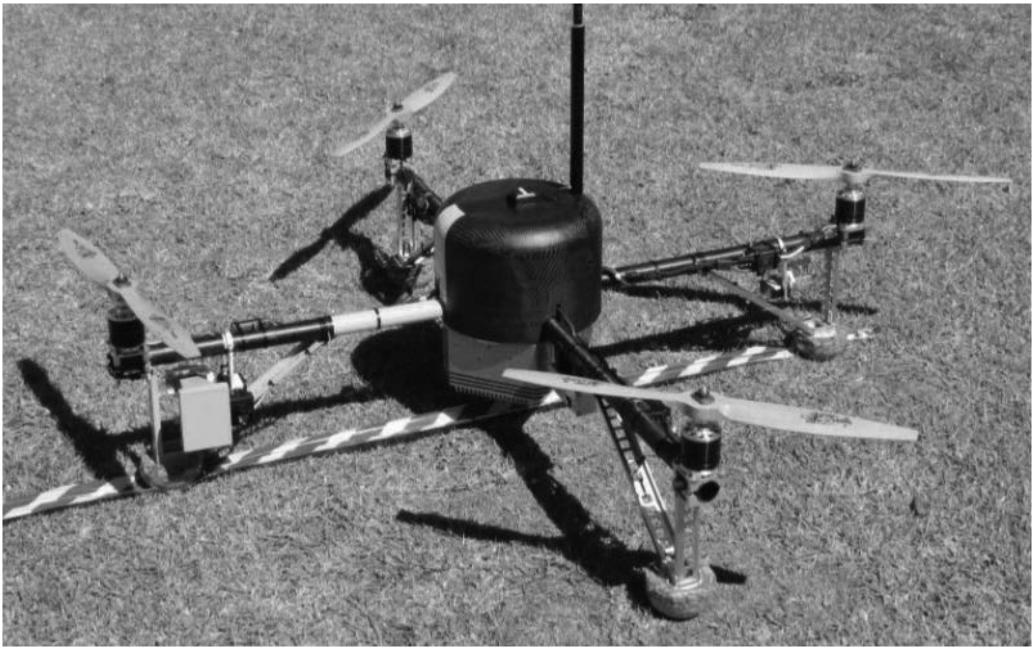


***Plate 12:*** *Active off-board decoy technology demonstrator.*

In order to provide the above-water naval systems services, the NSAW domain maintains the following facilities:

- Maritime Domain Awareness Test and Evaluation (MDATE): The MDATE is a facility that has the necessary secure information and communications technology (ICT) infrastructure to be utilised for the development of conceptual solutions for naval situational awareness, and command-and-control challenges. Although mainly a naval initiative, inputs from other government organisations, as well as the civilian maritime industry, are welcomed to provide a coherent maritime picture of the South African coastline.
- Modelling and simulation: This entails a naval systems modelling and simulation facility based on the SADM, among others. It allows complex simulations of system performance, which can either drive out system requirements or aid the development of doctrine for tactical and operational applications. As mentioned, the primary aim is to evaluate naval vessels' offensive and defensive warfare effectiveness.
- Littoral Detection Evaluation System (LDES): This is a transportable test-and-evaluation laboratory with various sensors to evaluate coastal surveillance in the MDA role. The system can be easily deployed to aid naval, governmental or marine industry surveillance exercises or operations.

***Plate 13:*** *The LDES and associated deployable power source.*

***Plate 14:*** *Evaluation of equipment on IMT's roof.*

- Maritime Microwave Test and Evaluation Facility (MARMITE): This facility is being developed. It will be a microwave testing and evaluation facility in support of the SAN to evaluate the effectiveness of a number of techniques. These techniques include electronic warfare techniques (e.g. chaff, jamming, decoys and stealth), radar waveforms, communication waveforms, equipment being developed by original equipment manufacturers (OEMs), and integration with other combat systems elements, such as command-and-control systems. IMT's location is ideal for maritime trials and the roof has been used for a number of successful trials of military equipment, as well as marine industry equipment, such as communication equipment, radars and searchlights.

## 5. Above-water Sensor and Signatures

The long-term goal of the AWSS domain is the maintenance and development of IMT's capability to exploit electro-optic, radar and radio wavelengths. This exploitation could ensure a winning advantage or force multiplier for the SAN in its above-water operations (not excluding underwater operations). The development of these technologies implies an advanced scientific understanding of detection, signatures and performance of sensing systems above and under water. The development of electro-optic and radar technologies requires a sound practical knowledge of how to apply scientific knowledge to improve operational systems onboard the SAN vessels (e.g. surveillance, tracking, communication, data capture and display systems). Lower-level key capabilities include platform signature measurement and simulation, vulnerability and survivability modelling (against likely threats), sensor testing and evaluation/modelling/simulation, and technology demonstrator development.

The vehicle to achieve this long-term goal is IMT's respective test and evaluation facilities in the three technology areas that are currently included in this domain: naval electro-optics (including infrared and lasers), naval radar/electronic warfare (EW) and naval communications.

Electro-optic technology support to the SAN includes testing and evaluating new sensor and laser systems, the infrared signature management of ships, and predicting the ship's vulnerability and survivability against the most likely threats (e.g. missiles). This technology support also includes the development of technology demonstrators, for example, improving situational awareness (also called the 'maritime picture' or MDA). This support enables the SAN to make sound decisions in terms of sensor selection for new platforms, develop optimised tactics against likely threats, improve the ship's situational awareness and survivability, and improve the performance of sensor systems currently in operation. Examples of the testing and evaluation of laser systems (communication and dazzler systems), technology demonstrators for harbour surveillance and panoramic thermal infrared systems are shown in Plate 15, Plate 16 and Plate 17.

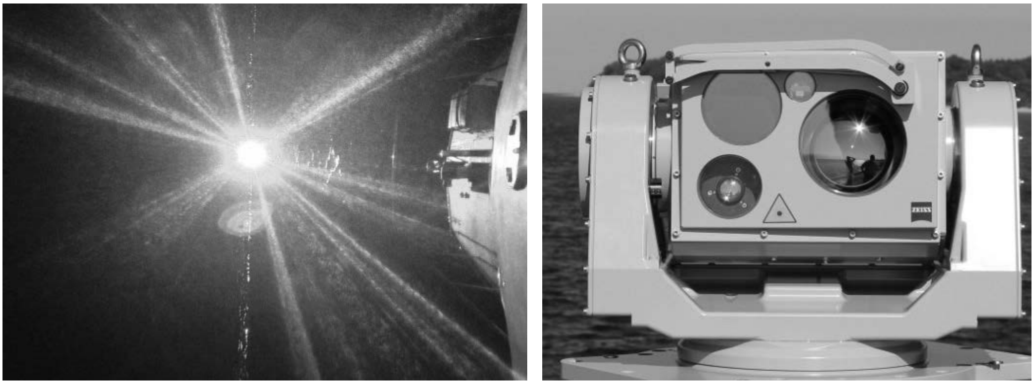


***Plate 15:*** *Laser dazzler and communication systems trials.*

***Plate 16:*** *Technology demonstrator – Harbour Surveillance System.*


***Plate 17:*** *Panoramic Infrared System.*

Naval Communications Technology Support builds expertise in radio frequency (RF) communications technology applicable to the maritime defence sector. It is also a potential technology partner of the SAN and the defence industry with respect to future maritime systems. This support is mainly to provide a test facility against which systems and technology can be evaluated, and where new techniques and system technology can be evaluated to define future systems, develop tactical data-link technology and build expertise in the field of RF design and digital signal processing. One focus area is high-frequency (HF) communications, since it is used for strategic command and control in the naval environment. This focused effort involves research into and the testing of HF antennas, signal processing and waveforms. Examples of communication support to the SAN involving the improved management of secure communication protocols are shown in Plate 18 and Plate 19.

