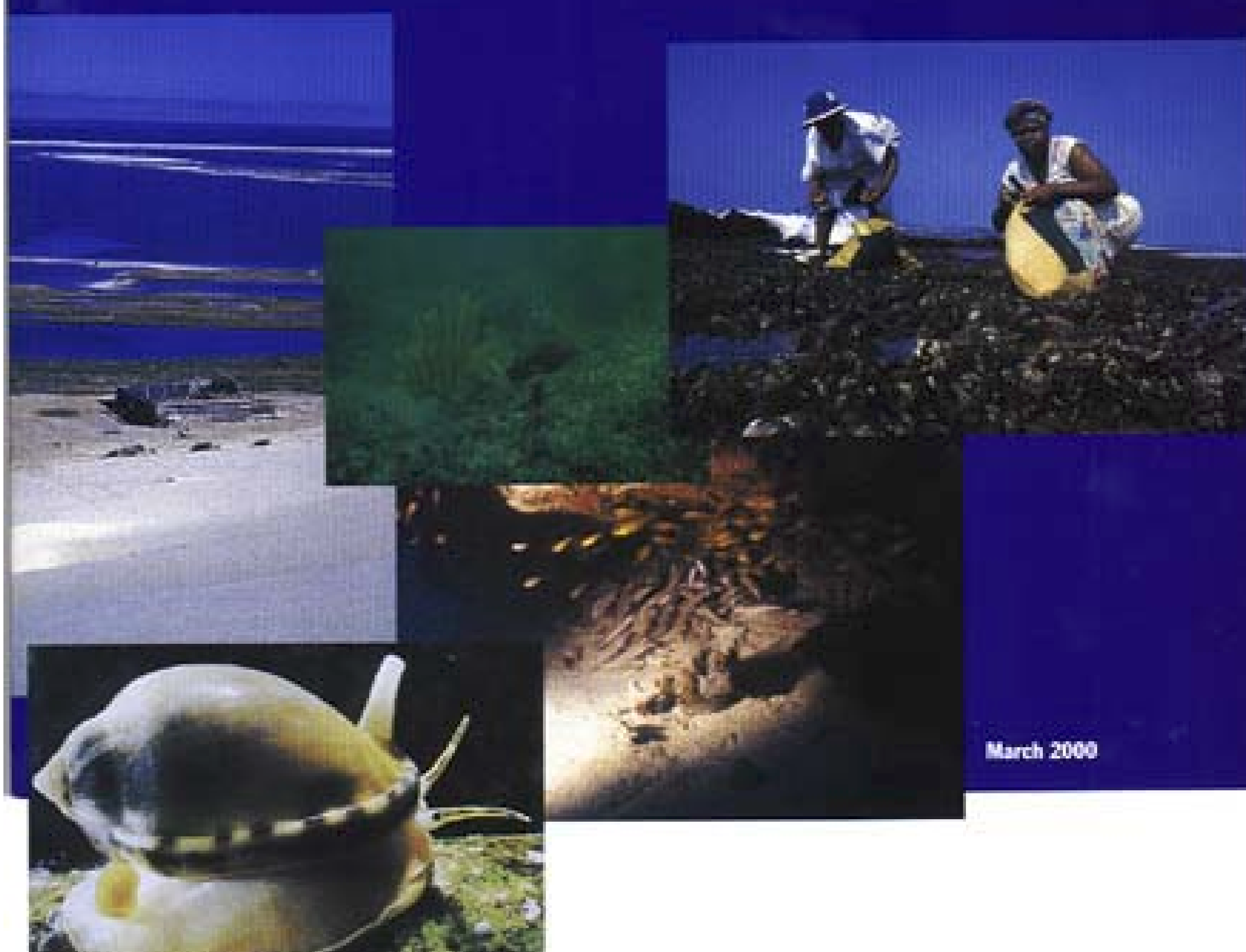
Summary

Marine Biodiversity Status Report for South Africa



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Summary
Marine Biodiversity Status Report for South Africa

At the end of the 20th Century

Edited by B.D. Durham & J.C. Pauw

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PO Box 2600
Pretoria
0001
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Tel: +2712 481 4000
Fax: +2712 349 1179
Email: ben@nrf.ac.za

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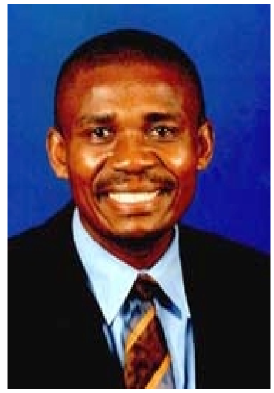
Preface



In striving to maintain research programmes in South Africa that are nationally topical and focused, the National Research Foundation (NRF) and one of its predecessors, the Foundation for Research Development (FRD), have developed this Summary Marine Biodiversity Status Report in collaboration with the South African Network for Coastal and Oceanic Research (SANCOR). The report, influenced by the principles of the Convention on Biological Diversity and the White Paper on Biological Diversity, has already guided the review of priorities in the Marine Biodiversity and Conservation Thrust.

While it was principally designed to guide the development of the NRF's research agenda, this report gives a snapshot of the status of marine biodiversity in South Africa at the end of the 20th century, and will undoubtedly prove useful to national and provincial organisations that are responsible for and/or manage South Africa's marine natural resources. This document will be also be available on the NRF Website (www.nrf.ac.za), and linked to the 1999 National State of the Environment Report.

Khotso Mokhele
President: National Research Foundation

Introduction

Biodiversity, the spectacular spectrum of life we observe on this earth, includes variability within species (genetic), between species, at the community and ecosystem levels, as well as the processes that underlie ecosystem functioning. Biodiversity thus refers to the environmental life-support systems and natural resources on which we, as humans, depend. A large portion of this biological diversity is found in the oceans. Reliance by growing human populations on the marine environment for primary needs (such as food) has resulted in threats to this marine biodiversity. These threats can be attributed primarily to the unsustainable use of many marine resources and habitat destruction. In South Africa, marine systems are showing signs of severe over-exploitation (e.g. the reef line-fishery is in crisis) and degradation (e.g. due to development on estuaries, pollution), and these are no doubt having significant impacts on biodiversity through removal of key species and disturbance of ecological processes. This in turn has social and economic impacts since it affects productivity and stability of fisheries, ecotourism opportunities and other industrial development. Global recognition of these problems and the fundamental link between biodiversity conservation and sustainable development is embodied in the United Nations Convention on Biological Diversity (1993) to which South Africa is a signatory.

An essential step in ensuring marine biodiversity conservation in South Africa is the assessment of its current status, and regular updates thereafter so that problem areas are identified and addressed. This report provides an evaluation of the current knowledge on marine biodiversity in South Africa. It identifies the large data gaps that exist, and highlights future priority actions and research requirements. In doing so it also gives insight into the areas where human capacity and expertise need to be developed. It provides an important benchmark for future status assessments, but is in itself a valuable reference document since it covers the range of marine biodiversity levels (genetic, species, ecosystems) as well as examining current threats and issues. It is particularly timely and relevant given the implementation of the new Marine Living Resources Act (1998), which has set new ground rules for utilization of marine living resources in South Africa. Conservation of biodiversity must be a strong partner to equity and new access rights, if long-term sustainability and stability in the fisheries are to be attained.

This report reflects the strong commitment of the marine science community of South Africa to contribute to marine biodiversity conservation. A large number of specialist scientists and managers were involved in preparing the various sections: the contents were derived by capturing expert inputs from teams of specialists who have direct knowledge of the different scientific fields and ecosystems. Therefore, this report contains a unique summary of the current marine biodiversity knowledge across the full range of ecosystems and disciplines in the South African marine environment.

On behalf of SANCOR, I congratulate the NRF in initiating and steering this marine biodiversity assessment. I further wish to confirm the willingness of the marine science community to contribute to the acquisition of the information, and the development of the capacity, required for conservation of biodiversity, so that lasting benefits are realized from the sustainable use of the marine living resources of South Africa.

Jean Harris
Chair: SANCOR Steering Committee

Development of the Marine Biodiversity Status Report

A review of priorities for marine biodiversity research in South Africa was first proposed at a Foundation for Research Development (FRD, now National Research Foundation) / the National Department of Environmental Affairs and Tourism / SANCOR Programme Advisory Committee held in Port Elizabeth in December 1996. This committee assessed the annual progress of each of the marine Thrusts, and advised on strategic and budgetary matters. Given the budgetary constraints, it was considered that the Marine Biodiversity and Conservation Thrust's objectives were too broad, allowing research to be funded that – despite having intrinsic merit – was not nationally important in terms of the Convention on Biological Diversity and the then Green Paper on Biological Diversity.

The FRD therefore undertook to review the priorities of the Marine Biodiversity and Conservation Thrust, through the development of a 'Summary Marine Biodiversity Status Report'. This report would summarize available information and not be an exhaustive review nor include new research. This was primarily because the principal purpose of the report was to broadly guide the FRD's role as a national capacity-building agency. A planning meeting was arranged in Cape Town and included representatives from the coastal provincial conservation bodies, the Chief Directorate of Sea Fisheries (now Marine and Coastal Management), the National Parks Board (now South African National Parks), SANCOR, and various academics.

Attendees were asked to present position papers indicating their organization's view of and role in effecting the Convention on Biological Diversity (CBD) and the Green Paper on Biological Diversity. It was immediately recognized that the biodiversity report would necessarily include far more than a taxon-based status list. The final plan included reviews of the various ecosystems, the conservation and use of resources, the implications of genetics and biochemical research, and the scope and efficacy of national policies. In addition, the above sections were subdivided to review the status of the knowledge, expertise, and capacity available – and the gaps therein - in South Africa. The structure, time-frames and roleplayers were identified, and the FRD then undertook to approach coordinators to develop the various sections of the draft report.

Following the drafting of the report sections, a workshop was held - attended primarily by the coordinators of the various sections – to review and structure the final report. Thereafter independent referees reviewed each section, and following modification, the final editing was effected. Owing to various time constraints and the number of people involved, delays have inevitably crept into the final date. Nevertheless, and immediately following the review workshop (November 1997), the report has already influenced the Marine Biodiversity and Conservation Thrust description, which now reflect priorities that are aligned with the CBD and the White Paper on Biological Diversity.

This final document was thus developed through multiple contributions in the forms of planning, drafting, reviewing, and general editorial assistance. All contributers are gratefully acknowledged, and are listed on the following page.

Acknowledgements

Planning meeting (27 May 1997):

M. Du Plessis (University of Cape Town) - chairman

C. Attwood (Sea Fisheries Research Institute)
J. Bolton (University of Cape Town)
G. Branch (University of Cape Town)
B. Durham (Foundation for Research Development)
J. Feely (E. Cape Provincial Administration)
S. Gabula (E. Cape Provincial Administration)
J. Harris (Natal Parks Board)
D. Impson (W. Cape Provincial Administration)
L. Johnstone (Foundation for Research Development)
D. Keats (University of the Western Cape)
R. Leslie (Sea Fisheries Research Institute)
J. Pauw (Foundation for Research Development)
I. Russel (National Parks Board)
R. Taylor (Natal Parks Board)
A. Williams (Cape Nature Conservation)

Review Workshop (26 November 1997):

M. Du Plessis (University of Cape Town) - chairman

M.E. Anderson (JLB Smith Institute)
R. Anderson (Sea Fisheries Research Institute)
G. Branch (University of Cape Town)
J. Bolton (University of Cape Town)
A. Booth (Rhodes University)
D. Brand (N. Cape Nature Conservation)
A. Brown (University of Cape Town)
M. Davies Coleman (Rhodes University)
B. Durham (Foundation for Research Development)
M. Gibbons (University of the Western Cape)
C. Griffiths (University of Cape Town)
J. Harris (Natal Parks Board)
P. Hockey (University of Cape Town)
L. Johnstone (Foundation for Research Development)
R. Leslie (Sea Fisheries Research Institute)
I Russel (National Parks Board)
A. Whitfield (JLB Smith Institute)
A Williams (Cape Nature Conservation)
R Wynberg (Consultant)

Referees:

C. Attwood (Marine and Coastal Management)
G. Bailey (Marine and Coastal Management)
R. Bally (University of Fort Hare)
P. Bloomer (University of Pretoria)
G. Branch (University of Cape Town)
M. Cherry (University of Stellenbosch)
J. Cooper (Department of Water Affairs and Forestry)
R. Crawford (Marine and Coastal Management)
J. Field (University of Cape Town)
A. Govender (Oceanographic Research Institute)
C. Griffiths (University of Cape Town)
J. Harris (KwaZulu-Natal Nature Conservation Service)
D. Keats (University of the Western Cape)
D.E. Malan (Marine and Coastal Management)
C. Moloney (Marine and Coastal Management)
R. Perissinotto (University of Natal (Durban))
R. Siegfried (Cape Town)
L. Underhill (University of Cape Town)
E. Witkowski (University of the Witwatersrand)

Editorial assistance:

G. Rolando (National Research Foundation)
A. Dawood (National Research Foundation)

List of acronyms

CBD International Convention on Biological Diversity
CCAMLR Convention for the Conservation of Antarctic Marine Living Resources
CERM Consortium for Estuarine Research and Management
CITES Convention on International Trade in Endangered Species
DEA&T National Department of Environmental Affairs and Tourism
EMP Environmental Management Programmes
ENSO El Nino Southern Oscillation
FAO United Nations Food and Agricultural Organization
FRD Foundation for Research Development
ICES International Council for the Exploration of the Sea
IMO International Maritime Organization
JMARC Japan Marine Research Commission
MARPOL International Convention for the Prevention of Pollution from Ships
MCM Chief Directorate: Marine and Coastal Management
MIRCEN Microbiological Resources Centre
MPA Marine Protected Area
NBI National Botanical Institute
NRF National Research Foundation
OMP Operational Management Procedure
ORI Oceanographic Research Institute
RU Rhodes University
SANCOR South African Network for Coastal and Oceanic Research
SCOR Scientific Committee on Oceanic Research
SDI Spatial Development Initiative
TAC Total Allowable Catch
UCT University of Cape Town
UDW University of Durban-Westville
UN University of Natal
UNEP United Nations Environment Programme
UNESCO United Nations Educational, Scientific and Cultural Organization
UNOLS University and National Oceanographic Laboratory Service (USA)
UPE University of Port Elizabeth
US University of Stellenbosch
UWC University of the Western Cape
WRC Water Research Commission

FUNCTIONAL ECOSYSTEMS

ROCKY SHORES

by C.L. Griffiths, C.D. McQuaid, J.M. Harris & A.H. Dye

What is the status of our knowledge of ecosystem functioning?

Analyses of the structure of rocky shore communities in South Africa date back to pioneer studies of vertical zonation and biogeographical distribution patterns summarised by Stephenson (1948). These patterns have subsequently been revised several times, most recently by Emanuel *et al.* (1992). Additional data on biogeographical and exposure-related variations in species richness, biomass and trophic structure are presented by McQuaid & Branch (1984; 1985) and Bustamente *et al.* (1995). Our state of knowledge of community structure on rocky shores is thus well advanced, certainly in relation to that in other Southern Hemisphere nations. The analysis of functional relationships (processes) is a much more complex issue, which has not been adequately resolved anywhere. Attempts have been made to draw up energy flow diagrams for South African shores (Field & Griffiths, 1991). The principal shortcoming in these studies is that, although it is possible to measure *in situ* production, the critical role played by water movement in rapidly transporting phytoplankton, detritus, resuspended faeces, etc., in and out of the system has yet to be adequately resolved. Thus it is, for example, possible to calculate the metabolic energy requirements of filter feeders and grazers, but extremely difficult to apportion these amongst the various possible sources of food. Moving to higher trophic levels rocky shores abound with intra- and interspecific competitive interactions and predator-prey relationships. A great many (often excellent) studies have addressed these, but a full understanding of, for example, the implications of exploitation of key species on ecosystem structure and function, has yet to be accomplished here, or anywhere else.

What gaps exist in our knowledge of ecosystem functioning?

- Relative contributions of *in situ* production and imported/recycled materials in supporting primary consumers, especially filter feeders.
- Relationships between parent stock size and recruitment e.g. larval dispersal patterns/survivorship rates, dispersal distances, critical spawner biomass. Both the above require small-scale oceanographic expertise which is not readily available.
- Effects of exploitation or disturbance of key species on species richness, community structure and ecosystem functioning, especially stocks of other exploited or exploitable species.
- Determination of which (and how) physical and/or biological factors control community structure, in particular what causes the extreme small and larger scale variability in community structure so characteristic of rocky shore systems.
- Limited ability to generalise from the particular to the general. Most ecosystem studies are short term and restricted to a single site, making it difficult to extend the conclusions made to temporally or spatially different circumstances. In other words, we need longer-term experiments undertaken simultaneously at a variety of sites.

What are the threats to ecosystem functioning?

The South African coastline suffers from an unusual combination of first and third world threats, including:

- Excessive and increasing exploitation of keystone species by both sophisticated industrial, illegal, recreational and subsistence users, resulting in radical and perhaps irreversible changes in community structure (e.g. mussel removal in Transkei giving a coralline-dominated shore and reducing parent stock to the point where recruitment fails).

- Progressive long-term degradation due to compounded human impacts, including direct exploitation, pollution, bycatch, disturbance, habitat degradation, holiday home and resort development, etc. Lack of sufficient unimpacted benchmark sites reduces awareness of this threat.
- Introduction of invasive alien species (e.g. the Mediterranean mussel has already radically altered community structure and function along the entire west coast).
- Catastrophic disturbances of this very linear and vulnerable (but resilient) system (e.g. oil spills, black tides - as in St Helena Bay and Lambert's Baai, freshwater floods - as in the Orange River).

What is the status of expertise and what capacity is lacking?

South Africa has a proud history of research on rocky shore ecology, dating back to the pioneering studies of Stephenson and co-workers. There are presently several strong research groups in this field and they are well distributed around the coast (University of Cape Town; Marine and Coastal Management; University of the Western Cape; University of Port Elizabeth; Rhodes University; University of the Transkei; University of Durban-Westville; Oceanographic Research Institute). Capacity is thus good in relation to other comparable, and certainly other African countries. Limiting factors are:

- the funding, and expertise at some (indeed most) centres is channelled through only one or two key individuals. If they leave the entire centre will collapse or change fields.
- many excellent foreign students wish to work in South Africa and offer valuable perspectives different from the strongly ‘incestuous’ local skills base. There is little opportunity to support these students and their input, both intellectual and in terms of tasks accomplished, is thus lost.
- the perceived lack of permanent posts discourages students from entering this field, or results in their subsequent loss.
- leadership capacity is lacking in certain crucial field such as taxonomy, evaluation of physical forcing factors (small-scale coastal oceanography) and larval ecology.

What is the status of the link between ecosystem functioning and management?

There is no doubt that we need to develop management policies that are predictive at an ecosystem, rather than a species level. For example, what will the effects of various mussel-harvesting strategies be on species richness, limpet biomass, exploitable seaweed stocks, etc? It is abundantly clear from case studies, such as the overexploitation in the former Transkei, that ecosystem impacts are profound, but few predictive experiments have been carried out. There is a wealth of circumstantial data available to suggest possible outcomes, but this is spread amongst numerous papers in the primary literature and is relatively inaccessible to the average manager (thus there is a pressing need for much of the existing scientific data to be synthesized and phrased in terms meaningful to managers).

Another management concern is the paucity of long-term monitoring studies to determine the scale of natural spatial and temporal variability. Without such an appreciation of the ranges of natural variation it is extremely difficult to evaluate the impacts of exploitation.