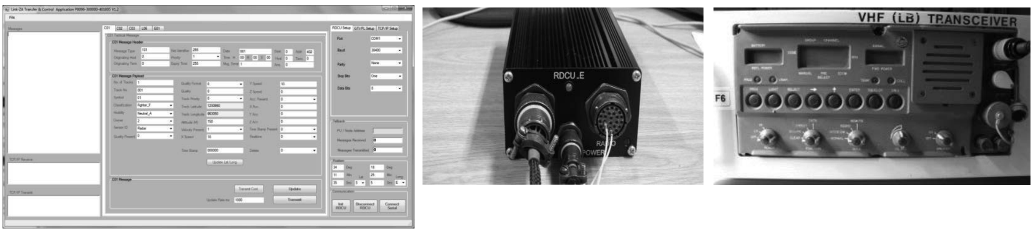



***Plate 18:*** *Tactical radio data communications components.*

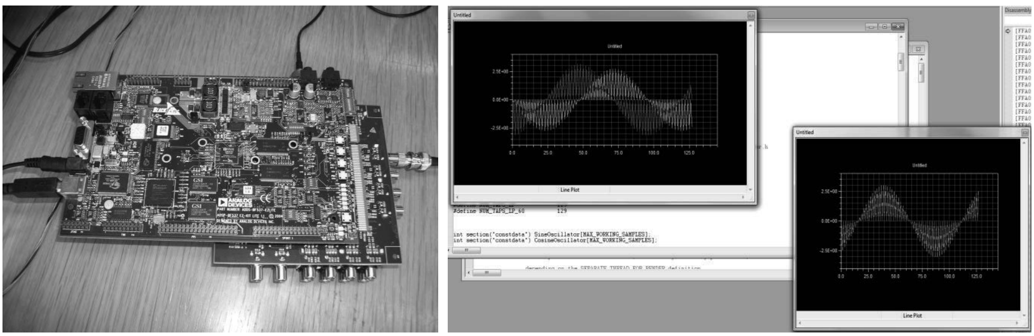



***Plate 19:*** *Real-time signal processing.*

Radar and electronic warfare support for the SAN includes operational testing and evaluation, RF signature measurement/management of ships (radar cross-section), the development of onboard data capture, display and monitoring demonstrator systems, the development of coastal radar network systems and the development of radar data extraction hardware, (e.g. peripheral component interface (PCI) bus boards). This support allows the SAN to have better knowledge of the accuracy of weapon systems, the radar signature vulnerability of their ships, the status and maintenance of critical subsystems (e.g. submarine batteries), optimised tactical data display (e.g. valour-class frigates) and the maritime coastal picture (the monitoring of ship movement around the coast). One utility example is shown in Plate 20, in this case involving the development of a helicopter landing aid display. This display gives the helicopter pilot a real-time view of the ship's roll, pitch and heave to enable informed decision-making about the probability of a safe landing on the ship's deck.

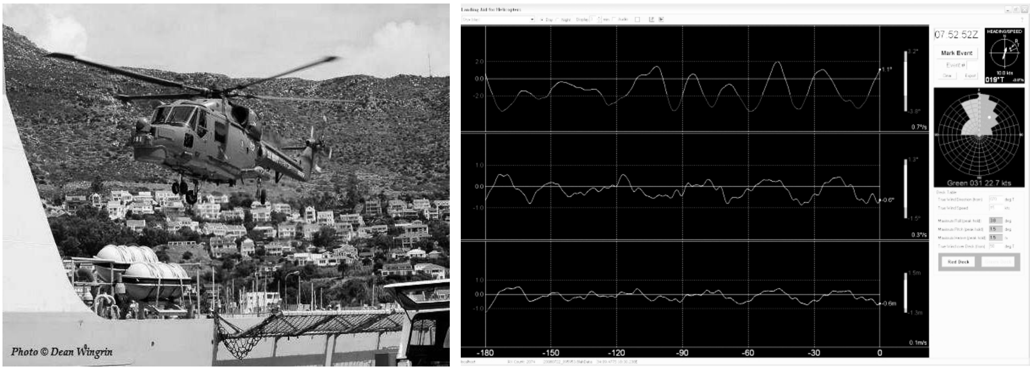



***Plate 20:*** *Helicopter landing aid display.*

## 6. Underwater Sensors and Signatures

The UWSS domain develops and maintains strategic capabilities and facilities in the underwater domain. The primary focus is on underwater acoustics, sonar, magnetic and electric fields with the aim of detecting, analysing and interpreting underwater signals.

A transducer testing and calibration facility provides a support service to the SAN and the maritime community. Expertise and systems include the ability to package and develop underwater sensors. A number of ocean-deployed and portable systems were developed in this capability area, (e.g. a water-bug sonar-listening facility, a multisensor facility and sonar targets). This ocean-sensing equipment is considered a key facility in the measurement and characterisation of underwater signals. The expertise and facilities are used to evaluate and support maintenance of the SAN's vessel acoustic signatures, as well as underwater sensors, such as sonar and underwater telephones for the SAN. These underwater sensors assist with the SAN's survivability at sea.

***Plate 21:*** *Transducer testing and calibration facility.*

Two large water tanks (2.5 million litres and 0.28 million litres respectively) are suitable for underwater transducer and sonar array calibration and acceptance, as well as for general testing of a variety of underwater systems. A sonar model was locally developed and verified to predict sonar performance modelling in the highly variable underwater environment. This is a critical tool to understand sonar propagation phenomena and to assist sonar users with tactical decisions.

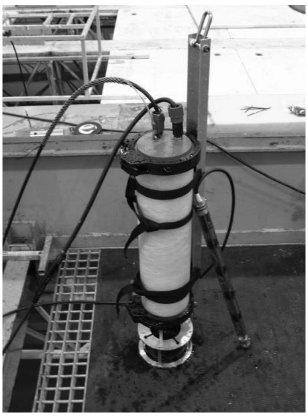


***Plate 22:*** *A sonar transponder target.*

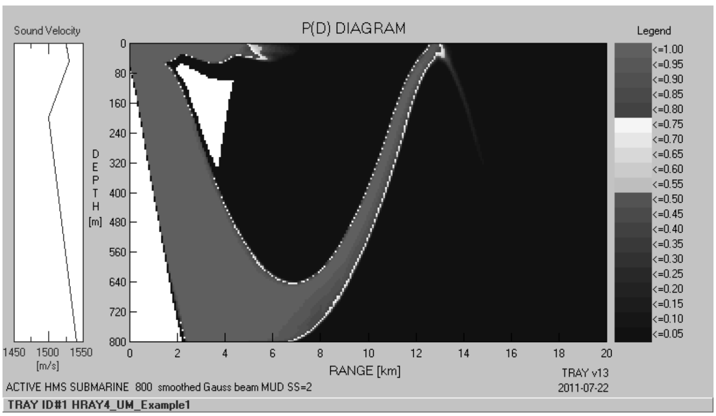



***Figure 9:*** *Sonar modelling developed with at-sea verification. [See colour figure on page 315.]*

A number of specialised underwater subject handbooks were developed to support the ongoing training of the SAN personnel ashore and at sea.

Sonar target noise diagnostic tools are developed and applied to signature management, as well as target classification. It is also used for the identification of signature faults or characteristic signature features. Improved computer-assisted sonar target classification expertise to assist submarine operations is being developed. Sonar target classification is a critical component of safe submarine operations, especially when diving and resurfacing. Sonar classification libraries are continually built up to improve the success of sonar target classification.

***Plate 23:*** *Technology transfer to the SAN.*

***Plate 24:*** *A permanently deployed hydrophone.*

## 7. Environmental Characterisation (naval metocean sciences)

The ENCH domain focuses on the characterisation of the natural marine and freshwater environment. This includes the areas both above and below the ocean, from the deep sea to the coastal and inland area, as well as navigable rivers and lakes where the SAN may operate.

Knowledge and expertise in the geographical, earth and ocean sciences (including climatology and meteorology) are required to provide solutions to practical and theoretical challenges. Some examples include predicting undersea temperature conditions for sonar propagation modelling, understanding changing seafloor conditions at major port approaches, defining sea states for optimal ship design and safe navigation, and characterising the contribution of winds and waves to ambient underwater noise for vessel detection, among others.


***Plate 25:*** *Ocean weather monitoring.*

The domain's overall strategic focus is to maintain and develop specialised, oceanographic-focused scientific capabilities, complemented by software and hardware tools and facilities to support the SAN. This is undertaken towards supporting the SAN's future requirements in the following:

- Hydrography
- Underwater security
- Maritime rapid environmental assessment (MREA)
- Marine-related acquisitions

- Applied oceanographic and atmospheric research (including underwater acoustics, above-water communications and sensors, and ocean health)
- Submarine operations and planning
- Monitoring the health of the ocean

***Plate 26:*** *Water sampling.*

***Plate 27:*** *Seafloor sampling.*

Various stochastic numerical models, such as sea state analysis (for naval acquisitions), seafloor object burial (for protecting port approaches), river outflow estimation (for submarine subsurface operations) and water column temperature structure predictions (for sonar predictions) have been developed.