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FUNCTIONAL ECOSYSTEMS

SANDY BEACHES AND DUNES

by A.C. Brown, A. McLachlan, G.I.H. Kerley & R.A. Lubke

What is the status of our knowledge of ecosystem functioning?

The principles of sandy-shore ecosystem functioning in southern Africa are in general well known and many relevant concepts world-wide have been developed in South Africa. These are set out in Brown & McLachlan (1990), although some revision of this book is indicated in the light of subsequent developments. Most attention has been paid to sandy shores around Algoa Bay and the Cape Peninsula but other localities have not been neglected and our knowledge of these systems extends from the coast of Namibia to northern KwaZulu-Natal. Knowledge of sandy-beach systems in Mozambique is also beginning to emerge.

The super-parameter controlling South African sandy-beach ecology and driving ecological processes is wave action. The characteristics of the beach system depend essentially on interactions between particle size parameters and wave action, with tides also playing a part. These physical interactions result in beach types ranging from reflective to fully dissipative, these two extremes representing different ecosystems and ecosystem functioning. Reflective beaches, lacking a surf zone and primary production, and with an impoverished macrofauna, are probably importers of material from the sea. Conversely, dissipative beaches, which may enjoy a high level of primary production in their extensive surf zones and a much higher diversity and biomass, are exporters. In general, community structure and functioning are dictated more by physical factors than by biological interactions (such as competition).

Dunes are essentially terrestrial systems in which wind-driven sand transport is of key importance. Sand exchange with beaches and their surf zones links these environments. Within dune systems, a spectrum is presented from physically-controlled, wind-dominated transgressive dune sheets, with high rates of sand movement and salt spray (common along the south and east Cape coasts), to systems with considerable biological structure, as evidenced by stable, vegetated dunes (typical of KwaZulu-Natal). West coast dunes appear to be greatly influenced by lack of rainfall. The most obvious feature of coastal dunes is the gradient they present from the sea landwards, this gradient being both physical and biological. Key references are Tinley (1985) and McLachlan (1991).

What gaps exist in our knowledge of ecosystem functioning?

- The role of biological interactions in influencing community structure.
- The functioning and bionomic significance of the surf-zone's microbial loop.
- The importance of phytoplankton foam to nutrition on west coast beaches.
- Quantification of dissipative surf zones as nursery areas for fish.
- Quantification of exchanges of material between the beach and the ocean.
- Dynamics and ecosystem functioning of beaches of mixed sand and rock (see Brown *et al.*, 1991).
- Ecosystem functioning of west coast dunefields.
- Insect biodiversity of vegetated dunes (especially forested dunes).

What are the threats to ecosystem functioning?

- Dune systems are under threat from development, including building construction, provision of recreational facilities, car parks, etc, and policy for such development is lacking.
- The predicted sea level rises.

- Any factors, including coastal developments, which modify sediment transport.
- Off-road vehicles on the back beach and in the dunes can have a major impact.
- Trampling of dune vegetation may have serious consequences where human access is not strictly controlled.
- Invasive plants may alter dune ecosystems through stabilization.
- Beach mining has adverse effects where this is undertaken.
- Pollution, recreational activities and localised impacts are less damaging to the intertidal zone than to dune systems and fast recovery is usually evident.

What is the status of expertise and what capacity is lacking?

There are very few scientists in southern Africa (or elsewhere) whose expertise centres on sandy shores. Thus the departure of A. McLachlan and the retirement of A.C. Brown and G. Bate present a significant decrease in the expertise available. There remains a small group of coastal dune researchers in the Eastern Cape and there are a few scientists with some experience of sandy-shore ecology at other centres but the latter tend to be isolated rather than team leaders and some are no longer active in the field. There is a general lack of expertise regarding the meiofauna and interstitial bacteriology and virtually no marine chemists with an interest in sandy beaches.

What is the status of the link between ecosystem functioning and management?

Sandy-shore managers generally have a poor understanding of management issues and how to address them. The key to successful management is understanding the processes and structures of sand transport and storage, and maintaining these intact. Biological factors are less critical on beaches but vegetation is important and sensitive in the dunes. There are numerous published papers and reports which could guide the authorities in attempting to manage sandy shores, summarised in Brown & McLachlan (1990). A document needs to be prepared and distributed which puts these issues into a format and language which managers would find meaningful. Such a document should cover both beaches and dunes.

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FUNCTIONAL ECOSYSTEMS

ESTUARIES

by A.K. Whitfield, R.H. Taylor, N. Grange, P.D. Cowley, T.H. Wooldridge, J.B. Adams & G.C. Bate

What is the status of our knowledge of estuarine ecosystem functioning?

In terms of the physical structure and functioning of South African estuaries much information is already available (see Reddering, 1988; Slinger *et al.*, 1994). The biotic structure of macrofloral and macrofaunal estuarine communities in South Africa is also well advanced (see Adams *et al.*, 1992; McLachlan & Grindley, 1974; Moll & Werger, 1978; Plumstead *et al.*, 1991) but knowledge of interactions within and between these components (see Emmerson, 1986; Whitfield, 1984), as well as temporal and spatial variability (see Marais, 1982; Wooldridge, 1994), is more limited. In the case of smaller size-classes (including micro-, meso-, nano- and pico-organisms), we are still in the process of determining which species constitute these assemblages (Roberts *et al.*, 1985; Steinke *et al.*, 1990) and have yet to embark on integrated studies that elucidate their role in ecosystem functioning. In summary, the state of knowledge of macrofaunal and macrofloral structure in South African estuaries is well advanced, certainly when compared to that in other Southern Hemisphere nations (Allanson & Baird 1999; Day 1981). We also have detailed information from laboratory and field experiments on the likely response(s) of certain plant, invertebrate and fish species to changing environmental conditions within estuaries (see Blaber, 1974; Forbes, 1974; Howard-Williams, 1981; Naidoo, 1987). However, the analysis of functional relationships or processes within estuaries at the ecosystem level is a more complex issue, which has not been adequately resolved. Nevertheless, qualitative and quantitative attempts have been made to draw up energy flow diagrams for South African systems (see Baird & Ulanowicz, 1993; Paterson & Whitfield, 1997), but spatial and temporal variability within the study estuaries has hampered the accuracy and/or applicability of quantitative aspects of these studies.

What gaps exist in our knowledge of estuarine ecosystem functioning?

The following major gaps, some of which are in the process of being addressed, include:

- water quality and quantity requirements of the estuarine biota.
- chemical exchanges/transfers between sediments and the water column.
- elucidating nutrient and detritus pathways within estuaries.
- determining microbial processes and microalgal (benthic and planktonic) production in estuaries.
- relative contributions of autochthonous and allochthonous production in supporting primary and secondary consumers.
- marine/estuarine interactions especially in terms of the outwelling hypothesis and the value of estuaries to the marine environment.
- details of the spawning migrations, breeding behaviour and recruitment processes of estuary-associated invertebrates and fishes.
- effects of human exploitation, especially subsistence fisheries, on community structure and ecosystem functioning.
- determination of which (and how) physical and/or biological factors control community structure in the different types of estuaries.
- long-term data sets that incorporate the temporal variability found within estuaries.
- understanding the effects of mouth breaching on the short and long-term ecology of temporarily closed estuaries.
- comparative functioning of estuaries in different biogeographic regions.

What are the threats to estuarine ecosystem functioning?

South African estuaries are threatened by many anthropogenic influences, including:

- catchment degradation which leads to excessive siltation within estuaries.
- freshwater deprivation, especially the capture of minor flood events by dams.
- encroachment by agricultural, residential or industrial developments onto the estuarine floodplain.
- water pollution (including nutrient enrichment) arising from harmful agricultural, aquacultural, industrial or residential activities.
- overexploitation of fish and bait resources.
- poor management, including a lack of expertise and/or administrative capacity.
- lack of education, particularly among the public, local authorities and regional planners with respect to sustainable use of estuaries.
- confused legislation governing management and use of estuaries.
- premature breaching of temporarily closed estuaries.

What is the status of estuarine expertise and what capacity is lacking?

South Africa has appropriate and highly qualified expertise in certain scientific disciplines, e.g. botany, hydrology, geology, ornithology and ichthyology. However, even in those fields for which expertise currently exists, it is usually so thinly spread that the loss of a single scientist can result in a discipline vacuum for a region and sometimes for the entire country. There is also a perception that the number of new scientists entering the field is declining, and, in the broader interests of science in South Africa, the absence of estuarine scientists from historically disadvantaged backgrounds needs to be addressed.

The Foundation for Research Development (FRD, now NRF) and Consortium for Estuarine Research and Management (CERM) have done much to foster the development of a multidisciplinary approach to research in South African estuaries. However, lack of capacity in certain fields (e.g. microbiology), as well as a scarcity of scientists capable of facilitating ecosystem-level studies, is hampering progress towards a fully integrated approach.

What is the status of the link between estuarine ecosystem functioning and management?

The increasing need for improved estuarine and coastal zone management dictates that scientists and managers must operate as a team with land-use planners and legislators. Scientists have a responsibility to make important information accessible to managers in a user-friendly manner, but at the same time managers have a responsibility to make use of such information in consultation with the relevant scientist(s).

The view has been expressed that greater representation by scientists on policy/management committees is desirable. All too often, decisions affecting estuaries are made without the relevant scientists being present or having the opportunity to make a submission. Such an approach to estuarine management needs to be changed and there is evidence to suggest that a ‘transparent’ approach to decision making is becoming more widespread at national, provincial and local government levels.

There is no doubt that scientists do need to develop management tools that are predictive at an ecosystem level. This approach is being actively pursued by CERM members who adopt an ecosystem approach when determining the freshwater requirements of estuaries for the Department of Water Affairs & Forestry. The Water Research Commission (WRC) is also funding estuarine research that will lead to the development of predictive models that will aid the management of these systems.

Perhaps the most significant step in bringing estuarine scientists and managers closer together in the future is the launch of the WRC funded Estuaries Management Handbook Project. This handbook will be aimed at serving management authorities, developers, planners, government, resource users, consultants, local interest groups and conservation services. The project, which will highlight the link between estuarine ecosystem functioning and management, was initiated in 1998 and is scheduled to be completed by the year 2000.

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FUNCTIONAL ECOSYSTEMS

SUBTIDAL HARD SUBSTRATA

by R.J. Anderson

What is the status of our knowledge of ecosystem functioning?

This varies between biogeographical areas. In kelp beds on the west coast of South Africa, we know a reasonable amount about energy at the various trophic levels (from primary producers through consumers, and including decomposers) and about energy transfer between them (see reviews by Newell *et al.*, 1982; Field and Griffiths, 1991). Our knowledge here is probably as good as any comparable system in the Southern Hemisphere. However, we know very little about community and inter-species interactions, or important processes such as recruitment.

Our knowledge of the functioning of ecosystems on the south and east coasts (from Cape Agulhas eastwards, but excluding the coral reefs of KwaZulu-Natal) is almost non-existent; we do not even know the size and extent of rocky reefs. The little information available usually relates to exploited species (for example counts of fish or crayfish) but there is almost none on community structure or ecosystem functioning. A notable exception is the so-called "ORI" (Oceanographic Research Institute) Reef, where we have some information on biomass of the major invertebrate and vertebrate fauna and the dynamics of reef functioning (see for example Berry *et al.*, 1979). The state of knowledge of the south and east coast systems is reviewed by Field and Griffiths (1991) and the marine vegetation by Bolton and Anderson (1997).

The coral reefs off the coast of KwaZulu-Natal represent the southern tip of more extensive east African systems, and are probably similar in many functional respects to some relatively well studied systems e.g. the Great Barrier Reef. In KwaZulu-Natal there are current studies on the reefs and reef fish, and on the effects of divers and factors such as sand inundation. Nevertheless, the functioning of these coral reefs is by no means understood, and their diversity and complexity make them difficult to study on a system basis.

What gaps exist in our knowledge of ecosystem functioning?

We know so little about rocky reefs on the south and east coasts that it is not possible to identify gaps in our knowledge. Nevertheless, there are a number of issues that need to be researched before we can fully understand the functioning of any of our subtidal reef systems.

The first of these is the "micro-oceanography" of water movement and hence transport of nutrients, larvae and propagules within reefs and between the reefs and their environment. This is important for an understanding of controlling processes such as larval recruitment, and necessary knowledge in designing and managing marine protected areas.

There is a lack of synecological understanding in all systems. We do not know the relative "importance" of species (e.g. which are the keystone species) or understand species interactions beyond the acquisition of energy. This is part of a broader need for an ecosystem approach to reef ecology, which must ultimately lead to reliable models of how these ecosystems function (e.g. ECOPATH models). However, we are a long way from achieving this sort of understanding, because in many areas even the basic information is missing. There are large gaps in our knowledge at all levels, including the basic biology of species (both those that are harvested and those that are not), larval dispersal and larval competence (relative to larval viability), fisheries-independent information on resource species, etc. An understanding of species interactions is particularly important for managing fisheries, where catches are reducing or even eliminating components of the ecosystem.

With Marine Protected Areas becoming an important tool not only for preserving biodiversity but also for managing fisheries, there is an urgent need for studies comparing ecosystems inside reserves with those outside. It is particularly important to obtain baseline information before new reserves are created, and to study subsequent changes in the system.

An important logistical need that is often overlooked with respect to subtidal research is the requirement for SCUBA capability. We need to maintain enough centres around the coast with the equipment and personnel to work in the shallow subtidal, where diving-time limits the work that can be done, and where team effort is essential.

What are the threats to ecosystem functioning?

The threats to ecosystem functioning in the shallow subtidal arise mainly from human activities such as coastal development, poor agricultural practices, and over-fishing. Threats include:

- Resource use (e.g. fishing), especially over-exploitation of keystone species
- Physical damage to biota on reefs as a result of fishing practices e.g. trawling
- Divers physically damaging coral reefs and removing keystone species from rocky reefs
- Pollution e.g. fishing lines and plastic on coral reefs
- Sedimentation from river runoff
- Siltation caused by shallow-water diamond mining on the west coast
- Introduction of alien species
- Possible climate-change affects

What is the status of expertise and what capacity is lacking?

In general there is less expertise on the subject of subtidal reefs than in the case of intertidal rocky shores, and this is reflected in the relatively poor knowledge of subtidal ecosystems. Furthermore, most researchers (especially fisheries scientists) work on single species, so that expertise in systems approaches is lacking countrywide. Despite the fact that some researchers question whether true ecosystem modelling is a viable goal (both from the point of view of available skills and applicability in management) it is clear that we need expertise in looking at the reef as a whole, as well as competent biologists to concentrate on particular questions or species. Furthermore, we sorely lack biologists who are competent to work with larvae.

The Western Cape is relatively well endowed with marine scientists, although even here there is relatively little capacity for ecosystem modelling. On the south coast and in the Eastern Cape there are marine biologists at the Universities of Port Elizabeth, Rhodes, and Transkei (Unitra), but probably only an effective diving capability at Port Elizabeth.

In KwaZulu-Natal there is little capacity to fill the gaps mentioned above, particularly in relation to physico-chemical studies on small-scale transport. A number of organisations are involved in marine biology (Oceanographic Research Institute, Council for Scientific and Industrial Research, Coastal Research Unit of Zululand, Institute for Natural Resources, University of Natal (Durban)) but all are severely financially strained. They are unlikely to be able to meet future needs or to undertake large new studies, for example modelling.

In general, it is important to develop expertise and leadership in all of the subjects mentioned here. This should be done both by training locals and by encouraging the involvement of foreign experts. Support for post-doctoral studies is crucial for the latter.

What is the status of the link between ecosystem functioning and management?

In general this needs to be improved. No reef ecosystems are monitored to check on the effects of use (usually species removal) and relative health can only be assessed from indicators such as catch records.

Furthermore, even when information is available on species, this is often not conveyed to management. Many researchers believe that the information in reports and scientific papers is often not used in management, and that this is the fault of both researchers and managers. It is not clear how to improve this situation, but it needs attention.

In the Western Cape Province the communication between scientists and management is generally good (via Marine and Coastal Management) in terms of the current single species approach, but the knowledge is lacking for a systems approach.

On the south coast there appears to be very little basic information, and generally poor linkage with management authorities (e.g. in the Eastern Cape).

In KwaZulu-Natal the linkage structures are relatively well developed (via the KwaZulu-Natal Nature Conservation Services, the KwaZulu-Natal Fisheries Licensing Board, Coastal Fisheries Liaison Committee, etc.). However, the management strategies in place generally focus on single species fisheries, particularly outside the Marine Protected Areas.

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FUNCTIONAL ECOSYSTEMS

SOFT SUBTIDAL SUBSTRATES

by R.W. Leslie in consultation with R.L. Tilney & J. Rogers

What is the status of our knowledge of ecosystem functioning?

There have been numerous studies of soft-sediment ecosystems internationally (see Alongi, 1990; Wilson and Brown, 1991), although there is very little known of local systems. An understanding of the physical environment is essential to understanding the ecology of soft-sediments. The status of our knowledge of the marine-geological aspects of the sediments off South Africa has been well reviewed by Rogers and Bremner (1991). This work has been extended by Bailey and Rogers (1997) and the database is available from H. van der Merwe (Geological Survey, Belville). However, the "geological" view of sediments is inappropriate when applied to benthic ecological studies (see Watling, 1991). There have been some studies on substrate damage due to mining. The effect of trawling and dredging on the benthos and the soft-sediment ecosystem is a very topical subject internationally. There is a wealth of international literature available (see Hall, 1994). The structure of the soft-sediment, and especially of infaunal, communities is very poorly known. There have been some studies of the trawl fish communities associated with soft-sediments (Roel, 1987; Badenhorst & Smale, 1991; Smale & Badenhorst, 1991; Smale *et al.*, 1993). Although there is very little known of the trophic functioning of the infauna and benthic invertebrates, there is some knowledge of the diet and trophic relationships amongst, trawl-caught teleosts and chondrichthyans (Macpherson & Roel, 1987; Meyer & Smale, 1991a; 1991b; Smale, 1993). On 15-19 March 1999, an ICES/SCOR symposium on "Ecosystem effects of fishing" was held in Montpelier, France. An important finding presented at this symposium was that standard measures of diversity and species richness have limited use in detecting the impacts of disturbance. This is because disturbance often leads to a change in entire communities, without changing species richness or diversity (L. Hutchins, pers. comm.).

What gaps exist in our knowledge of ecosystem functioning?

- Knowledge of the sediment at a scale appropriate to benthic infauna.
- The effects of trawling on the ecosystem have not been studied locally. In March 1999 three dives were carried out on the submersible, Jago, to identify a suitable site for an investigation into the effects of bottom trawling on soft sediments. A heavily trawled and an untrawled site were found and these will be investigated using grab and dredge samples. (De Beers Marine and Marine and Coastal Management.)
- The effects of mining on the ecosystem. An "International symposium on co-management of coastal/sea-bed mining and living marine resources off the west coast of southern Africa" was to be held in Swakopmund, Namibia in March 1999. However, this has been postponed.
- Knowledge of the effects of release of reduced chemical compounds (e.g. sulphide, ammonia and nitrite) occurring following physical disturbance of soft subtidal substrates on our organic-rich west coast sediments during mining and trawling operations. These compounds are known to exist in quite high quantities in the anoxic sediment zone just below the sediment interface and can be toxic to many species of fish.
- A major knowledge void is the benthic infauna (community structure, recruitment, productivity, etc.).
- Not much is known of ecosystem functioning, especially the links between the benthos and free-swimming predators.