The provision of these services, facilities and capabilities depends on ongoing capability development in the form of the following:

- The ability to scientifically measure various environmental parameters in a range of diverse environments, on land, above water, underwater, in and on the seafloor
- Scientific experiments or studies that include concept analysis, the interpretation of results and the provision of recommendations
- Advanced data analysis

***Plate 28:*** *Ocean current measurements.*

***Plate 29:*** *Specific seafloor studies.*

- Technical/engineering hardware and instrumentation preparation and usage at sea, including the deployment and recovery of scientific moorings
- Instrument calibrations
- Appreciation and advanced user knowledge of charts, mapping and GIS
- Seagoing and scientific (including underwater) photography and surveying
- 'Home-grown' naval oceanography handbook

***Plate 30:*** *Scientific diver support.*

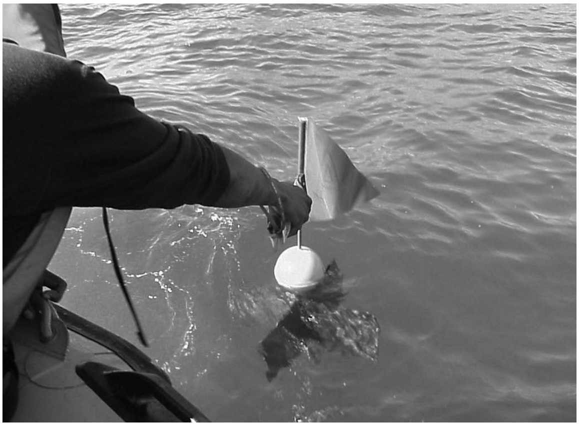


***Plate 31:*** *Drogue tracking.*

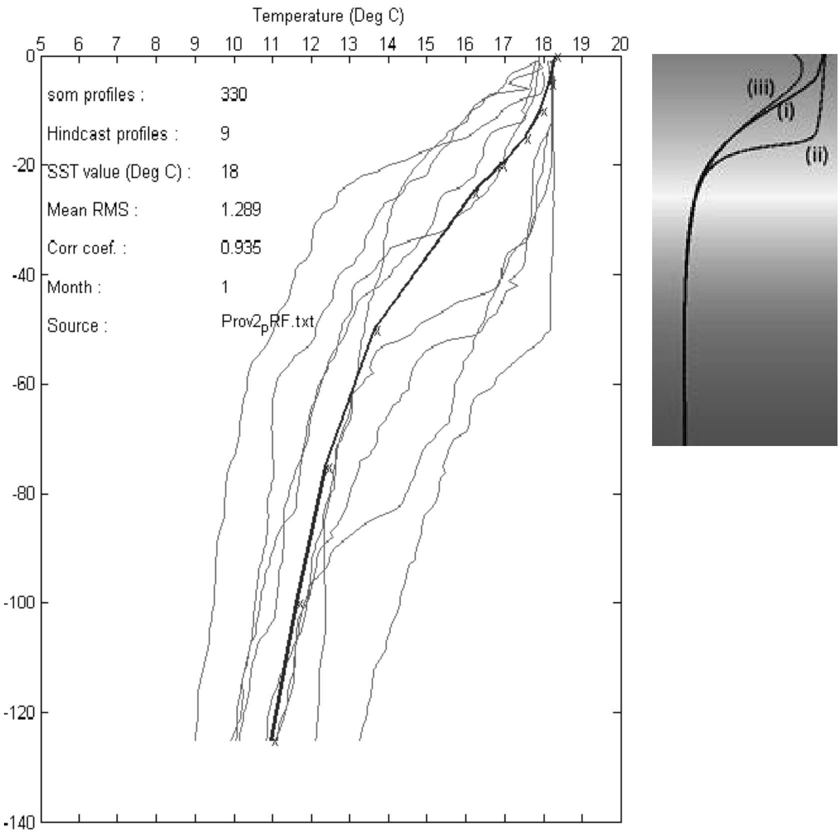



***Figure 10:*** *Temperature profile predictions.*

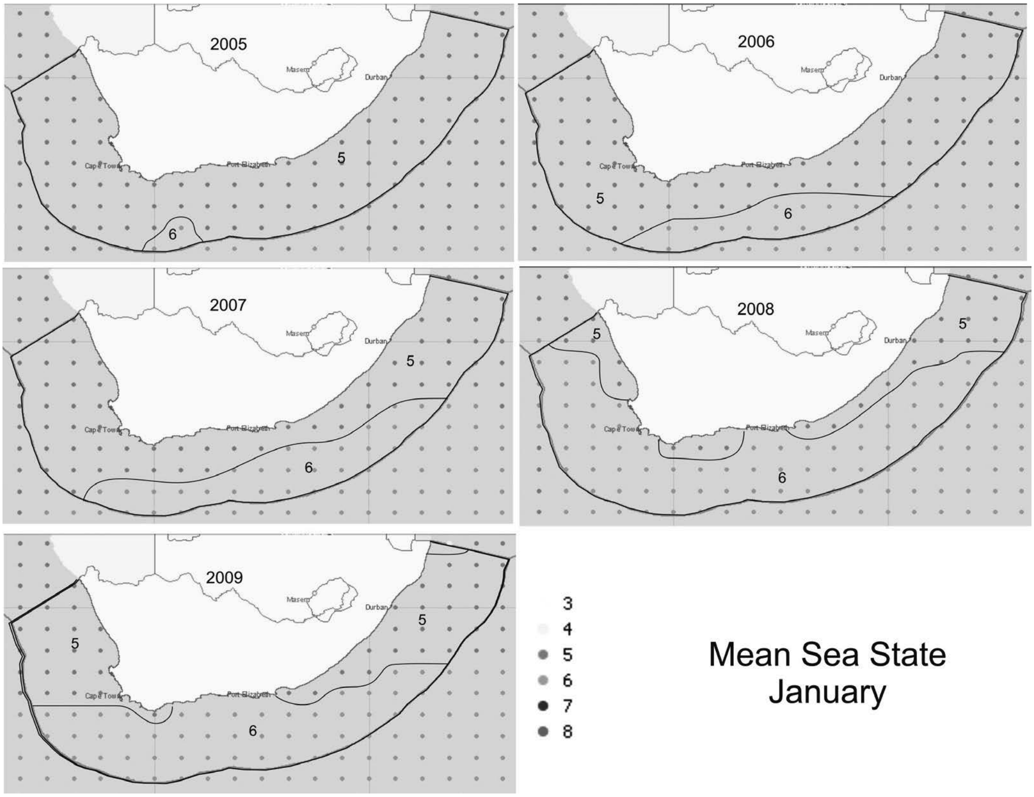



***Figure 11:*** *An analysis of public domain data showing mean sea states in South Africa's mainland EEZ for January for 2005 to 2009. The sea state is the combined effect of wind and waves that produces a so-called fully developed sea, as defined by Pierson and Moskowitz (1964), similar to that used by the World Meteorological Organisation. Values range from 0 to 9, where, for example, a sea state of 6 is considered 'high' and equates to wind speeds of about 22 to 30 knots and wave heights of about 4 m to 6 m.*



***Plate 32:*** *A mobile autonomous weather logger that was developed at IMT.*

Through the electronic integration of sensors and loggers, a ship-based, mobile, self-contained, autonomous weather monitor was developed. Weather parameters en route, such as air temperature, air pressure and wind, are recorded on a regular basis. This has proved successful aboard a number of long cruises, such as the maiden voyage of the *SA Agulhas II* to Gough Island and the Agulhas Current research cruise, a naval voyage from Cape Town to Durban.