What are the threats to ecosystem functioning?

- Fishing (substrate damage and exploitation, loss and dumping of fishing gear).

- Pollution (e.g. fallout from oil spills, effluent pipelines, aquaculture).
- Marine dump sites e.g. for material dredged from harbours.
- Mining of the sea-bed.
- Poor agricultural land management practices resulting in excessive silt loading of the many rapidly-flowing rivers which enter the sea on our east coast, threatening the survival of reef communities.

What is the status of expertise and what capacity is lacking?

- Lack of benthic biologists and ecologists.
- Lack of funding, suitable equipment (under water video, etc.) and expertise to investigate benthic ecology/ecosystem functioning and the effects of trawling, etc.

What is the status of the link between ecosystem functioning and management?

There is a need to consider the benthic ecosystem in the management of the South African fishery and mariculture industries, and the possible effects on the benthos must be considered when selecting potential sites for mariculture. Recent work by Le Clus and co-workers (Le Clus *et al.*, 1994; 1996; Le Clus & Roberts, 1995) has elicited the effect of the substrate on distribution and catch rates (and hence management) of Agulhas sole *Austroglossus pectoralis*. The introduction of open ocean marine reserves and areas closed to trawling must be considered. Although at present it would be impossible to police an open ocean marine reserve, it may become feasible once vessel-monitoring systems are installed on all fishing vessels.

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FUNCTIONAL ECOSYSTEMS

THE PELAGIC OPEN OCEAN

by L. Hutchings, M.J. Gibbons & R.J.M. Crawford

What is the status of our knowledge of ecosystem functioning?

South African pelagic ecosystems are characterised by a high species diversity and high oceanographic variability. Productivity varies around the coast so that largely subsistence fisheries along the east coast replace the rich commercial fisheries in the Benguela ecosystem. Our understanding of ecosystem functioning is decidedly patchy. In areas of rich fisheries, such as the south-west Cape, a considerable amount of information is known about the structure and functioning of the ecosystem, but less data are available for the Agulhas Bank region and even less for the west coast north of 32 S. The narrow shelf off KwaZulu-Natal and the eastern Cape was intensively studied in the 1970's but there has been little research since, especially of a functional nature. The same is also true of the oceanic waters round South Africa.

The primary producers are microscopic phytoplankton in the 0.1 - 300 µm size range. Production is largely driven by physical processes such as winds, tides, currents and light levels. There is negligible input of nutrients or organic matter from rivers and estuaries to the open ocean, except on localised scales of a few kilometres. In areas influenced by wind-driven upwelling, newly upwelled water is colonised by a variety of phytoplankton species, and succession is coherent at higher taxonomic levels. Small flagellates initially develop minor blooms before they are controlled by micro herbivores, and they are replaced by small diatoms, large diatoms and dinoflagellates consecutively. As these "large phytoplankton" utilise the bulk of the new nitrogen in the surface layers, the blooms decline and small nanophytoplankton come to dominate at much lower biomass levels. The pulsed, intensive nature of upwelling in the southern Benguela results in a series of ephemeral blooms, which are mismatched in space and time with planktivorous herbivores such as copepods and euphausiids.

Small, shoaling pelagic and mesopelagic fish consume a mixture of phytoplankton and zooplankton in competition with gelatinous predators, and in turn form the forage for larger predators, such as hake, snoek and tuna, and marine birds and mammals. By comparison with the Peru-Chile system, relatively low yields of harvestable fish are produced in the Benguela and this is the focus of considerable scientific debate at present.

There are long-term changes in the abundance of important forage fish species. Notably, anchovy and sardine have tended to alternate as the dominant food of predators. There have also been periods when horse mackerel and chub mackerel have been exceptionally abundant. There is evidence that these large-scale, protracted "regimes" of abundance of species occurred prior to intensive exploitation of them by man. However, it is also clear that fishing may substantially modify regimes, by shortening periods of abundance of a species and depressing peaks in biomass, or prolonging periods of low biomass of a species. In extreme cases, fishing may influence the natural succession of fish species. Although the combined biomass of forage fish tends to be more stable than that of individual species, there are periods when the combined biomass is depressed, especially when the dominance of fish species in the system is changing. Different species of forage fish have different distributions, although there is substantial overlap in some instances such that, for example, young anchovy and sardine may be found in the same shoal. A species may change its distribution from year to year, and in different periods of high abundance may have a substantially different distribution. Therefore, the species-composition, abundance and distribution of fish prey exhibit considerable variation.

Sea-birds reflect the variability in forage fish populations. Their diet has been shown to closely match survey estimates of fish stock abundance. Some sea-birds are dependent on particular fish prey, and their populations increase when that fish is plentiful and *vice versa*. Others are able to change their diet between different prey organisms and maintain stable populations.

What gaps exist in our knowledge of ecosystem functioning?

Although energy flows from the phytoplankton through a variety of planktonic grazers to the top predators, this constitutes only one (probably minor) pathway. However, only recently has an attempt been made (Jarre-Teichmann *et al.,* 1998) to quantify trophic flow through the Benguela ecosystem. From these models it is clear that we require better data on the sedimentation of organic matter and the recycling of carbon and nitrogen through the microbial food web. No attempts at modelling ecosystem function have been made for the Agulhas Bank, the open ocean or the east coast, because of a lack of data.

Exports from the shelf system to the open ocean (via advection and sinking), to the atmosphere (via gaseous exchange), and to the sediments are largely unquantified.

Whereas diatoms and dinoflagellates have been studied in a limited area in the south-western Cape, the smaller pico- and nano-phytoplankton have received little attention anywhere. Primary production measurements are scarce except in the south-western Cape. The SEAWIFS satellite colour imagery needs to be combined with measurements of photosynthesis-irradiance (P-I) relationships to produce good areal estimates of primary production.

Although studies of the major zooplankton taxa were undertaken in the 1950's and 1960's, they were limited in areal coverage and were largely qualitative. These were followed by autecological studies (growth, feeding, behaviour, distribution, seasonal life cycles, etc.) of only a few of the dominant copepods, chaetognaths and euphausiids. A large number of important species have not been studied at all.

Some research on the role of gelatinous organisms is progressing, but with limited manpower and funding. Gelatinous organisms may constitute an ecologically stable assemblage and in perturbed systems (such as the Black Sea or possibly Namibia), they may have dire economic effects through the suppression of commercially valuable fisheries.

Autecological studies of only a few of the dominant and economically important fish species have been conducted. A major gap in knowledge is the early life-history of nearly all the dominant or common species, particularly as the year-class strengths of many of the organisms are determined during the early phases, when the planktonic larvae are subject to environmental perturbations. The assumption is generally made that natural mortality of fish populations remains constant from year to year, but this is unlikely to be the case and requires investigation.

Our understanding of ecosystem functioning in regions other than the south-western Cape is very poor, largely for logistic reasons. Seasonal and depth-stratified studies in particular are lacking for many parts of the pelagic zone, as they are only sampled during infrequent fishery surveys.

What are the threats to ecosystem functioning?

South African marine resources are intensively harvested at present, and as technology improves there are continual, subtle increases in fishing efficiency. Studies on the ecosystem effects of fishing have only recently been considered. These include substrate damage, removal of selected components, the non-sustainable utilisation of resources due to illegal activities or under-reported catches, by-catch mortality and dumping, incidental mortality of associated bird and mammal predators, and insufficient food for predators. Some of these effects may be elucidated using models of ecosystem functioning (e.g. the removal of forage fish) but others will require dedicated research effort.

The influence of climate change on ecosystem functioning is unknown. Climate change may induce regime shifts (e.g. sardines to anchovies), or result in radical changes to the recruitment success of certain species. The location of South Africa at mid-latitudes and at the confluence of two major ocean current systems makes the whole ecosystem vulnerable to large-scale climate changes. This is in some way mitigated by the opportunistic nature of many of the key organisms present, which are highly adaptable to changed circumstances.

The energetic nature of the physical system, with strong wave action, currents and winds means that the threat of pollution from oil extraction, or shipping- and terrestrial-based discharges are unlikely to affect regularly the open ocean environment. However, some oil spills have had disastrous consequences for sea-birds.

The high primary production and associated red tides and high sedimentation of organic matter make sheltered bays on the west coast susceptible to organic overloading, which can lead to development of intense local anoxia.

The threat of introducing foreign pelagic species from ship-ballast is real, but except in enclosed embayments or on the central Agulhas Bank it is unlikely to have any lasting impact.

Some predators, such as seals, which scavenge behind trawlers and breed at secluded mainland sites, from which predators have been removed, have been advantaged relative to others. Others, e.g. penguins that formerly nested in burrows in accumulated deposits of guano that has been removed from islands, and that feed on epipelagic shoaling fish that is harvested in large quantities by purse-seine boats, have been disadvantaged by man's activities. This has altered the species composition of the top predators, and has led to interactions between them that have further exacerbated conservation issues.

What is the status of expertise and what capacity is lacking?

Other than in fields directly related to resources that are exploited, expertise in open-ocean research is experiencing a drastic decline. There is a dearth of mathematically competent biologists or biologically competent mathematicians, who can effectively combine ecological expertise with fish stock assessment and modelling.

Expertise in biological, physical and chemical oceanography is limited in South Africa. The lack of access to open-ocean sampling is a major deterrent to potential newcomers at universities and institutions such as JLB Smith Institute for Ichthyology and the Oceanographic Research Institute. This is combined with a general restriction in funding for basic research, and a need for people-orientated and "relevant" research on harvestable resources. Indeed, much of the research in oceanography is funded through the Department of Environmental Affairs and Tourism in the execution of "line-function" aspects of the mission of Marine and Coastal Management. This has resulted in a focus on the routine monitoring of fish resources, while there has been a dramatic decline in the amount of ships time available for process-orientated research. Creativity and skilful motivation are required to embed some original research within the constraints of routine fishery surveys.

What is the status of the link between ecosystem functioning and management?

Fish production, particularly of short-lived pelagic species, is characterised by high levels of variability and is driven by as yet little-understood mechanisms that link planktonic productivity to the survival and growth of fish. The management of fisheries is restricted to the manipulation of effort to control fishing mortality. However, most fisheries management systems currently in place have of necessity ignored much of the ecological complexity of the environment, including natural fluctuations, because of a lack of precision in estimating the effects of the environment on fish populations. A range of variability about some mean value of recruitment is assumed, and is taken into account as an element of risk in the operational management procedure, with some flexibility for limited species interactions.

Some progress has been made using environmental and biological factors in expert systems, to predict pelagic fish recruitment a few months ahead of the main fishing season. However these have not been formally adopted within the operational management procedure.

Information is becoming available that will permit models of the dependence of some species on others to be developed, the two being linked through functional relationships. This will enable cognisance to be taken of the needs of dependent species when managing fish stocks. At present predator requirements are not specifically accounted for.

The shift in emphasis towards biodiversity management and the realisation that environmental effects are often major determinants of year-class strength are posing considerable challenges for traditional fisheries management practices. While comprehensive ecosystem management is still operationally well into the future, it is clearly the approach which has to be adopted for progress to be made.

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FUNCTIONAL ECOSYSTEMS

THE DEEP-SEA

by M.E. Anderson & P.A. Hulley

Historically, deep-sea research has occurred in bursts of activity in a few developed nations. Although South Africa has not yet been an international partner in emerging technologies or explorations of the deep-sea, our own research cruises off KwaZulu-Natal and the west coast starting in the 1970's resulted in qualitative, mainly systematic, works that have formed a limited knowledge base locally. As questions on ecosystem structure and function require quantitative approaches, and, as no such studies exist for the deep-sea off South Africa, many of our comments are extrapolated from relevant studies elsewhere.

The "deep-sea" is here considered as two habitats: the deep pelagic midwaters (meso- and bathypelagic zones) and the benthos (the continental slope, or bathyal zone). Another benthic zone, the open abyssal plain, or depths greater than about 4 000 m, is so poorly known worldwide that we do not discuss our local abyssal zone. To our knowledge, it has never been directly sampled by South Africans, although one of us (M.E.A.) was involved in a Russian sampling voyage that trawled the floor of the Mozambique Channel. Each of the habitats described above is dealt with separately.

What is the status of our knowledge of ecosystem functioning?

Bathyal zone: The structure of ecosystems can be directly assessed or inferred from relevant studies on abundance, species diversity and richness, zonation, biogeographic analysis or biomass estimates, to name a few parameters. No study of the bathyal community to date has been undertaken in our waters, yet several local researchers know major structural differences between the tropical eastern and temperate west coasts. Studies on fish communities reveal poor faunal zonation in these mobile organisms (Haedrich & Merrett, 1990), while zonation is strong in ophiuroids (Tyler, 1980). No data exists on zonation in our waters. Biogeographic analysis on selected groups in South African waters has revealed connections to temperate North Atlantic, tropical Indo-West Pacific and cosmopolitan faunas, with a small degree of endemism, in grenadier fishes (Iwamoto & Anderson, 1994), hydroids (Millard, 1978), pennatulaceans (Willaims, 1990), bryozoans (Hayward & Cook, 1979), brachiopods (Hiller, 1986), isopods (Kensley, 1984) and pycnogonids (Arnaud & Child, 1988). No data exists on abundance, species diversity, species richness, biomass estimates or trophic structure of the complete ecosystem. Studies in the North Atlantic and elsewhere, if inferred for southern African waters, may be somewhat accurate, but no hard data exists to test this (Grassle & Maciolek, 1992; Haedrich & Merrett, 1992; Wishner, 1980). Roel (1987) quantified the west coast shelf-to-shelf/slope break megabenthic community, but sampling concluded at 500 m thereby giving a very incomplete picture of that upper bathyal (a community probably extending from about 350 to 1800 m here). Payne *et al.* (1987) elucidated the trophic role of hake in the west coast deep shelf-upper slope showing their opportunistic, prey-switching abilities and size, spatial and temporal prey variabilities. MacPherson & Roel (1987) described three major trophic groups of west coast demersal fishes to a depth of 650 m pointing out size and spatial variation in food habits in some species, while others had no such variation. In addition, abundance, niche width and diversity were discussed to enhance knowledge of community structure. However, this paper contains several taxonomic misidentifications and some deep pelagic fishes were included in the analysis that should have been omitted.

Ecosystem functioning in our bathyal waters may be discussed in light of works such as Rowe and Pariente (1992), but no energy-flow diagrams, productivity measurements, observations on competitive interactions, predator-prey models or the role of biological disturbance exist (see Dayton & Hessler, 1972; Richardson *et al.*, 1985; Robison & Bailey, 1981; Rowe, 1971; Stockton & De Laca, 1982; Wakefield & Smith, 1990).

Deep-pelagic zones: Grindley & Penrith (1965) described the biogeographic affinities of some of the local mesopelagic fauna (not bathypelagic as per title of paper) based on 45 trawl stations made during 1960-1963. Qualitative midwater trawl surveys undertaken during the 1970's and 1980's off the west coast and KwaZulu-Natal collected many deep-pelagic organisms, yet few papers on community structure or function resulted from these efforts. Hulley & Prosch (1987) estimated stock sizes, vertical migration and reproductive energetics in the abundant mesopelagic lanternfish *Lampanyctodes hectoris* and lightfish *Maurolicus walvisensis* (as *M. muelleri*). Hulley (1992) queried ideas on zonation and discussed lanternfish community structure and catch rates from which biomass may be inferred.

Biogeographic data relevant to our deep pelagic faunas may refer from those on lanternfishes (Hulley, 1986; 1989; Krefft, 1978; McGinnis, 1982; Rubies, 1985). Hulley & Lutjeharms (1989) elucidated the oceanic/pseudoceanic interface on the Cape west coast based on lanternfish distributions. However, this knowledge cannot be contextualized at a South African level. Taxonomic work (Smith & Heemstra, 1986; De Decker, 1973; 1984; Hulley, 1981; 1986; Kensley, 1983) suggests that few, if any, deep pelagic species are endemic to our region. Rather, they represent components either of the zonally-distributed faunas of the Atlantic and Southern Ocean, or of the gyrally-distributed faunas of the Indo-West Pacific. Models developed elsewhere could well serve as the launch pad for elucidating the structural dynamics of the southern African deep-sea ecosystems. Cohen (1986) examined the diversity and biomass, and their latitudinal gradients, of western Indian Ocean deep-pelagic fishes. Also in that area, Ryther *et al.* (1966) reported on primary productivity in relation to water chemistry and hydrography. Energy transport through the habitat by way of upwelling, vertical migrators and detritus fall ("marine snow") is well documented elsewhere, but unstudied in our waters (Bogdanov, 1965; Garrison, 1976; Silver & Alldridge, 1981). No studies exist on the physical role of currents on population disturbance, predator-prey relationships or competition in this habitat off South Africa.

What gaps exist in our knowledge of ecosystem functioning?

Bathyal zone: No ecological data from any dedicated, quantitative survey of any of the deep-sea habitats has been published, although Marine and Coastal Management (MCM) has trawl results from numerous, time-quantified benthic tows down to a depth of about 1500 m. We expect a megabenthos species diversity peak at about that depth for this zone. MCM's data needs to be analyzed now and the structure of the megabenthos described. Quantitative surveys of the macrobenthos and meiobenthos using a half-meter box core need to be undertaken. An ecological survey should aim to answer such questions as:

- What is the total annual production of nutrients from the euphotic zone by given depth increments from 300 to 3 500 meters? What is the role of mesopelagic vertical migrators in this transport?
- What is the relationship between depth and relative abundance, biomass, age/size class, species diversity and species richness?
- How do food web models vary temporally and spatially, particularly within biogeographic realms (i.e. tropical east coast; west coast plus Agulhas Bank)?
- What are the effects of the present deep-water fisheries on community structure and function?
- To what degree is extralimital recruitment important to exploited or exploitable stocks?
- What is the effect of submarine canyons and hard bottom outcrops on community structure and function? (It is expected these serve to concentrate organisms, but this may not be directly observable without a deep submersible survey).

Deep-pelagic zones: The same basic questions above need to be addressed for these zones, although the effects of fishery operations at present will have very little impact on the deep-pelagic zones.

The first question (above) may be modified to: what is the role of the upper-level vertical migrators on energy transport within the mesopelagic zone and to non-migrating bathypelagic organisms? Another important question that needs addressing is: what is the effect of predation by certain deep-water nekton and macrozooplankton on larvae of commercially utilized stocks (i.e. hake and rock lobsters)?

The largest gap in our knowledge of the functioning of these ecosystems lies in the fact that South Africa has not entered a quantitative phase in deep-sea biological exploration.

What are the threats to ecosystem functioning?

The deep-sea is the world's largest series of interconnected habitats. Generally beyond the reach of man, threats to ecosystem functioning off South Africa are minimal, and the three zones considered here are rather pristine. Some points to be made are:

- Gross overfishing or pollution in surface waters, if serious enough to reduce the productivity of the euphotic zone, would subsequently cause population reductions and interfere with community equilibrium in deeper waters. With our present management over these waters and the dynamics of the Benguela and Agulhas current systems, this is an unlikely eventuality.
- Overfishing bathyal stocks of commercial fishes and squid may temporarily increase local populations of the macrobenthos. The subsequent stress on this fauna, already existing in a food-poor environment, could lead to local crashes as populations exceed their resource bases. Also an unlikely scenario.
- The temporary nature of El Niño Southern Oscillation (ENSO) effects on local surface productivity probably has an extremely slight impact on the deep-sea faunas.
- Pollution from sunken ships, oil platforms, etc., probably has very localized effects, and perhaps no lasting effect on the mobile fauna.
- It is widely known that radionuclides in deep-sea sediments occur at elevated levels compared to terrestrial systems, chiefly due to the inverse relationship between the concentration of uranium disintegrants and calcium carbonate (Gage & Tyler, 1991). Therefore, use of our waters for deep-sea dumpsites of reactor waste by foreign powers who may be willing to pay well for the service, as well as our own nuclear industry, should be discouraged until more is known about the physical and biological parameters of our deep benthos, particularly the continental rise/abyss.
- Introduction of invasive species is not an issue.

What is the status of expertise and what capacity is lacking?

There are few South African workers today presently occupied with deep-sea biology. Limited expertise, but without much of an experimental research impetus, can be found at MCM. The South African Museum and the JLB Smith Institute have permanent staff regularly working on the systematics of deep-sea organisms, notably fishes, cephalopods and crustaceans. The authors of this report are among that group, but are also studying aspects of deep-sea fish ecology and biogeography. The Universities of Cape Town and Port Elizabeth have staff capable in taxonomy and identification services of selected deep-sea invertebrate groups. Terrestrial or near-shore marine ecologists who might work in these habitats have not been given either the opportunity or shown interest in the deep-sea owing to other research agendas, funding shortages, logistical problems or past national priorities.

Limiting factors in the development of capacity to initiate quantitative deep-sea ecology revolve around:

- All deep-sea surveys, especially submersible research as suggested above, are extremely expensive. Thus, this work may be seen as an unaffordable luxury in some circles in terms of South Africa's present political outlook. Unmanned robots (ROVs) are less expensive to operate than submersibles, but require an expensive infrastructure beyond the present capabilities of the country.
- Owing primarily to the reliance on MCM for scientific collection, there is little interest in academic deep-sea biology in the country. This could be rectified by broadening South Africa's international exchanges by both professionals and foreign student participation in directed programmes, pursuant to shiptime availability. Development of international contacts has been a major priority to both authors of this report.
- By expanding the scope of MCM monitoring in the deep habitats and coupling that with a work up of the quantitative data that already exists, these sources could help build capacity in the declining base of taxonomic expertise in the country and provide opportunities to engage needed ecological studies.
- Scientific collecting in these habitats aboard commercial trawlers is of a nature that is limited to gathering data on life history parameters and general biology.

- South Africa has no national scientific vessel for academic use such as the American UNOLS system, the Japanese JMARC ships, or the British, Canadian, German, Russian or Australian national government research vessels. The country also lacks the infrastructure and funding capacity to maintain such a system. This might be alleviated if MCM were encouraged, through a different funding system than is now in place, to contract ships out to other concerns. There is no incentive to do this at present owing to MCM's centralized budget structures. From previous mandates, MCM has invited proposals for shiptime, but requests for deep-sea surveys have not been fruitful since the change in government (1994). Nevertheless, some funds should be found for deep-sea research to fulfil our international and national obligations, especially the UN signatory agreements (see International and National Policies section, this report).

What is the status of the link between ecosystem functioning and management?

As the deep-sea off South Africa is little impacted at present, no major concerns now exist. Harvesting of hake, squid and all by-catch is a scientifically managed operation that, despite decreasing stocks in recent years, is healthy. These fisheries do not impact the region of species diversity maxima on the slopes nor the deep-pelagic realms. Future, potentially unrestrained, foreign fisheries involvement for our financial gain or local allowances for political expediency requires vigilance, monitoring of adverse ecosystem effects and policy development. Continuous, long-term monitoring of the upper bathyal zone is therefore required (of MCM), a difficult task without knowing much about community structure. In the near future the country will need to formulate policies regarding deep-mineral exploitation off the west coast, as the impact of sea-floor mining on benthic communities can be immense.

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FUNCTIONAL ECOSYSTEMS

COASTAL ISLANDS

by A.J. Williams, N.T.W. Klages & R.J.M. Crawford

Islands, unlike sandy beaches, rocky shores, abyssal plains, etc., are too diverse to form internationally comparable ecosystems, and so lack a study discipline. However, there are a number of factors which together make southern Africa's 33 continental islands a discrete bio-geographical unit worthy of comparison with regional ecosystems in terms of biological diversity.

Southern African coastal islands are more similar to each other than any is to other islands along Africa's coast. All are fundamentally rocky, whereas tropical African islands tend to be accretions of sediments. All southern African islands experience sparse or strongly seasonal precipitation which inhibits plant growth, whereas tropical islands have more reliable precipitation and are plant, often tree, dominated. The seas of southern Africa are more dynamic, and so more difficult to swim or sail across, than those of the tropics. As a result southern African islands have remained free of Africa's diverse terrestrial mammalian predators including, until the arrival of Europeans, the worst predator of all – man. This safety from terrestrial predators made the islands' limited areas (currently less than 2 000 hectares in total but formerly, with variable sea levels both substantially larger and possibly much smaller) favourable for breeding colonies of the Cape Fur-seal *Arctocephalus pusillus* and a suite of sea-bird species, six of which are effectively endemic to these islands, where it is likely that they evolved.

The common ecological factor linking southern Africa's islands as terrestrial entities is the dominance by seals and sea-birds with resultant trampling and, especially, by geo-historic accumulation of seal and sea-bird products, notably guano. The combination of trampling, smothering by guano, and restricted precipitation has led to a minimisation of niches and depauperate plant and invertebrate communities. Near-shore inter- and sub-tidal waters around the islands are substantially impacted by seals and sea-bird concentrations, relative to areas away from the islands, through the high input of nutrients either from faeces released directly into the water or from guano, etc., washed off the islands. Similarly there are local depletions of prey and to an extent materials, especially algae removed for nest materials, from adjacent inter- and sub-tidal waters. No fixed boundaries can be placed on this marine "island" element which for convenience is here taken to be waters within 500 m of the islands.

European settlement in southern Africa has seen dramatic changes in island communities. Seal killing, which exterminated seals from many islands, may have led to an increase in numbers of sea-birds through reduced competition for breeding space and for food. The mid-1840's saw the removal of accumulated guano deposits from all southern African islands, a radical ecological change to these systems. The value of guano as a resource led to early protection of selected sea-birds at islands, as a result of which all still have official protection. Regular removal of guano, coupled with a general reduction in seal and sea-bird numbers at most islands, has created new terrestrial niches. These are currently being colonised by species that are considered weeds or "aliens". Subsequently increase in seal numbers and changes in sea-bird numbers, substantially influenced directly or indirectly by human activities, have varyingly impacted island ecology. The overall result is an "ecosystem" dominated by anthropogenic influence.

Globally islands are often rich in endemic species. Southern Africa's coastal islands, apparently, have no endemic plants or invertebrates and the only species truly endemic to the islands is the Cape Gannet *Morus capensis*, as all other regionally breeding sea-birds have some mainland populations. However, it is believed that the African Penguin *Spheniscus demersus*, Bank, Cape and Crowned Cormorants, *Phalacrocorax neglectus*, *capensis* and *coronatus* respectively, and the Hartlaub's Gull *Larus hartlaubii* evolved on the islands and have subsequently colonised the mainland. Two key factors restrict endemism at southern African coastal islands: guano smothering and sea level changes. Guano smothering suppresses endemism by minimising niches. Geologically recent major sea-level changes have temporarily linked many islands to the mainland at times of lowered sea-level or have swamped islands at times of raised sea-level. There are a few cut-off populations of terrestrial vertebrate species at the islands, e.g. lizards on Algoa Bay and some Atlantic coast islands. There is no indication that island populations of these species differ substantially from mainland populations, though the genetic identity and dynamics of these populations merit study.

The status of the near-shore marine biota of the islands is less well known, but there seem to be no species yet known which are endemic to any of southern Africa's islands. The importance of the island near-shore biotas lies in the fact that most have been less exploited than mainland equivalents and the islands should therefore form biodiversity reservoirs.

The text so far has striven to emphasis the broad similarities of southern African islands. However, it is critical to appreciate that these islands vary considerably in terms of their geology, size, and especially in their location, cadastrally, distance off-shore as well as local oceanographic and climatic conditions. This individuality must enhance the overall bio-diversity of the islands' near-shore waters but emphasises the fact that protection of one or two islands will not ensure protection of the full range of biodiversity represented by the islands as a whole.

Most South African islands are under the control of authorities whose managers are terrestrially focused and for whom the islands often have a peripheral interest. In Namibia all islands fall under a ministry with a marine exploitative focus. Scientists conducting studies at or around all the southern African islands tend to be taxa focused. Marine resource managers tend to ignore the islands because of their minuscule size. The overall result is lack of appreciation of the islands, a situation that has been worsened recently by increased diversity of political control. It must be appreciated that the islands have many features in common, certainly more in common with one another than most have with their adjacent mainland. Therefore the protection of the biodiversity the islands support requires planning and co-ordination at a level encompassing all island controlling authorities, as well as marine resource managers and affected scientists. There is a need to bring together the interested parties in a workshop to exchange ideas and co-ordinate and prioritise actions and to establish means for future discussion and regionally planned management of the islands and their near-shore waters. Threats to the islands are increasing. These include pressures to open islands for public ecotourism interests and, more seriously, through the potential impact on islands of major regional industrial development schemes – notably around Saldanha Bay and Coega in Algoa Bay.

We still lack basic inventories of terrestrial invertebrates at many islands, and especially we lack documented inventories of the near-shore taxa around most islands. Yet it is in the near-shore environments that the most drastic inter-island differences have been found, e.g. between Malgas and Marcus islands.

What is the status of our knowledge of ecosystem functioning?

The numbers and population trends of the dominant vertebrates – seals and sea-birds – are well known. Indeed these data sets are among the world's best, but knowledge of the role of these animals as food consumers is less well known and even less is known about the demographic parameters, movements between islands, and the likely response of populations to long-term changes. There is 1980's base-line documentation of macro-invertebrate diversity but further investigation is needed to record invasion of plants and invertebrates, as these communities are often dynamic.

The inter- and sub-tidal biota of island near-shore waters is generally strongly influenced by the terrestrial biota and may differ markedly from shores of adjacent mainland. They merit consideration as distinct ecosystems. There is evidence, from islands in Saldanha Bay, that biota in near-shore waters can differ dramatically between islands but this is poorly documented. The relationship between island terrestrial inputs and adjacent near-shore communities is poorly known except for Saldanha Bay islands.

What gaps exist in our knowledge of ecosystem functioning?

The dynamics of imports from the marine system and the effects on these of demographic changes on the main terrestrial contributors is poorly known. Further study is needed of the nutrient and energy transport to and from islands and of the turnover of these products. Because of this we cannot determine the roles played by the islands in adjacent marine systems and the possible effects these may have on fish and shellfish production.

In terms of the dominant, marine-foraging sea-birds we still lack information on the foraging dynamics (ranges, depths, and diet) of some species and the degree of inter-island exchange (i.e. how discrete each island's populations are). We also lack some demographic parameters, especially on the survival of immatures, the age of first breeding, the longevity of adults, and on lifetime breeding success rates.

Little is known of the genetic identity and dynamics of isolated populations of vertebrates (mice, lizards, and snakes) at southern African islands. It is sometimes suggested that shallow waters around islands may have an important role as nursery areas for some commercial species, but lack of formal protection below the high-water mark indicates this is not widely known nor accepted.

What are the threats to ecosystem functioning?

Reduced availability of food, notably shoaling, near-surface pelagic fish (pilchard, anchovy) as a result of human fisheries and, locally, high numbers of fur-seals, has penalised some specialist-foraging sea-birds (African Penguin, Bank and Cape Cormorants) and resulted in substantial population decreases. Provision of subsidies in the form of new food sources – dumped fisheries by-catch and terrestrial garbage – has regionally increased numbers of wider ranging or polyphagous species (Cape Fur-seal, Cape Gannet, and Kelp Gull *Larus dominicanus*). Some of these "subsidised" species (fur-seals and Kelp Gulls) prey upon the specialists and this locally compounds adverse conditions such that there may be a severe local population decrease (e.g. African Penguins at Dyer Island). Subsidised species may also become dominant in competition for breeding space, for example seals have evicted sea-birds from several islands during the past 40 years.

Linkage of islands to the mainland by causeways has severely impacted island systems by providing access for terrestrial mammalian predators, including humans, e.g. to Bird Island at Lamberts Bay and to Marcus Island.

Global warming, with increased storm frequency and probable rise in sea-level, will reduce the effective terrestrial area of all islands and may jeopardise species breeding on these areas. Additional threats to the islands' dominant marine foraging seals and sea-birds are:

- pollution, especially from oil spills;
- disease, with increased potential transmission e.g. of Newcastle Disease, by birds using human garbage dumps;
- introduction of predators at manned and at causeway-linked islands;
- through entanglement in fishing gear, nets or long-lines; and
- through disturbance resulting from increased human access, controlled or illegal, to the islands.

Former threats, notably seal culling, penguin egg collection, have effectively ceased as has guano removal at South African, but not all Namibian, islands.

What is the status of expertise and what capacity is lacking?

The island dominating seals and sea-birds are well known and southern Africa has a high international status in terms of population censusing and diet assessments due especially to Bob Rand's pioneering work in the 1950's. We are falling behind in understanding of the activities of island-based vertebrates at sea and, despite the work of Rory Wilson in the late 1970's and early 1980's, specifically have failed to keep abreast of electronic tracking devices, due largely to lack of available funding. We lack understanding of the causes of natural disease mortalities and of mortality in the critical post-fledging period of most sea-bird species, especially the vulnerable African Penguin. The conservation agencies that nominally manage the islands generally lack funds and manpower to tackle the important tasks. There is inadequate veterinary expertise on sea-birds and there is poor expertise in the management of ecotourism.

What is the status of the link between ecosystem functioning and management?

Owing to their location, islands are frequently neglected by mainland-based decision-makers. In general, and in part because of minimal budgets, staff of managed islands have been poorly trained and motivated. The low regard in which islands are held is illustrated by the readiness to incorporate islands as breakwaters e.g. Lambertsbaai, Marcus Island, and proposals in Mossel and Algoa Bays.

There is a marked gap between scientists' perceptions of needs and on-the-ground management implementation. There is a need to implement basic environmental monitoring (temperature, rain measurements, etc.). No account is taken of sea-bird/seal food requirements in the managing of prey resources and the allocation of fishing areas and gear.

Management plans in final or draft form exist for Bird Island Lambertsbaai, Dassen, Robben, Dyer, and the Algoa Bay islands but not for those off Namibia, nor for the smaller South African islands. There is insufficient preparation for control over ecotourism and for coping with bio-emergencies (e.g. oil-spills, disease outbreaks). Importantly there is a serious lack of higher level co-ordination in management of what is a shared resource between the many managing authorities – South African National Parks, Robben Island Museum, Department of Defence, South African provincial conservation authorities and Namibia's Ministry of Fisheries and Marine Resources, etc. Scientists have a - currently inactive - Island Research Liaison Committee but there is no equivalent for managers and consequently little or no higher level inter-change between managers and scientists.

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FUNCTIONAL ECOSYSTEMS

THE PRINCE EDWARD ISLANDS

by S.L. Chown

What is the status of knowledge of ecosystem functioning?

This report is not exhaustive. Much of the available information is in the Prince Edward Islands Management Plan that was published in 1996 by the National Department of Environmental Affairs and Tourism.

Knowledge of the functioning of the Marion Island terrestrial and offshore ecosystem is particularly well advanced thanks to almost continuous biological research at the islands since 1965-66. A considerable amount of work has been done on the functioning of the terrestrial ecosystem, especially the lowland areas, and there has been some offshore ecological work (mostly done during the Marion Island Offshore Ecological Survey). Two ecological fields in particular have benefited from integrated research: the nature and influence of biological invasions, and the effect of climate change on both indigenous species and their interactions with invasives (Hanel & Chown, 1999). This work has been published in the primary literature (see Hanel and Chown, 1999) and an extensive and full bibliography is available online at (http://www.up.ac.za/academic/zoology/Marionpe.htm). Less complete bibliographies are available through the Directorate Antarctica & Islands, Department of Environmental Affairs & Tourism.

What gaps exist in our knowledge of ecosystem functioning?

Particular gaps in our knowledge of the islands and their ecosystems are the absence of data on the link between the terrestrial systems and the pelagic systems surrounding the islands, and the functioning of the terrestrial fellfield system at higher altitudes.

Current projects seek to address these gaps through:

- satellite tracking of pelagic seabirds and mammals coupled with studies of their population dynamics,
- studies of links between the pelagic and terrestrial systems (mostly via marine work and the way that pelagic bird and mammal populations respond to changes in the marine system),
- studies of the vegetation, invertebrates and vertebrates in high altitude areas on the islands.

What are the threats to ecosystem functioning?

Currently there are three major threats to ecosystem functioning.

- Alien species: There are a large number, but four are considered most important. House mice *Mus musculus* pose a considerable threat to ecosystem functioning at Marion Island (they are absent on Prince Edward Island), especially because their impact is predicted to increase with global warming. The alien plant, *Agrostis stolonifera* (*Poaceae*) has taken over more than 50% of the drainage line habitats it is suited to on Marion Island and is still expanding its range. In concert, an introduced fungal pathogen and the diamond back moth (*Plutella xylostella*) pose a significant threat to the indigenous Kerguelen cabbage, a species restricted to only four archipelagos in the southern ocean.
- Longline fishing: Longline fishing for the Patagonian toothfish (*Dissostichus eleginoides*) close offshore of the islands (and elsewhere) is posing a considerable threat to *procellariiform* sea-birds nesting on the islands, particularly *Thallasarche* albatrosses, *Procellaria* petrels and giant petrels (*Macronectes*). The problem goes beyond the real threat of extinction of these populations (which may well be subspecies or species), because these species form important links between the terrestrial and marine ecosystems.

- Uncontrolled tourism: This is likely to increase the chances of alien introductions. Although tourism to Marion Island is under investigation, uncontrolled visits to the pristine Prince Edward Island have already taken place and pose a severe threat to a pristine sub-Antarctic island (only Heard Island is less disturbed).

What is the status of expertise and what capacity is lacking?

There is a considerable body of expertise available concerning the biology of the Prince Edward Islands. However, this body of expertise is dwindling rapidly given that there have been dramatic cuts to the funding for work at this island in recent years.

What is the status of the link between ecosystem functioning and management?

The Prince Edward Islands Management Committee (PEIMC) liases closely with the Biological and Oceanographic Sciences Task Groups and the South African Committee on Antarctic Research (SACAR) of the Department of Environmental Affairs & Tourism. The PEIMC chair has representation at all levels in the Directorate Antarctica & Islands (i.e. in task groups, in SACAR, and within the Antarctic Management Committee). All research at the islands is assessed in light of the requirements of the Management Plan.

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TAXONOMY/SPECIES

PROTISTA AND ANIMALIA

by M.J. Gibbons

The following document essentially summarises the information presented in the accompanying Table (Table 1), to which your attention is drawn. This table in turn is a summary, by phyla, of a much bigger database constructed with the help of numerous international and national experts. It should be noted that some of the data were compiled from the literature by non-experts. Questions of synonymy and validity in these instances have not been addressed and this may lead to bias.

What is the status of taxonomy (including endemism)?

In excess of 11 000 species of marine Protista and Animalia have been described and documented from around South Africa. Of these, approximately 17% are considered to be endemic, or are known only from South African records (and herewith considered endemic - but see Gibbons et al. (1999)).