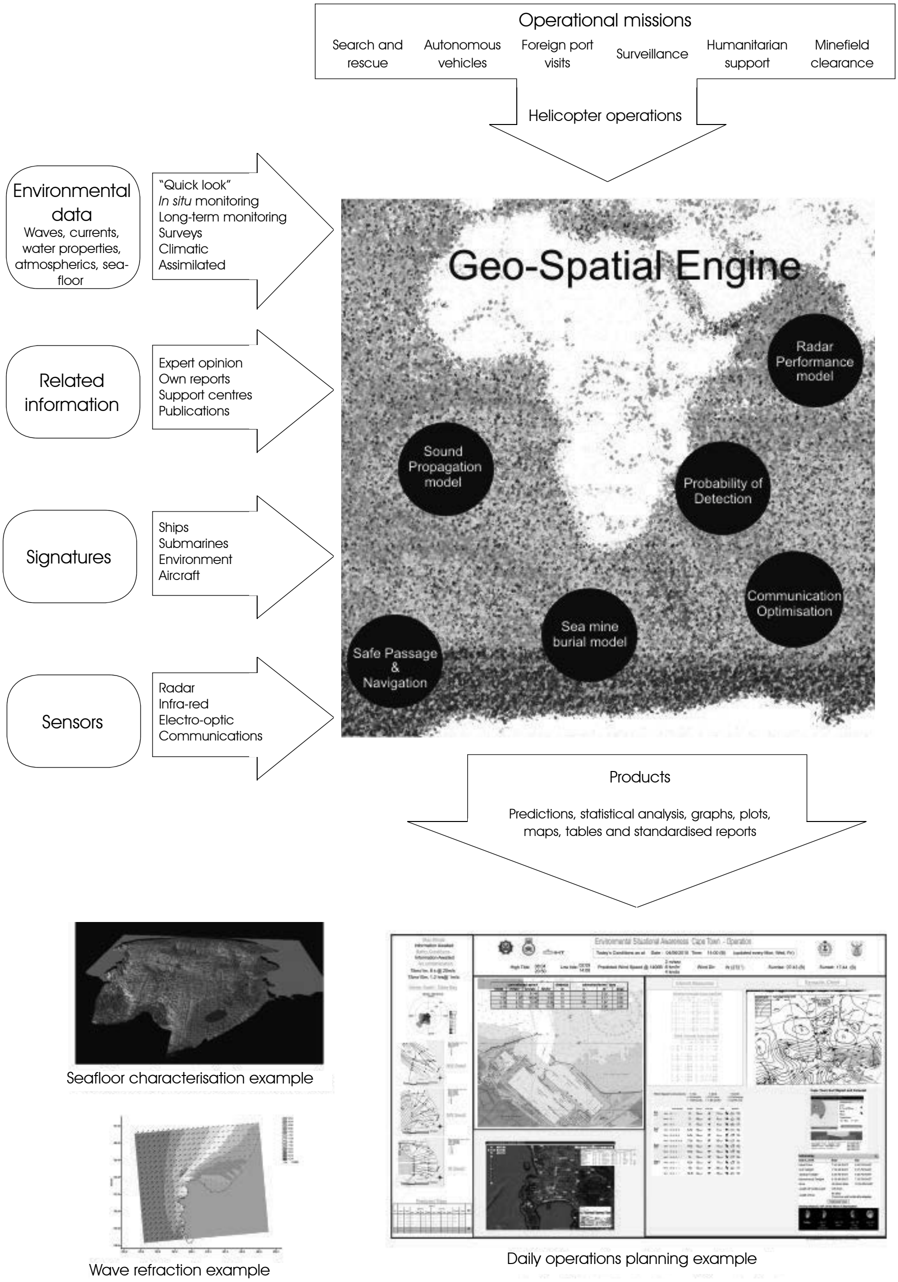



***Figure 12:*** *Maritime rapid assessment: A schematic showing the process flow.*

## 8. Maritime Decision Support

The MDS domain focuses on the maintenance and development of the scientific skills and tools required for the generation and extraction of the insight required for maritime decision-making. This domain analyses and evaluates technological and military progress to distil systemic insight for naval advantage. The domain is currently being reviewed to determine the direction capability development should take and how best to assist the SAN decision-makers to find optimal means of achieving their objectives. The capabilities of this domain play an important role in the technology sectors identified in the South African *National Defence Review* (DRC, 2014). These sectors are IT and data fusion, analysis and evaluation, and modelling and simulation.

Utility to the SAN is given in the following ways:

- The SAN indirectly benefits from auxiliary projects in other domains with specialised functions. Examples of this supporting utility are GIS support to MDA and the development of databases for a variety of projects in the other domains. These projects include infrared thermography, MREA, underwater measurements and an Ocean Information System. This support is represented as the horizontal bar in Figure 13. The other six domains are represented by the narrow vertical columns in this figure: ENCH, USEC, NSSS, UWSS, AWSS and NSAW.
- Utility is added directly to the SAN. Examples of these projects are the development of the content management system for Naval Cooperation and Guidance for Shipping (NCAGS), as well as the development of the Combat Readiness Model as a technology demonstrator. This support is represented as the broad vertical column with the domain abbreviation MDS.
- Data from other domains at IMT are integrated and coordinated. Examples of such projects are the Smart Integrated Database (SID) and the presentation of the theory part of the annual Commanding Officer Qualifier: Part 2 course. This type of support is represented by the overarching horizontal bar at the top of Figure 13.

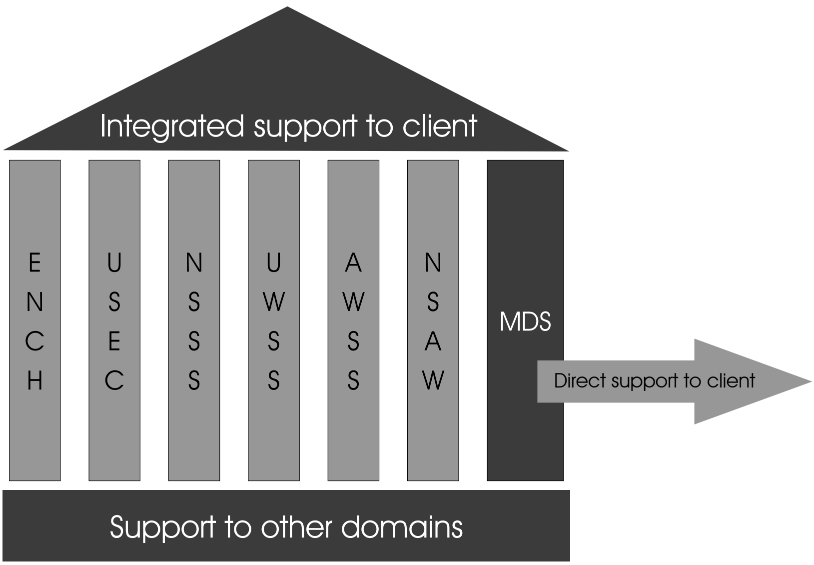



***Figure 13:*** *A summary of the utility given by the MDS domain.*

Utility is also given to all system levels of the SAN (see Figure 14). A process to transfer pure data (D) or measurements to information (I) takes place on each level. Knowledge (K) is created by putting this information into context. Lastly, by personalising this knowledge, insight (I) is created. This transfer process from data to information to knowledge to insight is called the DIKI process. This process takes place on each level of any organisation, also in the marine and maritime safety sector. This process is illustrated on each level by the Systemic Model for Decision Support as shown in Figure 14.

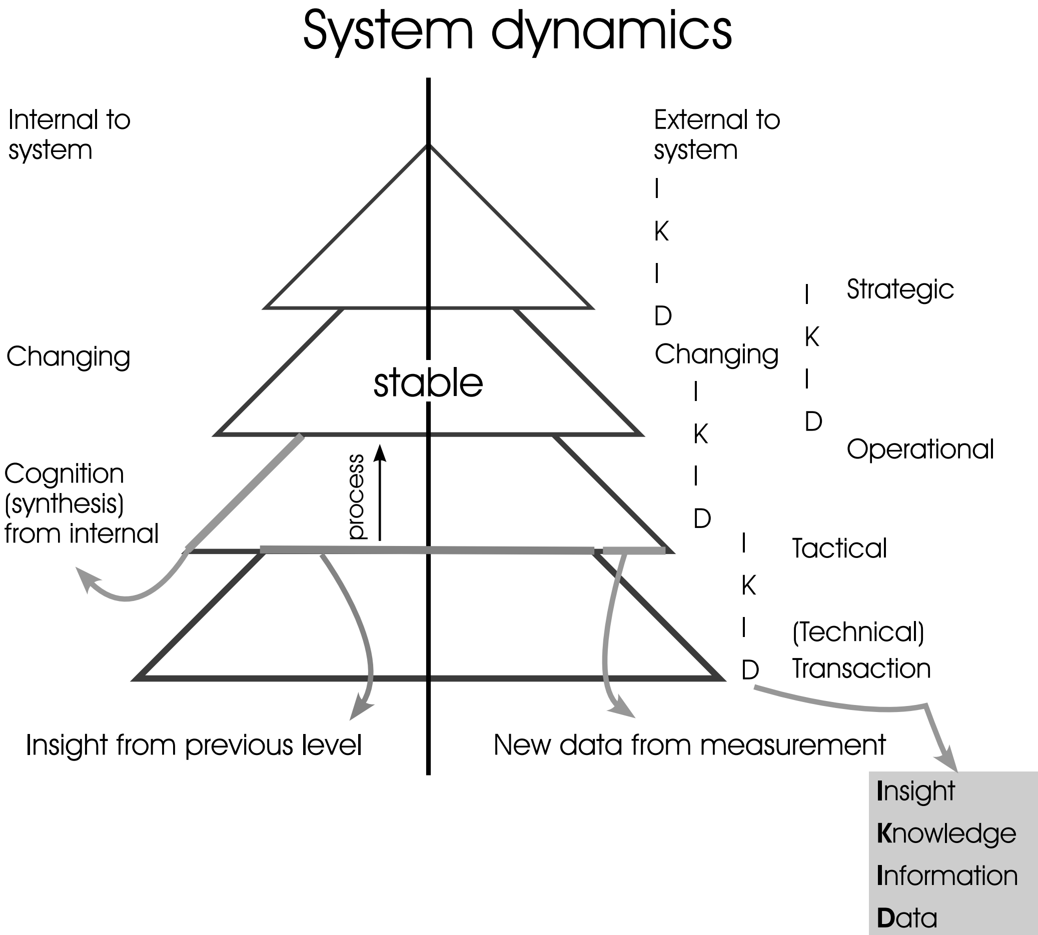



***Figure 14:*** *Systemic Model for Decision Support.*

To be able to provide decision support to all levels in the SAN in all the stages of the DIKI process and in all three ways of delivering utility, several capabilities and expertise are required. Some of these capabilities are fairly mature and include data management and database development, data analysis, geospatial technology, modelling and simulation, and operations research.