These summary data can be very misleading. Some taxa are fairly well known, such as the non-Piscean vertebrates, which means that the data are fairly accurate. By contrast, others have hitherto been ignored (the non-foraminiferan protists, and many of the free-living and most of the parasitic invertebrates), and the data are to be treated with caution. For example, it has been estimated that there may be between 1 000 and 10 000 species of free-living protists around South Africa (less than 400 have been described), and as many as 1 000 species of free-living nematodes (358 recorded). Even experts of invertebrate taxa, which are perceived to be relatively well known (through historical effort, such as Annelida and Hydroidomedusa), are unanimous in their opinion that the numbers of documented species are unrealistically small.

Given the incomplete data, comments on endemism are fraught with problems and are likely to be overestimates. This particularly so as the status of taxonomy and species-inventory in South Africa's neighbouring states is likely to be poorer than our own. Nevertheless, the degree of endemism amongst pelagic taxa is generally low, while that of some benthic taxa (e.g. Isopoda) may be in excess of 80%.

What is the status of expertise/capacity in terms of taxonomists?

A total of nine full-time taxonomists are distributed amongst the various institutions and universities in South Africa. A further 16 people have published senior-author papers on taxonomy, but their research is not directed full-time towards unravelling taxonomic/systematic problems. It should be noted that some of these part-time taxonomists have worked in more than one phylum.

The research emphasis of the full-time taxonomists is largely focused on species of commercial importance (fishes and molluscs), as too is much of the effort of the part-time taxonomists. This has not always been the case, and South Africa has produced a number of internationally important taxonomists who have studied taxa of little or no economic value. The current (financial) emphasis on commercial species will serve to perpetuate the lack of interest in other taxa, such as tardigrades and the parasitic phyla, about which we know nothing. This obviously has implications for our full understanding of biodiversity and we will continue to be reliant upon foreign taxonomists working at overseas institutions.

What capacity is needed?

Given that most of the full-time taxonomists, and many of the part-time taxonomists, are likely to retire within the next 10 years or so, the capacity needed is large and urgent. The internationally recognised

Table 1. Approximate number of species and status among most metazoan taxa described from the marine environment around South Africa (to the EEZ).

Phylum	No. spp identi-fied	No. en-demics	% En-demism	Esti-mated No. spp	Global Status of Taxonomy	Global Status of tools	Global Gaps	Status of Outreach	Status of reference collections	Status of tools (RSA)	Importance	Coverage	No. RSA Experts: Full time	No. RSA Experts: Part time
Protista	378	5	1.32	5000	Poor	Morphology, DNA	Inadequate coverage	Very poor	Largely non-existent	Morphology	Geological dating, food webs, parasites, indicators of environmental health, sewage treatment	Very poor	1	0
Placozoa	0				?	?	?	None	Non-existent		?		0	0
Porifera	289	10	3.46		Confused	Morphology, Chemistry, DNA, Allozymes	Inadequate coverage	Poor	Locally poor	Morphology	Source of biomedical compounds, indicators of environmental health, curio trade	Fragmented	0	0
Cnidaria	842	238	28.27		Fair	Morphology, Chemistry, DNA, Allozymes	Incomplete coverage, some revisions needed	Poor	Generally poor	Morphology	Parasites, indicators of environmental health, source of biochemical compounds, curio trade, ecotourism, fisheries pests	Generally poor, especially deep water	0	2
Ctenophora	11	0	0.00		Fairly good	Morphology of living material	Incomplete coverage, especially lobate and benthic forms	Poor	Non-existent	Morphology	Locally important predators of zooplankton and ichthyoplankton	Poor	0	0
Nematoda	358	30	8.38	1000	Fairly good	Morphology, some DNA	Incomplete coverage	Poor	Non-existent	Morphology	Indicators of environmental health, parasites	Very poor	0	0
Platyhelmiths	58	17	29.31		Fair	Morphology, DNA	Incomplete coverage	Poor	Largely non-existent	Morphology	Parasites, indicators of environmental health, potential source of biochemical compounds, important components of food webs	Poor	0	1
Rotifera	0	?		200	Fairly good	Morphology, some DNA and RNA	Incomplete coverage	Poor	Non-existent	Morphology	Source of food for aquaculture industry	Non-existent	0	0
Tardigrada	0	?			?	?	Incomplete coverage	Poor	Non-existent	?	?	Non-existent	0	0
Gastrotricha	0	?			?	?	Incomplete coverage	Poor	Non-existent	?	?	Non-existent	0	0
Kinorhyncha	1	0	0.00		?	?	Incomplete coverage	Poor	Non-existent	?	?	Non-existent	0	0
Annelida	766	161	21.02		Fair but in need of revision	Morphology, DNA, Allozymes	Incomplete coverage, especially oligochaetes	Poor	Fair for polychaetes, non-existent for oligochaetes	Morphology	Bait, indicators of environmental health, important component of benthic food chains and in sediment processing, habitat builders	Poor	0	0
Mollusca	3062	1592	51.99		Fair	Morphology, DNA, Allozymes	Incomplete coverage	Fair	Generally fair	Morphology, Allozymes	Food, curio trade, source of biomedical compounds, geological dating, important in food webs and sediment processing, bait	Patchy, poor in deep water	3	4
Insects	9	4	44.44		?	Morphology (?)	Incomplete coverage	Poor	Poor	Morphology	Decomposers of cast kelp	Poor	0	0
Crustaceans	2333	719	30.82		Generally fair	Morphology, DNA, Allozymes	Incomplete coverage	Poor	Generally poor	Morphology	Food, bait, parasites, important in food chains and sediment processing, source of biomedical compounds, curio trade, dating geological strata	Patchy, poor in deep water	0	6
Arachnids	115	57	49.57		Fairly good	Morphology, Allozymes	Inadequate coverage (especially Halacarida)	Poor	Poor	Morphology	Indicators of environmental health, potential biomedical and veterinary use	Poor, especially deep water	0	1
Brachiopoda	31	15	48.39	35	Fair	Morphology, DNA, Immunology, Biochemistry	Inadequate coverage	Poor	Fair (SA Museum and Albany Museum)	Morphology	Dating geological strata	Poor, especially deep water	0	0
Bryozoa	280	99	35.36	400	Fair	Morphology, DNA, Allozymes, Chemistry (?)	Inadequate coverage	Poor	Poor (SA Museum), others at NHM, London	Morphology	Potential source of biomedical compounds, biofouling, indicators of environmental health	Poor, especially deep water	0	0
Echinodermata	410	187	45.61		Good but out-dated	Morphology, DNA	Inadequate coverage	Fair	Fair	Morphology	Curio trade, food, indicators of environmental health, source of biomedical compounds, important in structuring communities and food webs	Poor, especially deep water	0	1
Priapulida	1	?			?	Morphology	Inadequate coverage	Poor	Non-existent	Morphology	?	Poor	0	0

Table 1, continued

Phylum	No. spp identi-fied	No. en-demics	% En-demism	Esti-mated No. spp	Global Status of Taxonomy	Global Status of tools	Global Gaps	Status of Outreach	Status of reference collections	Status of tools (RSA)	Importance	Coverage	No. RSA Experts: Full time	No. RSA Experts: Part time
Entoprocta	6	?			?	Morphology	?	None	Non-existent	?	?	Non-existent	0	0
Echiura	21	1	4.76		Fair	Morphology	Inadequate coverage	Poor	Poor	Morphology	Sediment processing	Poor, especially deep water & West Coast	0	1
Sipunculida	47	0	0.00		Fair	Morphology	Inadequate coverage	Poor	Poor	Morphology	Sediment processing	Poor, especially deep water & West Coast	0	0
Chaetognatha	28	0	0.00		Good	Morphology, DNA, Allozymes	Inadequate coverage of benthopelagic & benthic species	Poor	Poor	Morphology	Indicators of water mass identity, pivotal role in pelagic food chains	Poor, especially deep water & East Coast	0	0
Nemertea	17	5	29.41	34	Fair	Morphology, DNA, Allozymes	Inadequate coverage, confusion at lower taxonomic levels	None	Poor, some in Albany Museum, major collections overseas	Morphology	Pests of some mariculture species, potential source of biomedical compounds, indicators of environmental health, potential bait	Very poor	0	0
Mesozoa	0				?	Morphology	?	None	Non-existent	?	Parasites of marine invertebrates	Non-existent	0	0
Nematomorpha	0				?	Morphology	?	None	Non-existent	?	Parasites of decapod, and probably other crustaceans	Non-existent	0	0
Acanthocephala	0				?	Morphology	?	None	Non-existent	?	Parasites of crustaceans and fishes	Non-existent	0	0
Loricifera	0				?	Morphology	?	None	Non-existent	?	?	Non-existent	0	0
Pogonophora	1	0	0.00		Fair	Morphology	Inadequate coverage	None	Very poor	?	Pivotal role in some deep-sea communities	Very poor	0	0
Phoronida	1	0	0.00		?	Morphology	?	None	Non-existent	?	?	Non-existent	0	0
Gnathostomulida	0				?	Morphology	?	None	Non-existent	?	Members of the meiofauna in anoxic sediments	Non-existent	0	0
Hemichordata	11	2	18.18		?	?	?	Poor	Non-existent	?	?	?	0	0
Tunicates	220	81	36.82		Fair	Morphology, DNA, Allozymes, Chemistry	Inadequate coverage	Poor	Poor	Morphology	Indicators of environmental health and water mass identity, source of biomedical compounds, potential food	Poor, especially deep water	0	0
Cephalochordata	1	1	100.00			Morphology	Inadequate coverage	Poor	Non-existent	Morphology	Indicators of water mass identity		0	0
Fishes	2000	280	14.00		Fairly good	Morphology, DNA, Allozymes	Inadequate coverage	Fair	Generally good	Morphology, Allozymes	Indicators of environmental health, food, ecotourism, source of biomedical compounds, curio trade, pet trade	Fair, especially shallow water	5	4
Reptiles	6	0	0.00		Good	Morphology, DNA, Allozymes		Fair	?	Morphology	Indicators of environmental health, ecotourism, potential food	Good	0	0
Birds	222	0	0.00		Good	Morphology, DNA, Behaviour	Identity of island populations, congeneric species (Pachyptila)	Fairly good	Moderate, skins at Durban & Transvaal Museums, Bones at SA Museum	Morphology	Indicators of environmental health, ecotourism	Good	0	0
Cetaceans	37	0	0.00		Good	Morphology, DNA, Allozymes	Congeneric species and populations	Fair	Good (SA Museum and Port Elizabeth Museum)	Morphology, DNA, Allozymes	Potential food, ecotourism, indicators of environmental health	Good	0	4
Seals/otters	6	0	0.00		Good	Morphology, DNA	*A.Pusillus* subspecies identity confused	Fair	Good (SA Museum)	Morphology	Indicators of environmental health, no. pups indicate food abundance, ecotourism, potential food	Good	0	0
TOTAL	**11568**	**3504**	**30.29**										**9**	**24**

experts who have helped draw up the data for this report have suggested that South Africa needs a minimum of 73 full-time taxonomists. This number is clearly unreasonable given the financial constraints on marine science, and a more pragmatic approach to capacity that is founded on the important gaps in our knowledge-base is needed (see below).

Given South Africa's current need to transform society to reflect its demographics, the taxonomy 'profession' will also need to address the inequalities in terms of gender and race.

As South Africa currently does not have the capacity to train many of these new taxonomists, such people will have to be in part trained overseas. This training should be seen as a high priority as there are few international experts of some taxa, and many of these are close to retirement.

What gaps exist in our knowledge?

There are a number of taxa that have never been studied. At the level of the phylum, these include rotifers, gastrotrichs, tardigrades, kinorhynchs and entoprocts, as well as the exclusively parasitic phyla. At the sub-phylum level these include oligochaetes and leeches, and the non-foraminiferan protists. There are also a number of taxa which are in dire need of increased attention as a result of incomplete coverage and these include sponges, ctenophores, anemones, zooanthids, nematodes, nemerteans, insects, halacarids, copepods, bryozoans, tunicates and platyhelminths. This list is not exhaustive and reference to the accompanying table will illustrate this point further, especially with regard to marine parasites. There are also taxa that are in need of revision using modern techniques, and this includes polychaetes, hydroidomedusae and fishes.

While it can be argued that "minor phyla" are generally unimportant from an ecosystem point of view, we should not necessarily see this as an excuse to ignore them. Neither should we tend to generalise and suggest that the use of one or two well-known taxa to identify patterns of biodiversity will be indicative of all taxa. Although it is always tempting to think that we can send unknown specimens overseas for identification, this route to problem solving must be seen as a short-term solution. Having said that, however, even this is often difficult because although the experts may be interested in assisting us, they are generally few and otherwise committed. There is also an increasing trend nowadays to demand payment for services rendered, which means that fees must be budgeted for accordingly.

The long-term solution to the problem has to be the development of local expertise. With all the gaps in our knowledge a priority list of taxa needs to be developed in consultation with end-users. The criteria for inclusion on such a list should include such elements as, for example perceived functional importance, use as valid indicators of environmental health, and use in potential commercial ventures (including aquaculture, bioprospecting and ecotourism). With this in mind, a tentative list might include the following taxa: non-foraminiferan protozoa, sponges, anemones and zooanthids, free-living and parasitic nematodes and platyhelminths, copepods (especially benthic harpacticoids), tunicates, oligochaetes and possibly even rotifers. Such a list covers members of all the major taxa in marine environments around South Africa and should therefore satisfy some of the immediate needs of the different user groups.

What is the status of the tools of systematics and taxonomy?

Most of the taxonomy that is conducted in South Africa at the moment is alpha taxonomy, and workers are reliant almost exclusively on morphological characters. This is in direct contrast to international trends in taxonomy and systematics where a more holistic approach is being taken that integrates behaviour and ecology, as well as DNA and biochemical techniques together with morphology. The tools (and expert tool-users) that would enable South African taxonomists and systematists to enjoin the international trend are available in South Africa, but are not being used in taxonomy. The reasons for this are unclear, but possibly reflect a drive by taxonomists to document diversity first and understand phylogeny second. While a thorough understanding of taxonomy is generally needed before the phylogenetics can be usefully examined, there is no reason why communication between the different tool users should not produce a better taxonomy. However, molecular techniques can also be expensive and budget constraints might influence their implementation.

What is the status of outreach in taxonomy?

With the exception of the few books and guides which have been published expressly for the layman (mostly on vertebrates), most information on the taxonomy of the South African fauna lies in scientific journals. As a consequence, this knowledge is not readily accessible to the public, and even if it were, few would be able to understand it owing to its dry, specialised nature. Indeed, taxonomic keys are difficult to use by all but the specialist (as a rule), which makes their use by other scientists both time-consuming and problematic. Moreover, the journals in which this information is to be found are frequently old or obscure (and hence not widely held by South African institutions). Modern keys tend to be very expensive and affordable by only the most affluent institutions. There is the need for clear, user-friendly guides to help us take taxonomy to the 'end user'.

What is the status of reference collections?

For many taxa the reference collections are non-existent in South Africa. In some cases there may be better collections of South African material overseas, while in other cases there may be no reference collections at all. For other taxa there are fairly good local collections (e.g. fishes, molluscs, polychaetes and some crustacea).

Good, reliable taxonomy depends upon good, comprehensive reference collections. Without reference collections and the staff to curate them, South African taxonomy cannot move forward. South Africa has an international, moral obligation to maintain its current collections, and it desperately needs to expand them for its own use.

This document has been compiled by Mark J. Gibbons at the request of the NRF and is based upon reports submitted by Mr Toufiek Samaai, Ms Amina Sulaiman and the following experts.

NAME	ORGANISATION	ADDRESS
Martin Angel	Southampton Oceanography Centre	European Way Southampton SO14 3ZH, UK
C. Assuncao	Universidade de Sao Paulo	Depto de Zoologia Instituto de Biociencias Universidade de Sao Paulo, CP 11461 CEP 05422-970 Sao Paulo, Brasil
Bernardo Barraso do Abiahy	Universidade de Sao Paulo	Depto de Zoologia Instituto de Biociencias Universidade de Sao Paulo, CP 11461 CEP 05422-970 Sao Paulo, Brasil
Ilse Bartsch	Biologische Anstalt Helgoland	Biologische Anstalt Helgoland Zentrale Hamburg NotkestraBe 31 D 22 607 Hamburg, Germany
Peter Best	SA Museum	SA Museum PO Box 61 Cape Town 8000
R. Biseswar	University of Durban-Westville	Department of Zoology University of Durban-Westville Private Bag X54001 Durban 4000
Nando Boero	Universita di Lecce	Dipartimento di Biologia Stazione di Biologia Marina Universita di Lecce I-73100 Lecce, Italy
Demetrio Boltovskoy	Universidad de Buenos Aires,	Departamento de Ciencias Biologicas Facultad de Ciencias Exactas y naturales, Universidad de Buenos Aires 1428 Buenos Aires, Argentina
Jean Bouillon	Universite Libre de Bruxelles	Laboratoire de Zoologie Universite Libre de Bruxelles Av. FD Roosevelt 50 Bruxelles B-1050, Belgium
Bill Branch	PE Museum	PO Box 13147 Humewood 6013

E. Burreson	Virginia Institute of Science	PO Box 1346 Gloucester Point VA 23062, USA
Lester Cannon	Queensland Museum	Queensland Museum PO Box 4101, South Brisbane Queensland, Australia
Jean-Paul Casanova	Universite de Provence	Laboratoire de Biologie Animale (Plancton) Universite de Provence Case 18 3 place Victor Hugo 13331 Marseille Cedex 3, France
Alan Channing	University of the Western Cape	Department of Zoology University of the Western Cape, Private Bag X17 Bellville 7535
C Child	National Museum of Natural History	National Museum of Natural History Smithsonian Institution Washington DC 20560, USA
Len Compagno	SA Museum	SA Museum PO Box 67 Cape Town 8000
Paul Cornelius	Natural History Museum	Department of Zoology Natural History Museum Cromwell Rd London, SW7 5BD, UK
Jose Dadon	Universidad de Buenos Aires	Departamento de Ciencias Biologicas facultad de Ciencias Exactas y naturales Universidad de Buenos Aires 1428 Buenos Aires, Argentina
Jeremy David	Marine and Coastal Managment	Marine and Coastal Management Private Bag X2 Roggebaai 8012
Jenny Day	University of Cape Town	Zoology Department University of Cape Town Rondebosch 7700
Norberto Della Croce	Universita di Genova	Instituto Scienze Ambientali Marine Universita di Genova CP 79, 16038 S. Margherita Ligure Corso Rainusso 14, Genova, Italy
P. Emmschermann	Universitat Freiburg	Facultat fur Biologie de Albert Ludwigs Universitat Freiburg Biologie fur Mediziner Schanzlestr. 1 79104 Freiburg, Germany
Christer Erseus	Swedish Museum of Natural History	Department of Invertebrate Zoology Swedish Museum of Natural History PO Box 50007, SE-104 05 Stockholm, Sweden
Graciela Esnal	Universidad de Buenos Aires	Departamento de Ciencias Biologicas Facultad de Ciencias Exactas y naturales Universidad de Buenos Aires 1428 Buenos Aires, Argentina
Ray Gibson	Liverpool John Moores University	School of Biological and Earth Sciences Liverpool John Moores University Byrom St Liverpool L3 3AF, UK
Janet Grieve	National Institute of Water and Atmospheric Research	National Institute of Water and Atmospheric Research PO Box 14901 Wellington, New Zealand
Charles Griffiths	University of Cape Town	Zoology Department University of Cape Town Rondebosch 7700
R. Heard	Gulf Coast Research Laboratory	USM Institute of Marine Science PO Box 7000 Oceans Springs MS 39566-700, USA
Dai Herbert	Natal Museum	Department of Mollusca Natal Museum Private Bag 9070 Pietermaritzburg 3200

Phillip Heemstra	JLB Smith Institute of Ichthylogy	JLB Smith Institute of Ichthylogy Private Bag 1015 Grahamstown 6140
Robert Hessler	Scripps Institution of Oceanography	Scripps Institution of Oceanography La Jolla CA 92093-0202 USA
R. Higgins		2 Pond Lane Asheville NC 28804, USA
Norton Hiller	Canterbury Museum	Curator of Geology Canterbury Museum Rolleston Avenue, Christchurch New Zealand
Yayoi M. Hirano	Chiba University	Marine Ecosystems Research Center Chiba University Amatsu-Kominato 299-55, Japan
Peter Haywood	University of Wales Swansea	School of Biological Sciences University of Wales Swansea Singleton Park, Swansea SA2 8PP, UK
Brian Kensley	National Museum of Natural History	National Museum of Natural History Smithsonian Institution, Washington DC 20560 USA
Dick Kilburn	Natal Museum	Department of Mollusca Natal Museum Private Bag 9070 Pietermaritzburg 3200
Louis Kornicker	National Museum of Natural History	Curator Invertebrate Zoology National Museum of Natural History Smithsonian Institution Washington DC 20560, USA
John Lambshead	Natural History Museum	Department of Zoology Natural History Museum Cromwell Rd London, SW7 5BD, UK
R. Manning	Smithsonian Institute	National Museum of Natural History Smithsonian Institution Washington D.C. 20560, USA
D. Marshall	University of Durban-Westville	Zoology Department University of Durban-Westville Private Bag X54001 Durban 4000
Ian McMillan	De Beers Marine (Pty) Ltd	De Beers Marine (Pty) Ltd PO Box 87 Cape Town 8000
Hermes Mianzan	Instituto Nacional de Investigacion y Desarrollo Pesquero (INIDEP)	Instituto Nacional de Investigacion y Desarrollo Pesquero (INIDEP) casilla de Correo 175 7600 Mar del Plata, Argentina
Claude and Francoise Monniot	Museum national d'Histoire Naturelle	Biologie des Invertebres Marins Museum national d'Histoire Naturelle 55 rue Buffon, 75005 Paris France
W. Newman	Scripps Institution of Oceanography	La Jolla CA 92093-0202, USA
C. Nielsen	Zoologisck Museum	Universitets-parken 15 DK-2100 Copenhagen, Denmark
David Patterson	University of Sydney	School of Biological Sciences University of Sydney NSW 2006 Australia
Gordon Patterson	Natural History Museum	Department of Zoology Natural History Museum Cromwell Rd, London SW7 5BD, UK
Wolfgang Petz	Universitat Salzburg	Institut fur Zoologie Universitat Salzburg Hellbrunner Strasse 34 A-5020 Salzburg, Austria
Phillip Pugh	Southampton Oceanography Centre	Southampton Oceanography Centre

		European Way Southampton SO14 3ZH, UK
Martina Roeleveld	SA Museum	SA Museum PO Box 61 Cape Town 8000
Peter Ryan	University of Cape Town	Zoology Department University of Cape Town Rondebosch 7700
John S. Ryland	University of Wales Swansea	School of Biological Sciences University of Wales Swansea Singleton Park, Swansea SA2 8PP, UK.
Mike Schleyer	Oceanographic Research Institute	Oceanographic Research Institute PO Box 10712 Marine Parade Durban 4056
Ernest Schockaert	Limburgs Universitair Centrum	Limburgs Universitair Centrum - Dept. SBG B-3590 Diepenbeek Belgium
Roger Seapy	California State University	Department of Biological Sciences California State University Fullerton, CA 92634 USA
Russ Shiel	CSIRO Land and Water	CSIRO Land and Water, MDFRC PO Box 921, Albury, NSW 2640 Australia
Ronald Sluys	University of Amsterdam	Institute for Systematics and Population Biology, Zoological Museum University of Amsterdam, PO Box 94766 1090 GT Amsterdam, Netherlands
Eve Southward	Marine Biological association of the UK	The Laboratory Citadel Hill Plymouth PL1 2PB, UK
Mary Spencer-Jones	Natural History Museum	Department of Zoology Natural History Museum Cromwell Rd London, SW7 5BD, UK
Ole Tendal	Zoological Museum	Zoological Museum Copenhagen, Denmark
Ahmed Thandar	University of Durban Westville	Department of Zoology University of Durban-Westville Private Bag X54001; Durban 4000
Hjalmar Thiel	Alfred Wegener Institut fur Polar- und Meeresforschung	Alfred Wegener Institut fur Polar- und Meeresforschung Columusstrasse, 27568 Bremerhaven, Germany
Siebrecht van der Spoel	Universiteit van Amsterdam	Zoologisch Museum, Universiteit van Amsterdam Postbus 94766 Amsterdam, Netherlands
Rob van Soest	University of Amsterdam	Institute for Systematics and Population Biology Zoological Museum University of Amsterdam, PO Box 94766, 1090 GT Amsterdam, Netherlands
J. van der Land	National Museum of Natural History	PO Box 9517, 2300 RA Leiden, Netherlands
Eric Vetter	Hawaii Pacific University	45-045 Kamehameha Highway Kaneohe HI 96744-5297, USA
Egor Vinogradov	Russian Academy of Sciences	AN Severtzov Institute of the Problems of Evolution Russian Academy of Sciences Lenin Avenue 33,Moscow 117071, Russia
Steve Webb	University of Cape Town	Zoology Department University of Cape Town Rondebosch 7700
Gary Williams	Los Angeles County Museum	Los Angeles County Museum Los Angeles, USA
Tris Wooldridge	University of Port Elizabeth	Department of Zoology University of Port Elizabeth PO Box 1600; Port Elizabeth, 6000

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TAXONOMY/SPECIES

PLANTS (COMPRISING FLOWERING PLANTS, ALGAE, FUNGI, LICHENS)

compiled by J.J. Bolton

Introduction

The photosynthetic organisms in the sea are from a wide variety of groups. The group most familiar on land, the flowering plants, are important only in certain coastal fringe environments (particularly estuaries), whereas rocky seashores and the sea itself have photosynthetic organisms which come from a variety of different groups. In the past most of the latter have been lumped together as 'algae'. The 'green algae' (Chlorophyta) include the green seaweeds and a wide variety of smaller algae, and are true green plants, related to the flowering plants. Other algae comprise at least twelve 'Divisions' (equivalent to zoological Phyla). The broad term 'algae' has also traditionally included the 'blue-green algae', which are true bacteria (the Cyanobacteria), and are important in many marine environments. The fungi, though not photosynthetic, have often in the past between treated as 'plants', and of course this is even more confused by the lichens, which are a symbiosis of an alga and a fungus. Molecular phylogenetic studies are revealing that relationships between these organisms are much more complicated than first thought, and that there are many more groups of living things than just 'plants' and 'animals'. For example one Division, the Heterokontophyta, now comprises a remarkable diversity of organisms, including brown algae (e.g. *Ecklonia*) and diatoms as well as a group that was traditionally in the fungi (the Oomycetes). The organisms discussed below are thus grouped primarily ecologically, rather than phylogenetically.

Flowering Plants

by J.J. Bolton & R.A. Lubke

Generally, the expertise to identify flowering plants is available in a number of centres (e.g. National Botanical Institute (NBI) and various herbaria), and literature on and well-curated collections of flowering plants are also readily accessible within the country. Many ecological studies have been carried out in marine systems where flowering plants occur - generally estuaries and lagoons with mangroves, salt marshes or seagrass beds (Lubke *et al.*, 1997) - and identification of specimens has not proved a problem.

A large body of ecological and ecophysiological work has been carried out on South African mangrove systems, particularly at the University of Durban-Westville (Steinke, Naidoo and colleagues). Mepham & Mepham (1985) published locally a list of the flowering plants occurring in mangrove systems in the Indo-West Pacific. Detailed descriptions of main mangrove trees are in preparation for the series of Flowering Plants of Southern Africa (H.F. Glen, pers. comm.). South African saltmarshes are rather small in area, but interesting and important systems. They were studied in detail by O'Callaghan (1994), who also carried out studies to improve identification, e.g. of the Salicornieae (O'Callaghan, 1992).

Seagrasses are not very diverse in most of South Africa, with *Zostera capensis* being the dominant species in the Cape Provinces. Diversity increases into the tropics, with three other species in estuaries and on rocky shores in KwaZulu-Natal. Salomao Bandeira of the Universidade Eduardo Mondlane in Maputo is currently working on the autecology of seagrasses of the Mozambique coast. He is familiar with their taxonomy and has indicated the need for more work on these taxa.

Algae

Perhaps the main problem facing algal taxonomy in South Africa is that there is no government agency which will accept responsibility for it. This was traditionally the responsibility of the Botanical Research Institute (now the National Botanical Institute, NBI) who were the original employers of the "government seaweed biologist" (then R.H. Simons before his transfer to Marine and Coastal Management (MCM)). The Seaweed Unit of MCM does not currently have taxonomy as part of their brief. The NBI indicated to the Phycological Society of Southern Africa in 1997 that "it is unlikely that the NBI would taken on a national responsibility for algal taxonomy". For those who intend training (or funding the training of) algal taxonomists it is obviously problematic that there is no national agency which will take responsibility for algal taxonomy.

Macroalgae

by J.J. Bolton, R.N. Pienaar & S.D. Sym

Status of taxonomy and levels of endemism?

Most of the taxonomic descriptions of marine macroalgae (seaweeds) are from the 19th century, and many groups have had little or no subsequent taxonomic revision. Since 1980, significant studies have added greatly to our knowledge of the taxonomy of the seaweeds of the South African west coast (west of Cape Agulhas; see Stegenga *et al.,* 1997) and the red algae of KwaZulu-Natal (numerous papers on specific groups by R. Norris). Species are being regularly sent to overseas workers to form part of systematic studies on specific groups - particularly using molecular techniques (e.g. studies by Hommersand and colleagues). A large body of work is being carried out by Y. Chamberlain (University of Portsmouth, U.K.) and D. Keats (University of the Western Cape) and colleagues on the non-geniculate (coralline) red algae. These are ecologically extremely important in shallow waters, and many new species have been recently described.

Apart from D. Keats' work on crustose corallines and a few contributions by R.H. Simons (now retired), R.J. Anderson and J.J. Bolton, almost all taxonomic work has been done by visitors from overseas (e.g. Norris, Stegenga, Chamberlain) who have now left. The seaweeds of the west coast are rather well documented (Stegenga *et al.*, 1997), and those of KwaZulu-Natal, particularly the red algae, are reasonably documented (although the information is in algal journals, and only accessible to the expert). The seaweeds of the south coast (Agulhas marine province) have had little recent taxonomic study, apart from a few contributions by Herre Stegenga. The roughly 800 recorded species of South Africa seaweeds is a rich flora by world standards, with high levels of endemism (Bolton & Anderson, 1997). For example, over 50% of the west coast species in Stegenga *et al.* (1997) are endemic to temperate southern Africa. An NRF project currently running (principal investigator J.J.B.) is summarising our current knowledge of the seaweed flora, including analyses of distribution and endemism. There are still many new finds to be made, particularly in the subtidal regions of the Eastern Cape and KwaZulu-Natal.

Seaweed collections

There are good collections of seaweeds at the Universities of Cape Town (UCT) and Natal (Pietermaritzburg) and the Pocock collection in Grahamstown. Although these are curated technically, there is no real regular taxonomic input at any of these, due to the lack of a seaweed taxonomist working on them, and the future of the Pocock collections in the Albany Museum is not certain.

Status of the tools of systematics and taxonomy

The tools of taxonomy are available in South Africa, and there is a movement towards taxonomic studies using molecular techniques. These studies have begun on corallines (under D. Keats at University of the Western Cape) and on endophytic algae and the red algal genus *Porphyra* jointly supervised by J.J.B. and Vernon Coyne at UCT. These techniques are, however, expensive, and the NRF is currently likely to be the only sponsor for this sort of research.

Status of outreach in seaweed taxonomy

The ability of the marine biologist to identify seaweeds on the west coast has taken a major step forward with the publication of Stegenga *et al.* (1997). Proper identification of even some of the more common seaweeds in the Eastern Cape and KwaZulu-Natal still requires an expert with access to the primary literature. Marine biologists in these regions still have only illustrations of larger common species in Branch *et al.* (1994) or similar publications to identify seaweeds. While useful, these have no scientific detail to confirm identification, and contain less than 25% of the seaweed species present.

Main problems

The main problems in seaweed taxonomy are thus:

- No government body taking responsibility for algae.
- Little recent work on the south coast or the brown and green algae of the east coast.
- Unavailability of existing taxonomic information on the south and KwaZulu-Natal coasts to marine biologists.
- Need for detailed studies (including those using molecular techniques) on taxa of particular economic and ecological importance.

Microalgae

by R.N. Pienaar and S.D. Sym

General comments

The status of our knowledge on the diversity of marine and estuarine microalgae, on the whole, is poor. This is due to the fact that there are very few laboratories in South Africa that are doing research on microalgae. This is probably because of the very specialised techniques that are needed to identify microalgae, coupled with the fact that there is really only one laboratory in the country that is specialising in microalgal research (viz. R.N. Pienaar's laboratory at the University of the Witwatersrand).

There are a number of algal divisions that are well represented in the marine and estuarine environment and about which we know very little. The following algal divisions are known to occur in our marine and estuarine environments. We have also attempted to indicate the status of our knowledge for each division.

Division	Status of Knowledge
Cyanophyta	Reasonably good since S. Silva joined R.N. Pienaar's research group. This work has concentrated primarily on the benthic members of the group and very little on the planktonic forms. The work S. Silva has done is exclusively inshore and tidal pool flora
Chlorophyta Class Chlorophyceae	Poor
Class Prasinophycea	Reasonable to good
Chrysophyta	Poor except for the very common forms
Prymnesiophyta	Reasonable with respect to the non-coccolith bearing forms. Poor when it comes to the coccolith-bearing forms
Raphidophyta	Poor
Eustigmatophyta	Poor
Cryptophyta	Reasonable to poor
Dinophyta	Reasonable with respect to inshore and tidal pool species and for some of the heavily armoured forms. For the colourless and un-armoured forms our knowledge is very poor. Marine and Coastal Management and to a lesser degree the University of Port Elizabeth have being doing some work on marine inshore dinoflagellates
Bacillariophyta	Marine inshore and tidal pool forms poor to reasonable; Estuarine planktonic forms poor

Status of expert knowledge in microalgae

There is at the moment a dearth of scientists who have developed any expertise in the taxonomy of marine and estuarine microalgae. The main laboratory that has been working on microalgae is that of R.N.Pienaar. This laboratory has had a number of researchers working on specialised groups of marine inshore and tidal pool representatives of microalgae.

These include:	S. Silva	Postdoctoral Fellow working on the Cyanophyta.
	T. Horiguchi	Visiting postdoctoral fellow who worked on tidal pool dinoflagellates.
	S.D. Sym	Current member of staff specialising in the Prasinophyceae.
	R.N. Pienaar	Currently specialising in the Prymnesiophyta and also working on the Dinophyta, Cryptophyta and Chrysophyta.
	I. Inouye	Visiting postdoctoral Fellow who worked on Prymnesiophyta.

The Universities of Port Elizabeth and Durban-Westville are currently involved in work on the Bacillariophyta (diatoms) but still have to build up a good knowledge base on diatom taxonomy. This is an important group of microalgae and there should be a laboratory in South Africa that specializes in this group.

Facilities for studying microalgae

Facilities for the study of microalgae are good with respect to R.N. Pienaar's laboratory. Good light microscope facilities are required, as well as a well-equipped electron microscope unit and good culture facilities to maintain culture collections.

Outreach in microalgal systematics

There is a need to once again commence offering specialist courses in microalgal systematics and the techniques used to study microalgae. Courses were offered by R.N. Pienaar - one on techniques used to study microalgae and a second on microalgal systematics. These were run under the umbrella of the Phycological Society of Southern Africa. These should possibly be run again and elaborated upon based on the status of our current knowledge.

Status of reference collections

These are virtually non-existent. The University of the Witwatersrand has a microalgal reference culture collection but it is by no means extensive. It currently houses about 150 isolates. It takes a great deal of time and money to maintain and curate a good collection. Funding for a research assistant to undertake this work has not been forthcoming. The collection is frequently called upon to provide cultures to organizations doing work in the mariculture field, research organizations and tertiary institutions requiring material for teaching purposes.

We are striving to develop a reference catalogue of the organisms that we have identified, isolated, etc., which could eventually be used by new workers in the field.

Fungi
by T. Steinke

Kohlmeyer & Kohlmeyer (1979) state that "information on the geographical distribution of marine fungi is missing particularly in the Southern Hemisphere, in the Arctic, Antarctic and Indian Oceans, and in the eastern Mediterranean and Black Sea". The author appears to be the only local person researching marine and estuarine fungi. This work concerns the estuarine fungi associated with the degradation of mangrove leaf and stem litter, and the marine fungi of sandy beaches and rocky shores (Steinke & Gareth-Jones, 1993). The mangrove project covers estuaries only where mangroves occur, i.e. from East London northwards, the sandy beach survey stretches from the Kosi system in northern KwaZulu Natal to Henties Bay in Namibia, and the rocky shore survey extends from Mission Rocks (St. Lucia) to Langebaan. The latter project is restricted to fungi associated with intertidal driftwood. It is hoped that this work will be published in the next year or two. There are serious gaps in that no investigations have been carried out in estuaries where mangroves do not occur, even along the east coast substrates other than mangroves need to be investigated, and more collections of rocky shore fungi are needed from East London northwards. Little information is available on marine fungi associated with marine algae and marine animals.

Fungi have been shown in recent years to play a significant degradative role in marine and estuarine environments. Unfortunately in this country, and also elsewhere, marine fungi seem to have been almost overlooked in evaluating food chains. Knowledge of the occurrence and distribution of fungi will contribute towards a greater understanding of the role of these organisms in different marine ecosystems.

Extensive taxonomic surveys of marine fungi have been conducted in Europe, North America and the Far East. There are a number of very competent taxonomists working in these areas. Although most of our marine fungi are common to these areas, clearly there are some new species that require investigation. Local researchers investigating our marine fungi will require basic mycological laboratory research facilities and access to electron microscopes. Most importantly, to assist in building up their expertise, local researchers must have the opportunity to make contact with overseas workers in their field. It is essential that a reference collection should be established as, apart from T. Steinke's own collection, little seems to be available. Attention must be drawn to the fact that in recent years isolates of marine fungi have proved a new source of commercially important fungus metabolites, which could serve as an additional motive for their investigation and possibly a source of funds for taxonomic studies.

Lichens
by J.J. Bolton

The taxonomy of lichens is currently a gap in South African taxonomy in general, with no active resident lichen taxonomist. Work has been done in the past, and there are local collections, and it is likely that names exist for species in the spray (maritime) zone above the intertidal, but for a reliable identification an overseas taxonomist would have to be approached.

Intertidal lichens are in need of study. They are not uncommon on rocky shore mollusc shells on the west coast, with a species of *Verrucaria* being fairly common as black crusts with rounded edges on whelks and limpets in the mid-intertidal, and two species of *Pyrenocollema* occurring as whitish patches on limpets (A. Fletcher and Y.M. Chamberlain, pers. comm.). These species remain undescribed.