New capabilities that are being developed include the investigation of best practices for knowledge transfer to the SAN, which include content management systems and internet website development. The latest technologies to develop web-based e-learning material for knowledge transfer are being investigated to keep the SAN in line with the standards used elsewhere in the world. Knowledge management is looking at ways to achieve knowledge and skills retention for the SAN's future needs.

Current activities also include investigating new technologies for decision support, such as mobile technology. As more and more tactical, business and social media capabilities migrate to smartphones and handheld devices, the investigation looks at the usefulness of smartphones across the full spectrum of military operations and domains, while ensuring that security and war-fighter protection are maintained and enhanced.

## 9. Conclusion

With changing naval and geopolitical trends and priorities, new projects are created while others are realigned. IMT and the SAN often practise in the field to augment practical research outcomes. Collaboration with other similar international organisations is encouraged and a close working arrangement is fostered with formal academia.

This chapter has demonstrated how technology has been developed, adapted and applied locally to address the SAN's operational and future requirements. This technology is available for the greater good of the Republic of South Africa and can be used to directly benefit the wider maritime sector.

## References

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Pierson, W.J. and Moskowitz, L. 1964. A proposed form of fully developed seas based on the similarity theory of S.A. Kitaigorodski. *Journal of Geophysical Research,* 69:5181–5190.

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# Acknowledgements

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# Colour figures

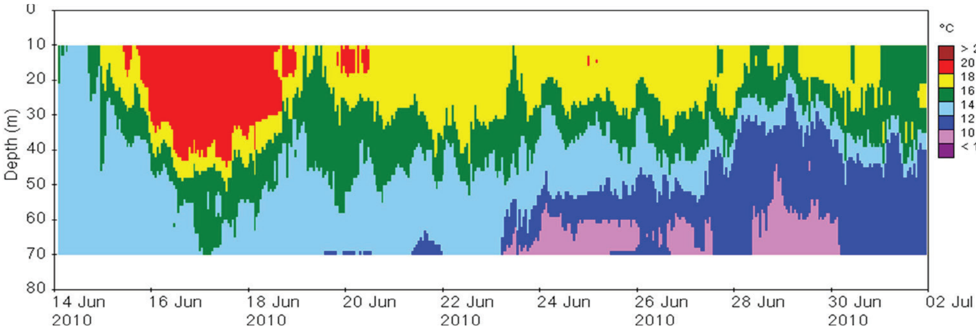


***Figure 3:*** *An example from one UTR mooring showing Agulhas Current-driven upwelling (purple and blue) in Algoa Bay during a Natal Pulse. The shoreward intrusion of a warm surface plume attached to the leading edge of the meander is shown in red.* *[See page 70.]*

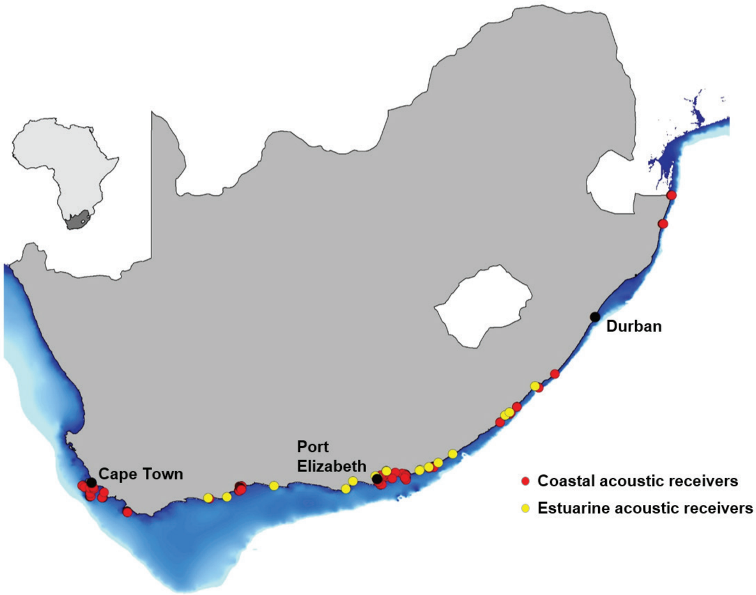


***Figure 6:*** *ATAP network in South Africa (image by Taryn Murray and Amber Childs).* *[See page 77.]*

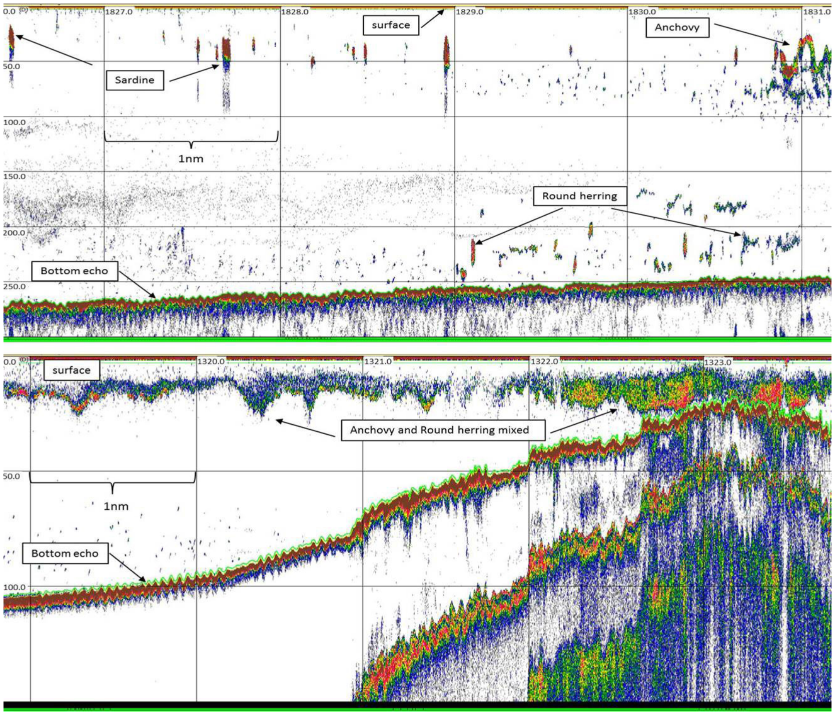


***Figure 3:*** *Two 38 kHz echograms showing aggregations of sardine, anchovy and round herring on the Agulhas Bank by day (upper panel), and a mixed layer of anchovy and round herring by night (lower panel). [See page 129.]*

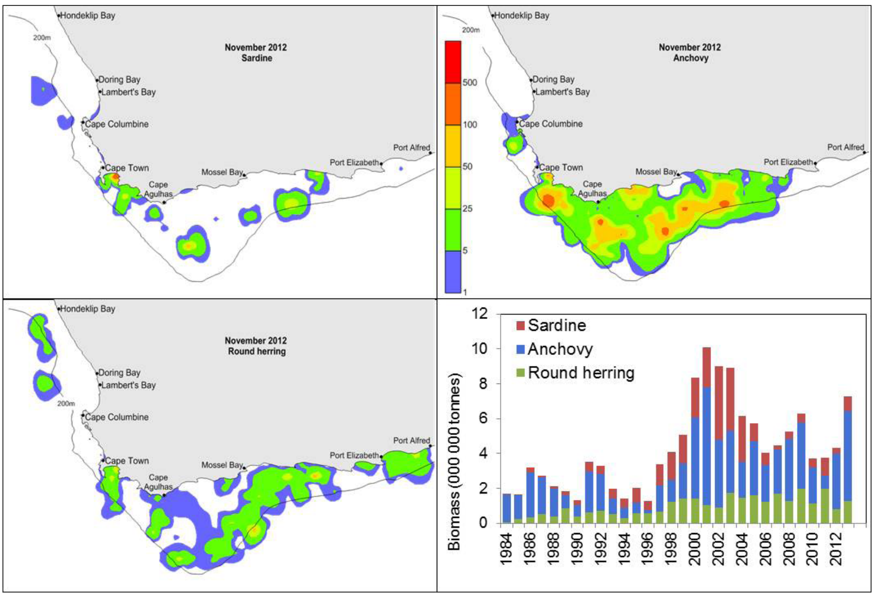


***Figure 4:*** *Maps of sardine, anchovy and round herring density derived from surveys by FRS* Africana *and FRS* Compass Challenger *in November 2012. The density scale is in gm$^{-2}$. The bottom right panel shows the biomass estimates for the three species from the surveys in November since the start of the time series in 1984. [See page 131.]*