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TAXONOMY/SPECIES

MARINE MICROBIAL BIODIVERSITY

by V.E. Coyne

Current knowledge

Historically, microbial taxonomy has been conducted using a variety of physical and biochemical tests that allow the grouping of microbial isolates into genera and species. This approach requires laboratory cultivation of the microbes in order to separate the various isolates into monocultures. This approach (classical taxonomy) has been used to identify and characterise many of the culturable marine bacteria. However, typically less than one percent of the bacteria present in the marine environment can be cultivated in the laboratory. Indeed, only 3 000 - 4 000 species of bacteria have been described (Hawksworth & Colwell, 1992), even though it has been estimated that the number of bacterial species world-wide is close to three million (Colwell, 1997). Because of this limitation, bacterial biodiversity can only be accurately determined using molecular taxonomic tools that obviate the need for laboratory cultivation of isolates. Thus, the use of techniques such as polymerase chain reaction (PCR) amplification and sequencing of 16S ribosomal RNA genes, randomly amplified polymorphic DNA (RAPD), and whole community nucleic acid hybridisation provide a more reliable approach to determining bacterial biodiversity. Furthermore, hybridisation of DNA probes specific to genes coding for particular enzymes to either DNA (potential function) or messenger RNA (expressed function) isolated from seawater samples allows one to monitor microbial metabolic processes *in situ* (Colwell, 1996).

Besides the lack of knowledge concerning marine bacteria, even less is known about marine viruses. Recent studies have shown that viruses are far more common in the marine environment than previously thought (Colwell, 1997). It seems that these microorganisms outnumber bacteria in the open ocean. Many of these viruses attack bacteria and may represent a significant control agent of both bacteria and algae (Colwell, 1997). Consequently, viruses may be a source of selective pressure that contributes to the high bacterial diversity in marine environments (Giovannoni *et al.,* 1990).

An understanding of marine microbial biodiversity is of utmost importance for a variety of reasons. It is well known that bacteria play an integral role in the cycling of carbon, nitrogen, sulphur and phosphate. Indeed, key aspects of the carbon and nitrogen cycles are carried out solely by bacteria, i.e. anaerobic fermentation of carbohydrates and fixation of atmospheric nitrogen. As such, it is important to determine the types of bacteria present in a particular ecosystem, the role they play in the functioning of that system, and to gauge the effects that anthropogenic forces (particularly pollution) are exerting on the diversity of marine microorganisms. Indeed, it has already been shown that sewage sludge dumping off the coast of New Jersey has impacted the benthic microbial ecology at this site (Hill *et al.,* 1993).

The link between biotechnology and biodiversity is another key reason for cataloguing and conserving marine microbial biodiversity. The marine environment is proving to be a valuable source of novel bioactive compounds with antibacterial, antiviral, and anticancer properties (Colwell & Hill, 1992). Both free-living bacteria and bacteria that are symbionts of marine invertebrates are likely to be a good source of useful bioactive compounds. An example of this is seen in the work being done by Russell Hill (Centre for Marine Biotechnology, USA) with respect to marine actinomycetes. Seventy percent of the world's antibiotics originate from terrestrial actinomycetes. However, drug companies are finding that their screening programmes are re-isolating the same compounds. Hill has shown that the diversity of marine actinomycetes is considerably different to that of the terrestrial actinomycetes, and as such, is expected to yield novel antibacterial compounds that are urgently required in the battle against drug-resistant human pathogens (pers. comm.).

Another example of the important link between marine bacterial biodiversity and marine biotechnology is that of marine sponges, which are widely known for their ability to produce chemicals that deter predators. It has recently been shown that bacterial species that produce antimicrobial compounds are intimately associated with sponges from the Caribbean coral reefs. Cross sections of these sponges revealed that 50% of the sponge mass is comprised of prokaryotic structures which are thought to be bacteria (Colwell, 1997). Although most of these bacterial species have not yet been cultured, several of those that have been cultured have been found to produce bioactive compounds with potential pharmacological value. Indeed, it is now thought that many of the bioactive compounds synthesized by sponges are actually produced by the diverse bacteria living within their tissues (Colwell, 1997).

Bioremediation, which is an aspect of biotechnology that makes use of bacteria to restore polluted environments, is another compelling reason for the study of bacterial biodiversity. Microorganisms are useful in restoring polluted environments due to their ability to degrade a wide variety of xenobiotic compounds. Characterisation of diverse bacterial species will lead to the discovery of novel xenobiotic-degrading enzymes which may eventually be used to genetically engineer microorganisms to enable them to degrade chemical pollutants more rapidly and completely.

Problem areas

Given the extensive coastline and marine resources available to us, South Africa, and indeed southern Africa, is ideally situated to pursue a programme in the rapidly emerging field of marine biotechnology. Already we lag significantly behind in research compared to other parts of the world, and it is imperative that such a programme is initiated. There is now an American Society of Marine Biotechnology, which comprises the U.S.A., Canada, Mexico and the Latin American countries, an Asia-Pacific Marine Biotechnology Society and a European Society for Marine Biotechnology. These societies have been formed in order for the countries located in these regions to reap the benefits of their marine resources in terms of new bioactive products for the treatment of diseases and cancer, the use of transgenic animals in aquaculture, bioremediation, etc. Funding for marine biotechnology in the Unites States has increased from less than one million dollars in 1983 to approximately $45 million in 1994 (Zilinskas *et al.*, 1995). In conjunction with this, biotechnology sales in the United States (in total, not just marine biotechnology) were $10-12 billion in 1993 (Colwell, 1997).

Much of the success of marine biotechnology relies on investigating, characterising and maintaining the biodiversity of marine microorganisms. Similarly, it will only be possible to accurately determine the structure and function of marine ecosystems once the types of microorganisms that colonise a particular habitat, and the metabolic processes they perform, are accurately determined. To date, no significant work has been done with regard to investigating marine bacterial biodiversity in southern African oceans. As far as I am aware, my research group is the only South African laboratory concerned with the identification and characterisation of marine microorganisms. However, we have addressed marine microbial taxonomy as a component of our research and not as the main thrust of our laboratory.

Accurate identification and characterisation of the microbial biota of the southern African territorial waters and coastline will only be possible with the use of molecular taxonomic techniques. Most South African university microbiology departments have the capacity, in terms of expertise and equipment, to investigate the molecular taxonomy of microorganisms. However, the vast majority of South African scientists currently involved in marine research are unfamiliar with molecular protocols. Thus, a concerted effort needs to be made in training young scientists in order to build the necessary capacity required for investigating the microbial biodiversity of the marine ecosystems of southern Africa. One of the main problems that I have encountered in this regard is the difficulty in attracting students from other disciplines to laboratory-based research. This problem will only be remedied by broadening the curricula offered to undergraduate students at tertiary institutions so that they will gain an appreciation of the importance of molecular tools in addressing marine microbial systematics and ecology. Capacity building in terms of marine microbial taxonomists / scientists will benefit greatly from a sustained effort in informing statutory bodies such as the South African Network for Coastal and Oceanic Research of the importance of such research with respect to our proper understanding of ocean ecosystems, as well as the commercial spin-offs that accrue from this type of research. Unfortunately, a lot more needs to be done with regard to outreach before the shortage of marine microbiologists in South Africa is adequately addressed.

Another major problem preventing the establishment of a "state of the art" marine biodiversity and biotechnology programme in South Africa, is the significant lack of funding for such research. Unfortunately, research that relies heavily on molecular techniques is extremely costly. However, this should not be used as an excuse for not embarking on such a programme. It is important to adopt a long term strategy which realises that the relatively large investment which is necessary now, will lead to significant returns later in terms of scientific knowledge, preservation of the biodiversity of southern African marine ecosystems, job creation in a growing South African biotechnology industry, financial benefits accrued from such an industry, and the training of internationally competitive marine scientists.

Should the points discussed above be adequately addressed, and consequently, South Africa embarks on a serious marine microbial biodiversity research programme, it will be important to ensure that marine microbial isolates are preserved and catalogued in a national culture collection. Such a facility, which does not currently exist, will be a necessity if we are to preserve the biodiversity of microorganisms isolated from marine ecosystems surrounding South Africa. UNESCO awarded a Microbiological Resources Centre (MIRCEN) to the Department of Microbiology and Biochemistry at the University of the Orange Free State, with the purpose of developing and supporting microbiology and microbial biotechnology in southern Africa (http://www.uovs.ac.za/nat/mkboc/mircen/micro.htm). One of the activities of this MIRCEN is to establish an extensive microbial culture collection. It is possible that the MIRCEN collection could be extended to providing a depository for cultures isolated from the marine environment. However, issues such as intellectual property rights and commercial interests will need to be addressed if a central strain depository for the preservation of marine microbial biodiversity is to be successfully maintained.

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THE STATUS OF THE GENETIC AND BIOCHEMICAL ANALYSIS OF MARINE ORGANISMS IN SOUTH AFRICA

by M. Davies-Coleman and B.A. Cook in consultation with E. Harley, R. Leslie, M. Schleyer , P. Cook, C. Brown, V. Cockcroft and T. Robinson

The application of genetics to biodiversity and the conservation of biodiversity (including a review of the status of the expertise, techniques and equipment)

A variety of molecular markers have been used to quantify genetic diversity in marine organisms. In South Africa, the primary technique that has been employed to date has been protein electrophoresis. Allozymes of different electrophoretic mobilities are assumed to be coded for by different alleles, where variation detected is due to genetic changes in coding regions that have altered amino acid sequence. Data generated by this technique are in the form of allele frequency differences. Allozyme electrophoresis is most appropriate, and often the method of choice for studies of population genetic structuring, species boundaries and hybridization, since the technique is relatively inexpensive and easy to undertake. DNA level markers reflect variation in both coding and noncoding regions, and data can either be in the form of length variation in specific DNA fragments, or divergence in nucleotide base sequences. Like allozymes, DNA restriction analysis is useful for population genetic studies, species delineation and hybridization, as well as for the determination of phylogenies of closely related taxa. The development of the Polymerase Chain Reaction (PCR) along with improved primer design has enabled researchers to target specific genes that can either be digested with endonucleases to produce Restriction Fragment Length Polymorphisms (RFLPs), or can be directly sequenced. The use of Random Amplified Polymorphic DNAs (RAPDs), has become popular amongst the non-biochemically inclined, mostly because the analyses are quick and easy to perform. However, this PCR method is of limited value because inability to identify specific loci or alleles and its poor reproducibility prevents good quantitative statistical analyses of the data generated. Although multilocus DNA fingerprinting (e.g. Southern Blot approach using a technique such as Jefferies probe) is good for forensic analysis, and more reproducible than RAPDs, its inability to identify alleles easily, again limits statistical analyses. DNA sequencing is the definitive method for systematic studies. Sequencing of variable regions such as the mitochondrial DNA-D loop can provide useful data for population differentiation. Microsatellites provide the modern definitive method for fine level population genetics including population differentiation, inbreeding and forensic analyses. Unfortunately, this method is only feasible where PCR primers for microsatellites loci have been isolated (a time consuming process).

Marine fishes

Commercially important fish species are subdivided into “management units” or stocks by geographical markers such as headlands (e.g. Cape Agulhas) or international boundaries. Fisheries management treats each stock as a single population, assuming little or no migration between stocks. Testing the validity of these assumptions is therefore important to fisheries managers.

Biochemical genetic analyses are powerful techniques to assess the level of gene flow between, and within, populations or stocks. Initial genetic studies on South African marine fishes were aimed at investigating the population genetic structure of commercially important species. The pioneering work of Grant (1985a; 1985b; 1985c) made use of biochemical genetic markers to determine the stock structure of anchovy *Engraulis japonicus capensis* and pilchard *Sardinops sagax capensis* off the coast of South Africa. Other subsequent population genetic studies on commercially important fish species have included the Cape hakes *Merluccius capensis* and *M. paradoxus* (Grant *et al.*, 1987), the horse mackerel *Trachurus trachurus capensis* (Naish, 1990) and the South African anglerfish *Lophius vomerinus* (Leslie & Grant, 1990). Population studies of non-commercial fish species have been limited to the estuarine minnows *Athernia breviceps* and *Gilchristella aesturia* (Ratte, 1989; Grant & Ratte, unpublished data). Minimal gene flow amongst populations will maintain genetic homogeneity and given the paucity of natural barriers to marine fish migration and the dispersal of eggs and pelagic larvae, it is not surprising that most of these studies found no, or insignificant, indication of genetic population substructure. However, restriction of gene flow between populations in different estuaries is possible and some population substructure was accordingly observed in the latter study.

Genetic analyses can find very useful application in taxonomic studies. Using a combination of genetic and classical taxonomic techniques, Grant & Leslie (1984) were able to show that two “types” of South African anglerfish were simply morphs of a single species *Lophius vomerinus*. The genetic data contributed significantly to correcting the original nomenclature of this species (Leslie & Grant 1991). Van der Bank & Kirchner (1997) used allozyme electrophoresis to distinguish the two kob species *Argyrosomus* and *A. inodorus*.

Biochemical genetic analyses can also help establish the approximate timing of species divergence provided a taxonomically appropriate calibration is available, and can therefore, be extremely useful in understanding phylogenetic relationships within genera. For example, Grant *et al.* (1988) and Becker *et al.* (1988) were able to propose that the lineages leading to *M. capensis* and *M. paradoxus* diverged between seven and 13 million years ago. Phylogenetic studies of four commercially important fish genera have been undertaken on a global basis. Two of these have been completed and published, pilchards *Sardinops* (Parrish *et al.*, 1989; Grant & Leslie, 1996: Bowen & Grant, 1997; Grant *et al.*, 1998) and anglerfish *Lophius* (Grant & Leslie, 1993; Leslie & Grant, 1994). The other two, hakes *Merluccius* (10 out of 15 species analysed) and anchovies *Engraulis* (all seven species analysed) have yet to be published (Grant & Leslie, unpublished data). W. Florence (University of the Western Cape (UWC)) has recently submitted his MSc. thesis on allozyme variation among South African and Australasian stocks of the lanternfish species *Lampanectodes hectorus.*

In forensic tests using biochemical genetic analyses in 1990 Grant and Leslie were able to show conclusively that hake fillets found on a Spanish trawler caught in Namibian waters were from deep-water cape hake *M. paradoxus*, and not from patagonian hake *M. hubsii* as claimed by the Spanish captain. Based largely on the genetic evidence the vessel and catch were subsequently confiscated. Although genetic expertise remains at Marine and Coastal Management the allozyme analysis equipment is presently on loan to B.A. Cook (University of Stellenbosch (US)).

Marine mammals and birds

Genetic studies of this group of marine organisms are presently being carried out in the Department of Chemical Pathology at the University of Cape Town (UCT). Harley *et al.* (1995) has recently completed a phylogenetic analysis of 14 species of South African cetaceans (including members from two baleen whale families and three toothed whale families) using restriction site mapping of mitochondrial DNA. An ongoing project in Harley’s group involves the construction of a DNA genomic library (from which loci containing microsatellites can be identified and utilised for quantitative population genetic analyses) for the white chinned petrel *Procellaria aequinoctialis* a species subject to bycatch in long-line fishing. The methodology employed in this project could find application to a variety of other related sea-birds (e.g. albatrosses). Harley’s research group has the expertise, techniques and equipment already in place to be more actively involved in genetic analysis of marine species provided appropriate research funding is made available.

An allozyme study of *Spheniscus* penguins by Grant *et al.* (1994) established insignificant allozyme differentiation firstly amongst three of the four species of *Spheniscus* penguins (African penguin, *S. demersus*, magellanic penguin, *S. magellanicus*, and humbolt penguin, *S. humboldti*) and secondly between two species of *Eudyptes* penguins (rockhopper penguin, *E. chrysocome*, and macaroni penguin, *E. chrysolophus*). As expected there were strong genetic differences between the two penguin genera.

A recently completed PhD. at Rhodes University (Goodwin, 1997) dealt with the use of mitochondrial DNA sequencing as a means of investigating the stock differentiation of bottle nosed and humpback dolphins (*Tursiops truncatus* and *Sousa plumbea*) off the KwaZulu-Natal coast. The dolphin population along this stretch of coast has been declining since the 1980's and the project was able to establish that there is very little, if any, recruitment from Transkei and East Cape populations of these species. This disturbing conclusion may have important long term implications for the survival of these species.

Marine invertebrates

Allozyme electrophoresis has been used successfully for species delineation in a variety of molluscan species including mussels (Grant *et al.*, 1984; Grant & Cherry, 1985), winkles (Heller & Dempster, 1991), whelks (Dempster, 1995) and limpets (Ridgway *et al.*, 1998). In all cases, fixed allele differences and strong genetic heterogeneity has provided evidence for a lack of gene flow between taxa. Similarly, Augustyn & Grant (1988) used a combination of genetic and classical taxonomic techniques to resolve the taxonomic status of the South African "chokka" squid *Loligo vulgaris reynaudii*. The use of DNA markers for species boundary studies is less common. Using direct sequencing and restriction analysis of the mitochondrial 16S rRNA gene, Geller *et al.* (1997) were able to establish the cryptic invasion of two *Carcinus* crab species into Cape Town waters. More recently, Sweijd *et al.* (1998) have developed a PCR-RFLP technique based on the lysin sperm protein complimentary DNA sequences to facilitate forensic species level identification of abalone tissue. Once proper legal implementation and application has been developed, this study has exciting implications for the control of abalone poaching in South Africa.

Studies of the phylogenies of marine invertebrates include that of Dempster (1995) on the whelk *Burnupena* (based on allozyme data) and that of Brasher *et al.* (1992) who used mitochondrial DNA variation to elucidate relationships in the rock lobster genus *Jasus*. Similar phylogenetic projects underway include a study of *Siphonaria* limpet relationships (PhD. project, Rhodes University, J. Gush) and dromiid crab relationships (B.A. Cook, Zoology Dept, University of Stellenbosch). As part of a study of chordate relationships, Durrheim *et al.* (1993) sequenced the mitochondrial DNA cytochrome oxidase gene from the common South African tunicate *Pyura stolinifera*.

Most studies of genetic structuring of populations of South African marine invertebrates have been based on allozyme data. These include investigations of the black mussel *Chloromytilus meridionalis* (Lombard & Grant, 1986), brown mussel *Perna perna* (Grant *et al.*, 1992), the African periwinkle *Nodilittorina africana knysnaensis* (Grant & Lang, 1991), *Burnupuena* species (Dempster, 1995), the plough shell *Bullia digitalis* (Grant & da Silva-Tatley, 1997), the limpets *Patella granularis* and *P. barbara* (Ridgway *et al.*, 1998; Ridgway *et al.*, in press), and the abalone *Haliotis midae* (Sweijd, 1999). These allozyme studies have generally shown limited population differentiation, often associated with broadcast spawning. In conflict with the allozyme findings, analyses of mitochondrial DNA haplotype variation in the abalone *H. midae* revealed a major genetic discontinuity at Cape Agulhas (Sweijd, 1999), and Neville Sweijd offers a detailed explanation for this conflict in his thesis.

Laboratory facilities and expertise for further work on the genetics of marine invertebrates are well established in the Cape Town area, with active laboratories operating at UCT (E. Harley, C. O'Ryan) and US (B.A. Cook), and possibilities for development at UWC (A. Channing).