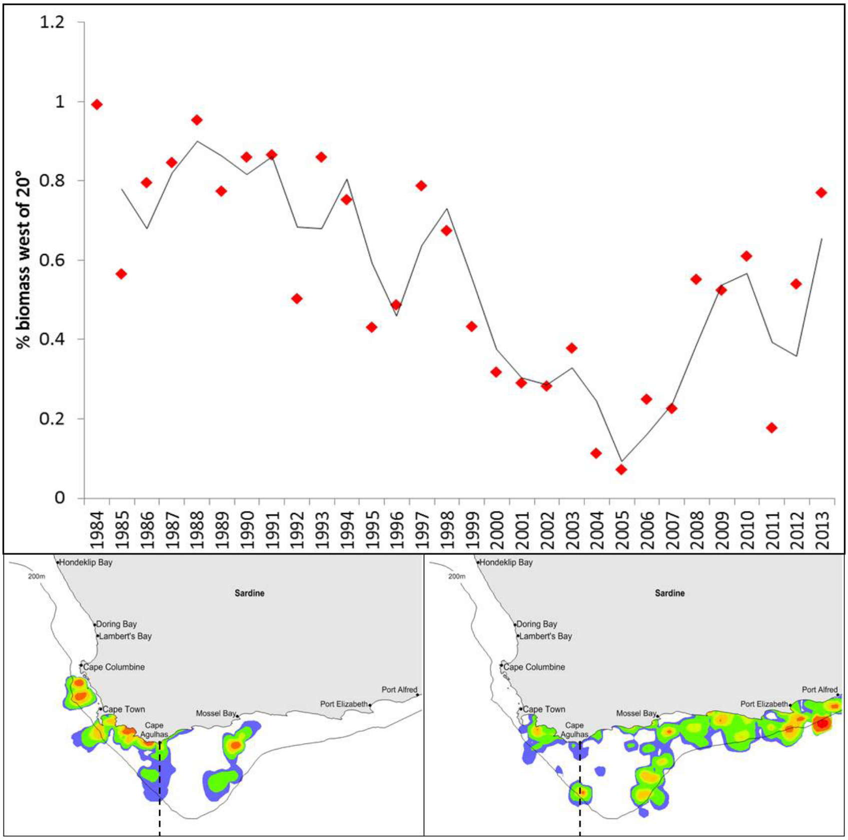


***Figure 5:*** *Changes in the proportion of the sardine biomass in November lying west of 20° E every year since the start of the surveys in 1984. The lower panels show the distributions in 1997 (left) and 2004 (right). [See page 133.]*

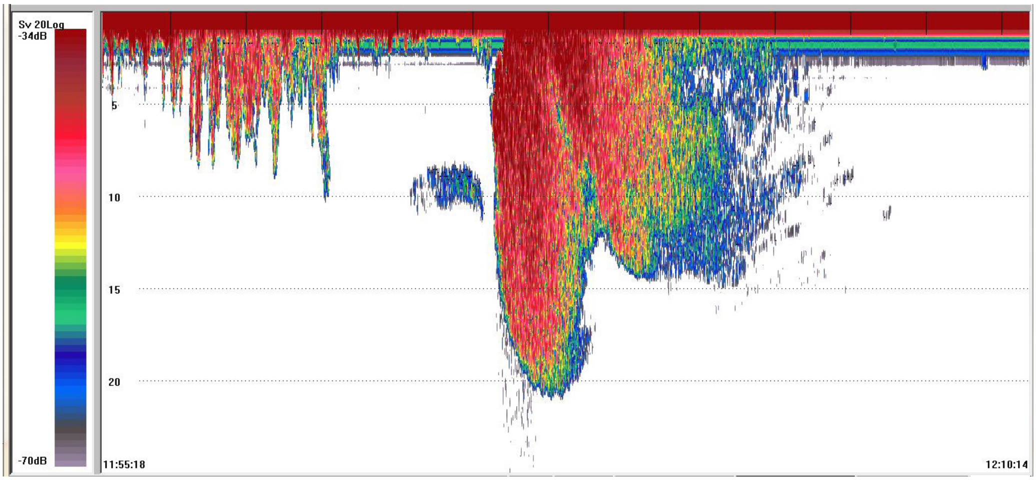


***Figure 6:*** *A 120 kHz echogram of a dense swarm of Antarctic krill in the upper 20 metres of the water column at midday. Data collected during the January 2014 South African National Antarctic Expedition (SANAE) from* SA Agulhas II*.*
*[See page 134.]*

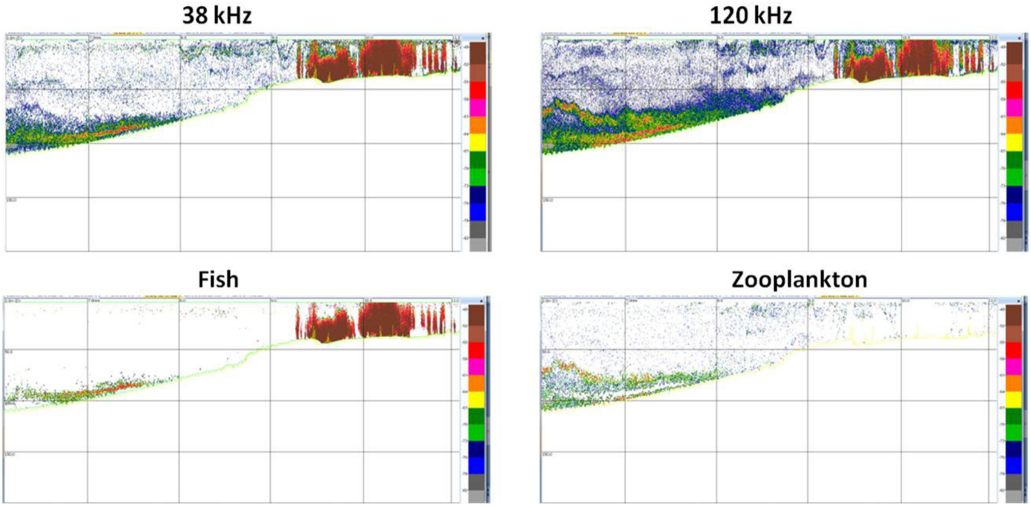


***Figure 7:*** *Acoustic discrimination between fish and zooplankton through the comparison of the scattering at 38 kHz and 120 kHz (top panels) and the filtering out of unwanted targets (bottom panels).* *[See page 135.]*

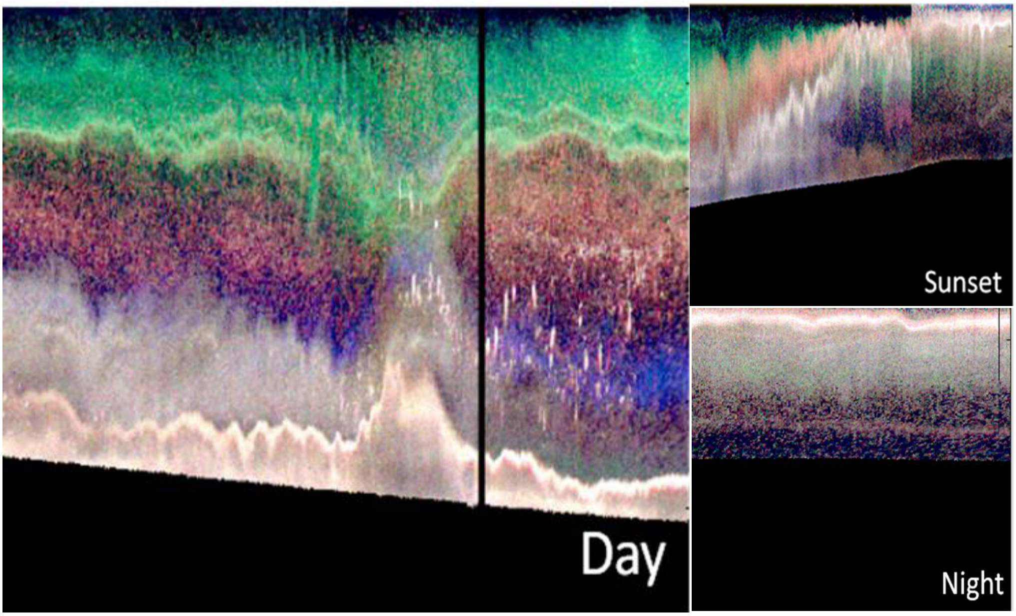


***Figure 8:*** *Discrimination of scatterers on the West Coast, based on the comparison of backscattering strength at three frequencies (18 kHz, 38 kHz and 120 kHz) at different times of the day. Four dominant classes of acoustic scatterers could be observed, namely (white) swim-bladdered fish, (pink) organisms with an echo maximum at 18 kHz (gelatinous zooplankton), (green) organisms with an echo maximum at 38 kHz (gas-bearing zooplankton), and (blue) organisms with an echo maximum at 120 kHz (fluid-like zooplankton).* *[See page 136.]*

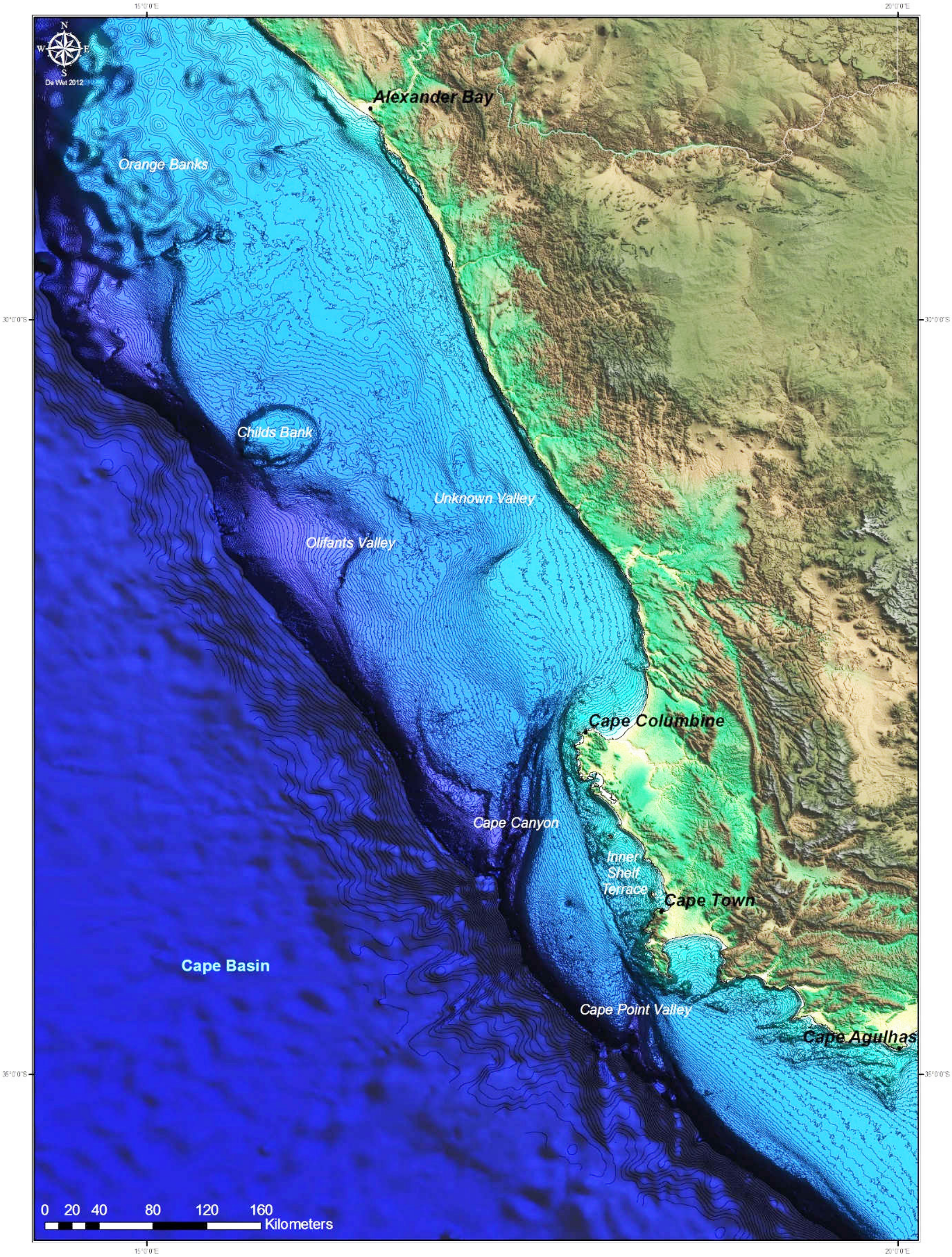


***Figure 9:*** *Bathymetric map of the western continental margin of South Africa and adjacent deep ocean area. Bathymetric isobaths are spaced at 5-metre intervals for water depths ranging between 0 and -500 metres, at 10-metre intervals for water depths ranging between -500 and -1 000 metres, and at 100-metre intervals for water depths greater than -1 000 metres (image taken from De Wet, 2012).* *[See page 138.]*

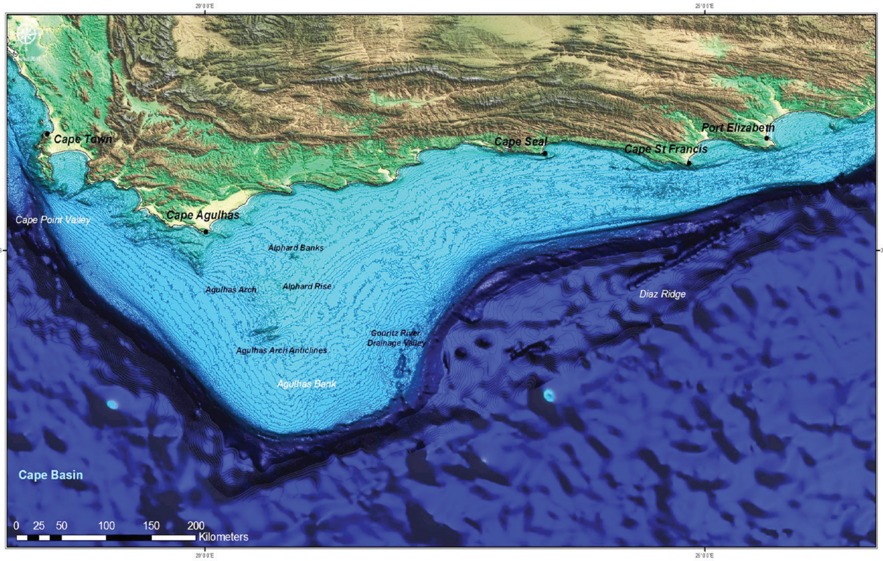


***Figure 10:*** *Bathymetric map of the southern continental margin of South Africa and adjacent deep ocean area. Bathymetric isobaths are spaced at 5-metre intervals for water depths ranging between 0 and -500 metres, at 10-metre intervals for water depths ranging between -500 and -1 000 metres, and at 100-metre intervals for water depths greater than -1 000 metres (Image taken from De Wet, 2012).* *[See page 139.]*

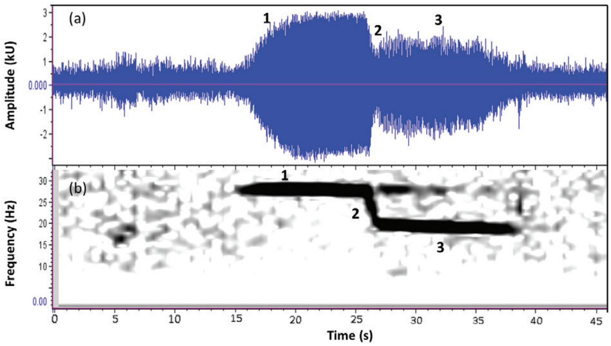


***Figure 2:*** *A typical Antarctic blue whale Z call illustrating the wave form amplitude modulation (a), with the corresponding frequency modulation and duration of each unit of this three-unit call (b). The 28 Hz unit is the high-energy component of the call as it has the highest amplitude compared to the other two components of the call as shown by the amplitude values. The amplitude is presented here in a thousand unit, also known as a kilo unit (kU), of the dimensionless sample values. Data was collected during the 2001/02 IWC SOWER cruise.* *[See page 163.]*

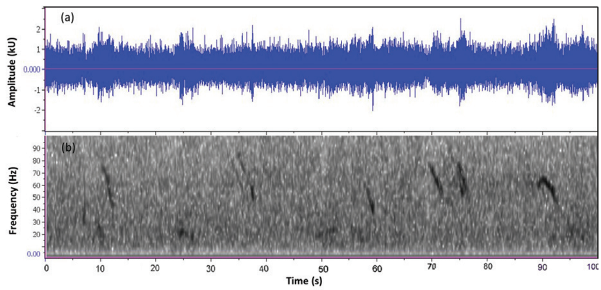


***Figure 3:*** *A spectrogram of the Antarctic blue whale's high-frequency modulated D calls showing the waveform amplitude modulations (a) and frequency modulations (b) over time during the 2001/02 IWC SOWER cruise.* *[See page 163.]*

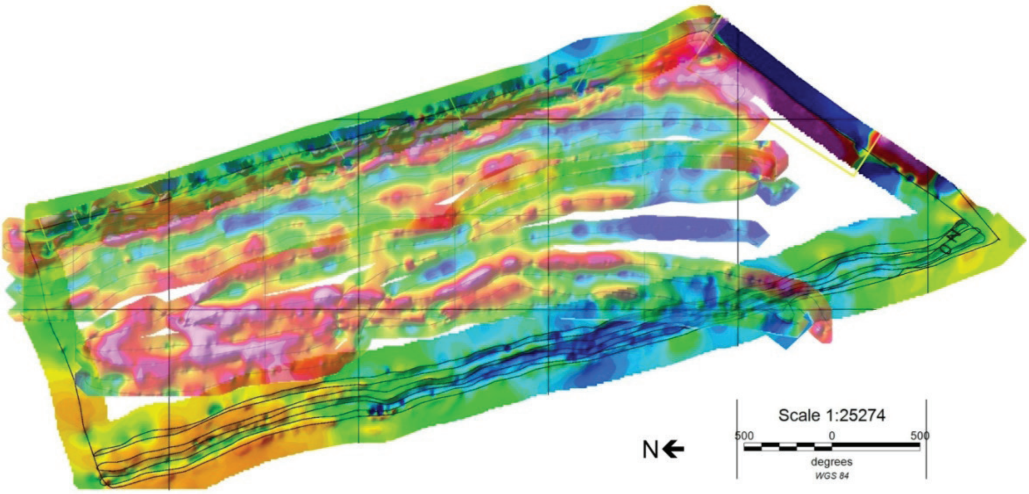


*Figure 2:* *Magnetometer map off Durban with seabed magnetic anomalies indicated in warmer colours (Maitland, 2012). [See page 224.]*

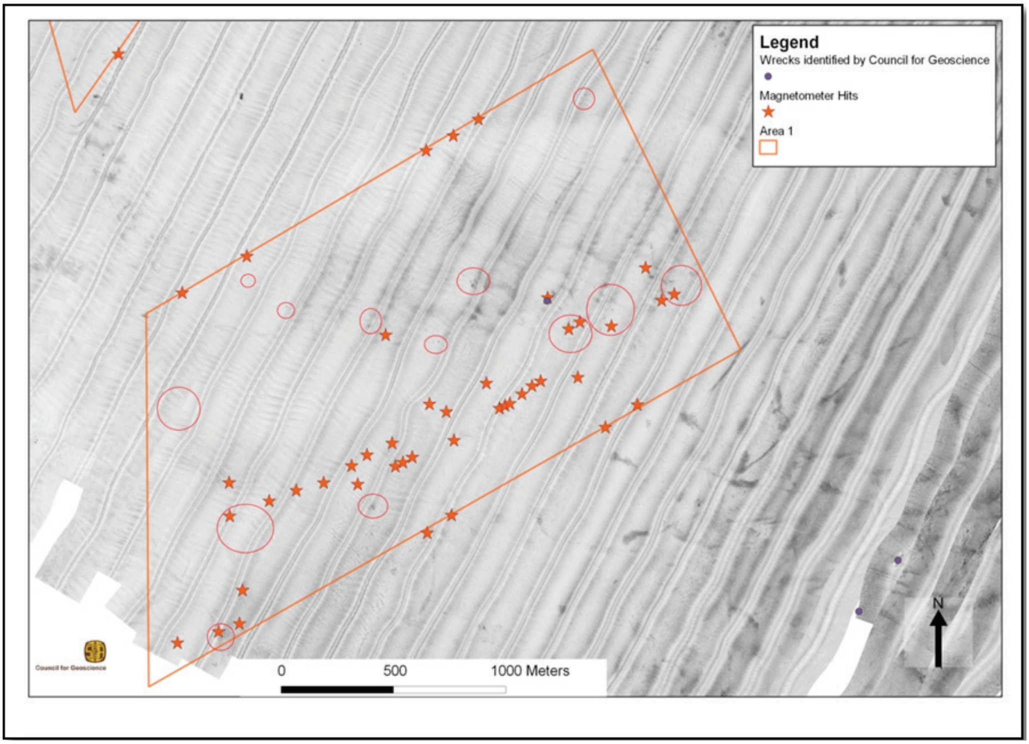


*Figure 3:* *Sidescan sonar image with magnetic anomalies correlated to identified debris (Adapted from Council for Geoscience map in Maitland, 2012). [See page 224.]*

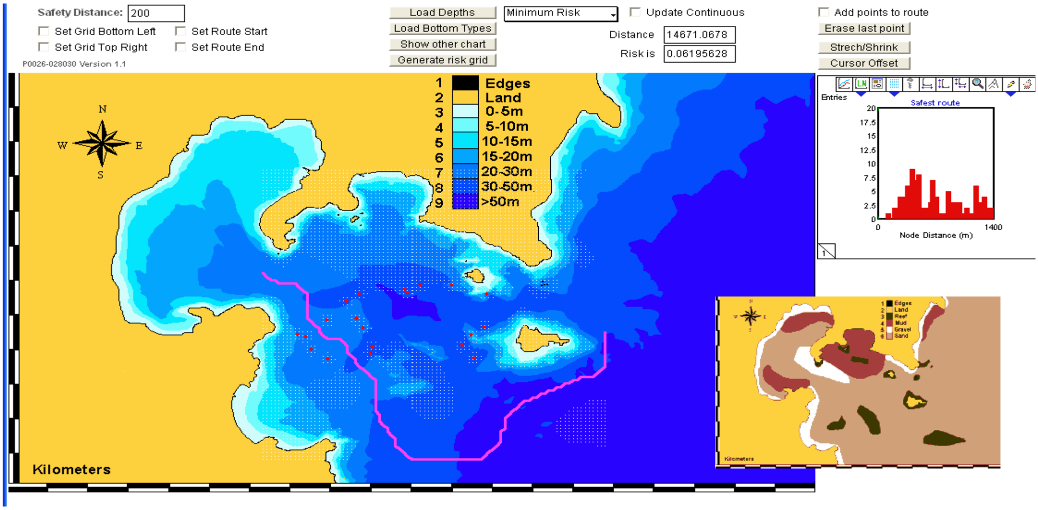


***Figure 2:*** *Route optimisation through a shallow-water minefield. [See page 283]*

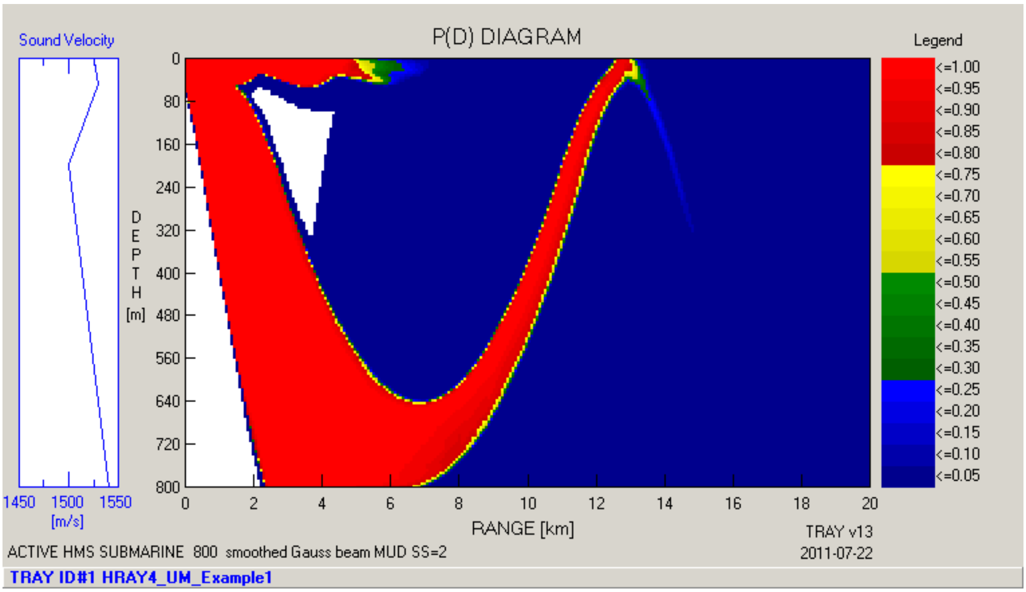


***Figure 9:*** *Sonar modelling developed with at-sea verification. [See page 294.]*

*"The transformation of the South African economic landscape, the alleviation of poverty, the provision and development of skills across the maritime industry are key cornerstones of Government's developmental agenda."*

J.G. Zuma, President of the Republic of South Africa, 2012.

*"The long-term developmental programmes of the world can no longer be based on land resources only; it must also include the coast and ocean resources."*

E. Molewa, Minister of Environmental Affairs, 2014.

*"Constant research is needed to maintain an advantage through the development of new concepts, smarter production techniques, materials and methods. This research must be relevant and be directed by industrial needs. Research must form the building block for improved prosperity and sustainable development."*

J. Potočnik, European Commissioner for the Environment, 2006.

These statements highlight the importance of research, technology and innovation for unlocking the economic growth and development potential of the marine and maritime sectors both in South Africa and globally. *Reflections on the State of Research and Technology in South Africa's Marine and Maritime Sectors* presents examples of current research and technology related to the country's marine and maritime sectors, and their potential to contribute to the growth and development of these sectors. In addition, the book includes reflections by the authors on what research and technology-related gaps still exist in the examples they present, and how these can be overcome. The book is written in an accessible style to appeal to a wide range of readers from across the marine and maritime sectors and beyond.

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