Genetic manipulation of marine organisms

Research into the genetic manipulation of marine organisms has been very limited, with only one study published to date. Using a chemical treatment (Cytochalasin B), Stepto and Cook (1998) were able to induce triploidy in the abalone *Haliotis midae*. Although triploidy has been shown to improve growth in other abalone species, a large quantity of treated zygotes would be required for a commercial venture owing to the high mortalities of triploid larvae.

Bioprospecting (including a review of the status of the expertise, techniques and equipment)

Bioprospecting is the search for commercially valuable genetic and biochemical resources from nature. The resources are generally the latter, i.e. novel natural products (biologically active organic secondary metabolites) which could be used to develop new pharmaceuticals or agrochemicals. As the occurrence of novel marine natural products is directly related to the level of biodiversity and endemism, South Africa's marine invertebrate, algal and bacterial resources are a globally recognised, potential source of commercially exploitable chemical entities (Davies-Coleman, 1996). It must be noted, however, that commercial ventures in this field are expensive and not without risk, for example the development of a new pharmaceutical from a natural source can cost in excess of US$300 million with a developmental time frame of 13 - 26 years and a success rate of one in 10 000. The infrastructural and economic capacity to develop new drugs and agrochemicals does not presently exist in South Africa thus necessitating collaboration with international pharmaceutical and agrochemical companies operating in this field (Cragg, 1995; Wynberg & Laird, 1997). Bioprospecting in South Africa is controversial and the present white paper on the conservation and sustainable use of South Africa's terrestrial and marine biological diversity (July 28, 1997) addresses a number of the more emotive issues for example royalties, technology transfer from bioprospecting companies and the development of research capacity in South Africa.

International marine bioprospecting is presently focussed on the search for novel natural products from marine organisms. It is therefore important that South African marine natural product expertise be maintained. Marine natural product chemistry research in South Africa is centred at Rhodes University with a smaller research group emerging at the University of Natal (Durban). The former research group is well equipped and internationally competitive in the field with several recent publications dealing with the chemistry of bioactive natural products from South African sponges, ascidians, soft corals and molluscs (Davies-Coleman *et al.*, 1997)[1]. The natural product chemistry of South African marine invertebrates has also been investigated by foreign researchers most notably Faulkner (1995) and Kashman (1996a; 1996b). The former collaborates with both the Rhodes and Natal groups while the latter collaborates with Mike Schleyer at the Oceanographic Research Institute (ORI). Marine natural product chemistry programmes are most successful when they operate in tandem with biodiversity studies and an important aspect of the South African marine natural product investigations has been the discovery of new species of marine invertebrates. Two notable examples are the soft coral *Eleutherobia aurea*, (Schleyer, 1995) and a new genus of latrunculid sponge from the Tsitsikamma Marine Reserve (Davies-Coleman *et al.*, 1996). Although several South African marine natural products with moderate anti-inflammatory, anti-HIV and anti-cancer activity have been discovered in the Rhodes/Faulkner/SmithKline Beecham and ORI/Kashman/Pharmamar collaborations only one has been patented for its pharmaceutical activity (Kashman, 1996b). A proposed marine bioprospecting collaborative programme between the US National Cancer Institute (NCI) and Rhodes University is presently under review by the Department of Environmental Affairs and Tourism. The extensive nature of this proposed programme could provide the necessary infrastructure to co-ordinate marine natural product research and marine bioprospecting in South Africa.

Applications of genetics and bioprospecting to mariculture

It is often not feasible to harvest sufficient marine invertebrate material off the reefs to obtain sufficient quantities of natural products for pharmaceutical or agrochemical development. Accordingly, either synthesis of the marine natural product in the laboratory or mariculture of the natural product-producing organism is a viable alternative. The latter option is preferred (Christian, 1997) when the natural product has a particularly complex chemical structure (e.g. bryostatin-1). The production of natural products either through marine organism cell culture or the manipulation of marine genetic material has not, as yet, been successful anywhere in the world.

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UTILISATION OF SOUTH AFRICA'S LIVING MARINE RESOURCES

by A.J. Booth and T. Hecht

Introduction

South Africa has diverse and abundant living marine resources. In an effort to contribute to their rational and sustainable development and management, this report documents the various consumptive and non-consumptive components and the sectors that utilise them. In addition, it reports on the current exploitation status of the resources and their economic value, the management procedures that are in place, future research requirements, development opportunities and potential threats.

Marine fisheries

Trawl fishery

Harvesting of demersal fish in South Africa is conducted by three separate fishing sectors. The western Cape based deep-sea trawlfishery is the largest (84% in terms of catch) followed by the smaller south Cape coast based inshore trawlfishery. The deep-sea trawlfishery is restricted to fishing in waters deeper than 120m whilst the inshore trawlfishery is restricted, on the other hand, by vessel length (30m) and engine power (750hp). As a consequence of these physical restrictions the inshore trawling fleet does not fish in waters deeper than 120m. The mid-water trawlfishery, although governed by separate permits, is closely linked to the deep-sea sector. The same vessel often conducts demersal and mid-water trawling, depending on the availability of various fish resources.

The deep-sea trawlfishery targets the Cape hakes *Merluccius paradoxus* and *M. capensis*, whilst the inshore fleets targets the shallow water Cape hake *M. capensis*. A few inshore trawl vessels operating from Mossel Bay target the Agulhas sole *Austroglossus pectoralis*. A Total Allowable Catch (TAC) of 151 000 tons was set for the Cape hakes in 1998. The TAC is proportioned between the west and south Cape coasts using a 2:1 allocation ratio. A TAC of 872 tons has been set annually for sole over the past five years. Horse mackerel *Trachurus trachurus capensis* is targeted by the mid-water trawlfishery with chub makerel *Scomber japonicus* and ribbonfish *Lepidopus caudatus* as the dominant bycatch species. The total horse mackerel catch is currently controlled by an annual precautionary catch limit of 34 000 tons.

For the past three years, eight trawlers have been permitted to fish for crustaceans off KwaZulu-Natal. Trawling occurs principally on the Tugela Bank with five shallow-water vessels allowed within a seven nautical mile limit of the shore and three deep-water vessels outside of it. Vessels fish with bottom trawl gear with small-mesh (38mm) cod-ends. The shallow-water vessels target white prawn *Penaeus indicus*, brown prawn *Metapenaeus monoceros* and tiger prawn *P. monodon*. The deep-water sector targets pink prawn *Haliporoides triarthrus*, langostines *Metanephrops mozambicus* and *Nephropsis stewarti* and rock lobster *Palinurus delagoae*. The targeted catch/bycatch ratio for both sectors is commonly high for a prawn directed fishery. Between 1988 and 1993, 350 tons of targeted catch was landed with 1 700 tons of bycatch. Retained bycatch include red crab *Chaceon macphersoni*, teleost fish species and cephalopods (Fennessy & Groeneveld, 1997).

There are numerous bycatch species that are caught incidentally by the demersal trawlfisheries. Booth & Hecht (1998) list the species discarded and landed by the Eastern Cape inshore trawlfishery. Fennessy (1994a; 1994b) documents teleost and elasmobranch bycatch species landed in the prawn trawlfishery. Teleost and elasmobranch bycatch species caught by the deep-sea trawlfishery are summarised by Japp *et al.* (1994).

Longline fishery

The longline fishery was initiated in 1993 to selectively harvest the hake resource. Soon after its inception, the fishery switched to kingklip *Genypterus capensis*, a highly valued yet quota-unrestricted species. Catches were high yet declined rapidly due to the high directed fishing pressure on the spawner stock, which in retrospect, was already overfished (Punt and Japp, 1994). As a result the kingklip longline directed fishery was closed in 1991. The longline fishery has remained open with the development of an “experimental” fishery for shallow water hake *Merleuccius capensis.* An additional “experimental” longline fishery was also reopened in 1997 for albacore tuna *Thunnus alalunga* for a limited number of participants. The target species quickly switched to broadbill swordfish *Xiphias gladius*, the principal bycatch species. There is now increasing concern over the sustainability of this fishery and the fact that R80 million has already been invested in it despite its “experimental” status.

Linefishery

The linefishery is complex and is broadly comprised of three components: the squid-jigging fishery, the tuna fishery and the recreational and commercial linefisheries.

The squid jigging fishery, initiated in 1983, targets the chokka squid *Loligo vulgaris reynaudii* off the south-east Cape coast. Fishing is conducted from vessels ranging from ski-boats to 20m deckboats. Fishers use jigs to catch spawning aggregations of adults. Catches are relatively stable at 6 000 – 7 000 tons per annum, yet due to increasing levels of fishing effort, there has been a steady decline catch-per-unit-effort (Roel *et al.*, 1998).

A longlining tuna fishery was initiated in 1960. Due to fluctuations in catches and the expensive nature of the fishery, poling is now used as the principal fishing method. Fishing effort is directed at albacore *Thunnus alalunga* (Punt *et al.*, 1995).

The third component of the linefishery can be further subdivided into five user groups. These are the shore fishers, commercial ski-boat and deck-boat fishers, recreational ski-boat fishers, light-tackle ski-boat fishers and spearfishers. Each sector has its own suite of target species with little overlap between the offshore and inshore sectors. Over 200 teleost and elasmobranch species are caught, but only 95 species contribute significantly to the catches (Van der Elst, 1989; Brouwer *et al.*, 1997; Mann *et al.*, 1997; Sauer *et al.*, 1997).

Pelagic fishery

The pelagic fishery is the largest by mass of fish landed in South Africa. Most vessels are purse-seiners and operate on the south-west and west Cape coasts. There is also a small land-based net fishery in KwaZulu-Natal and a single purse-seiner operating from Port Elizabeth. Despite the considerable mass landed, the unit value of the catch is low, bringing the economic value of the fishery below that of the demersal trawlfishery. Vessels catch and land pilchard *Sardinops sagax*, anchovy *Engraulis capensis*, round-herring *Etrumeus whiteheadi*, chub mackerel *Scomber japonicus*, horse mackerel *Trachurus trachurus capensis* and other mesopelagic species. Catches in the pelagic fishery are highly variable. In addition, there is considerable interaction between the catches of anchovy and pilchard. Pilchard was historically the dominant fish harvested and processed by the canning industry. Since 1963, however, anchovy has been the dominant species landed by this fishing sector and processed primarily for fishmeal and oil. There now appears to be evidence for a recovery of the pilchard resource. Whilst the anchovy harvest remains the largest component of the pelagic fishery, catches have decreased from 350 000 tons in 1992 to 170 000 tons in 1995. Pilchard catches have increased from 50 000 to 150 000 tons over the past five years. Red-eye round herring yields the only other significant harvest, ranging between 33 000 and 80 000 tons per annum. In 1998, TACs of 175 000 tons and 126 900 tons were set for anchovy and pilchard, respectively.

Rock lobster fisheries

South Africa's rock lobster fishery is based principally on two species, the south coast rock lobster *Palinurus gilchristi* on the south Cape coast and the west coast rock lobster *Jasus lalandi* on the west Cape coast. The west coast rock lobster is caught inshore by commercial operators who use hoops and traps deployed from small vessels and by recreational divers. The south coast rock lobster, in contrast, is a deep-water species caught by means of longlines of traps deployed from large freezer vessels. An experimental deep-water longline trap fishery for the Natal spiny lobster *Palinurus delagoae* has also been initiated in 1994 to determine the potential of a sustainable fishery. Catches of west coast rock lobster have been declining over the past four years from 2 192 tons in 1994 to 1 680 tons in 1997. Similarly, south coast rock lobster and Natal spiny lobster catches have declined over the same time period from 1 021 tons to 892 tons and from 33 tons to 10 tons, respectively.

Abalone

South Africa's commercial abalone *Haliotis midae* is harvested by licensed commercial divers operating from small vessels with portable compressors that supply air to divers through a reinforced hose. There has been a relatively stable catch over the past few years that is controlled by an annual whole mass quota between 500 and 600 tons. The fishery is divided into seven fishing zones with a TAC set for each zone. Recreational catches are increasing rapidly and despite recommendations for a reduction in this fishery, nothing has been established. Poaching is having a serious effect on the fishery. Poaching was initially restricted to one location (Mudge Bay/Hawston) but has now spread along the coastline.

Beach-seine and gillnet fisheries

It is estimated that there are currently 7 000 netfishers using both beach-seine and gill nets in South Africa. Most of these fishers (86%) operate on the west and east Cape coasts (Lamberth *et al.*, 1997). Effort is directed at the harder *Liza richardsoni* resource that comprises 60% of the total net caught catch. Other species caught in appreciable amounts include the St Joseph shark *Callorhynchus capensis* (10%) and other "bycatch species" such as galjoen *Dichistius capensis*, yellowtail *Seriola lalandi* and white steenbras *Lithognathus lithognathus* which in total contribute 30% of the catch. The net fisheries land an average of 1600 tons of fish per annum. A small beach-seine net fishery of 600 tons exists for pilchard *S. sagax* in KwaZulu-Natal.

Mariculture

Mariculture in South Africa is principally based on molluscs. The principal species cultured are the Spanish mussel *Mytilus galloprovincialis* and the pacific oyster *Crassostrea gigas* (Hecht & Britz, 1992; Britz & Hecht, 1997). Approximately 2 500 tons of mussels and 480 tons of oysters are cultured annually. Oysters are cultured at Knysna, Port Elizabeth, Saldanha Bay, St Francis Bay, Port Nolloth, Port Alfred and Alexander Bay. Mussels are cultured at Saldanha Bay, Stompneusbaai and St Francis Bay. Abalone, principally for the export market, is cultured at Danger Point, Hermanus, Port Nolloth, Stompneusbaai, Hout Bay and Port Elizabeth whilst prawns are cultured at Amatikulu, KwaZulu-Natal.

Recreational molluscs and crustaceans

Recreational fishers harvest Octopus spp., mussels *Perna perna*, *Choromytilus meridianalis* and *Mytilus galloprovincialis*, oysters *Striostrea margaritacea*, limpets *Patella* spp., giant periwinkles *Turbo sarmaticus*, white mussels *Donax serra* and abalone *Haliotis midae*. Crustaceans fished recreationally for consumption are the rock lobsters *Jasus lalandii* and *Palinurus homarus*, the estuarine mud crab *Scylla serrata* and the prawns *Penaeus indicus* and *P. monodon*.

Mammals

Seals have been exploited since the early 17th century until 1989. In 1990 a moratorium was placed on sealing, which is still in existence until further information regarding seals and their associated fisheries are available (SFAC, 1990). There is a strong anti-sealing lobby within South Africa, which threatens the potential viability of this resource.

Subsistence fisheries

Subsistence fishing has recently been identified as a distinct harvesting sector. Whilst little of the catch is sold, it constitutes a large portion of the diet of the fishers. Subsistence fishers operate along the entire

South African coastline, particularly in the former Transkei and west Cape coasts (Fielding *et al.*, 1994; Robertson & Fielding, 1997). Resources that are harvested are predominantly inter-tidal and estuarine.

Bait fishery

South Africa has a variety of bait species used by the longline, recreational and commercial linefisheries and rock lobster fishery. Bait organisms harvested from the rocky intertidal zone for use in the recreational linefishery include brown mussel *Perna perna*, red bait *Pyura stolonifera*, reef worm *Gunnarea capensis*, chiton *Dinoplax gigas*, abalone *Haliotis midae*, venus ear *H. spadicea*, limpets *Patella* spp. and octopuses *Octopus* spp. Marine sand-associated recreational linefish bait organisms include white mussel *Donax serra* and mole crab *Emita austroafricana*. Estuarine linefishers collect pencil bait *Solen capensis* and *S. cylindricus*, blood worm *Arenicola loveni*, sand prawn *Callianassa kraussi*, mud prawn *Upogebia africana* and swimming prawn *Penaeus* spp. Small fish species are used for bait by the offshore and inshore commercial and recreational fishing sectors and include strepie *Sarpa salpa*, mullet *Mugil* spp, Cape stumpnose *Rhabdosargus capensis*, fransmadam *Boopsoidea inornata*, piggie *Pomadasys olivaceum*, red tjor-tjor *Pagellus natalensis*, panga *Pterogymnus laniarius* and steentjie *Spondiosoma emaginatum*.

Seaweeds

Various species of seaweed form the basis of a modest but viable commercial fishery for the production of alginate products. These seaweed resources include the beach-cast kelps *Ecklonia maxima*, *Gracilaria* spp., *Laminaria pallida* and *L. schinzii* on the west coast and *Gelidium* spp. (in particular *G. pristoides*) on the east coast. The South African coast between the Kei River and Orange River mouths is divided into 18 concession areas, which are held by six companies. The South African seaweed harvest between 1993 and 1994 was dominated by *Eklonia maxima* (509-738 tons) and *Gracilaria* (272-439 tons). The *Gelidium* harvest over the same period ranged between 73 and 86 tons. The seaweed fishery is limited by entry with the harvest of fresh kelp *E. maxima* restricted by a TAC at Kommetjie.

Non-consumptive resources

Various non-consumptive resources are utilised in South Africa. Many of these derive substantial income for the tourist industry such as whale watching, dolphin watching, bird watching, turtle tours, SCUBA diving and snorkelling. The collection of bird guano used to form the basis of a small industry, however, little or no guano has been collected over the past five years (see Ecosystem functioning: Coastal Islands section, this report).

Status of the fisheries

Demersal fisheries

The Cape hake stocks are considered to be fully utilised (Punt, 1994) and the kingklip stock(s) over-utilised (Punt & Japp, 1994). The horse mackerel stock is considered to be either fully or under-utilised (SFAC, 1997) as there is a considerable shelf-break biomass over the eastern Agulhas Bank. Bycatch species within this sector are considered under-utilised (Japp *et al.*, 1994; Booth & Buxton, 1997; Booth & Punt, 1998) but more research is necessary before directed exploitation is possible (Booth *et al.*, 1999).

Pelagic fishery

Pilchard and anchovy are both considered to be fully utilised (Bergh & Butterworth, 1987; Butterworth *et al.*, 1993). The mesopelagic and round herring stocks are, in contrast, considered to be under-utilised (Roel & Armstrong, 1992).

Crustaceans

Prawns and langoustines are considered to be fully utilised, whilst the mud crab is considered to be under-utilised.

Rock lobster fisheries

Both the west and south coast rock lobster and Natal spiny lobster resources are considered to be fully/over-utilised (Cockcroft & Payne, in prep.; A.C. Cockcroft, pers. comm.).

Squid jigging

The squid resource is considered to be fully utilised (SFAC, 1997).

Tuna

This fishery is fully utilised (Punt *et al.*, 1995).

Linefisheries

Most stocks are overfished (Garratt, 1985; Bennett, 1988; 1993; Buxton, 1992; Griffiths, 1997a; 1997b; Punt *et al.*, 1993) with a few that are fully fished (Pulfrich & Griffiths, 1988; Buxton, 1992) and fewer that are showing signs of under-utilisation (Chale-Matsau, 1996; Van der Walt & Govender, 1996; Booth & Buxton, 1997; Booth & Punt, 1998). There is a large "shifting effort" problem, where fishers deplete a resident stock and shift their fishing effort onto another. This gives the impression of the fishery maintaining stable CPUEs and being sustainable. The status of the kob *Argyrosomus japonicus* and *A. inodorus* fisheries is of particular concern due to their importance in the rock and surf, commercial and recreational offshore linefisheries. Their statuses are severely overfished according to Griffiths (1997a; 1997b).

Abalone

On the west Cape coast, abalone is considered to be fully utilised. This is likely to cause a decline in the TAC in future years as a response to increased utilisation by recreational users and an uncontrollable level of poaching (estimated at 600 tons in 1997). A recent telephone survey revealed that recreational abalone divers harvest nearly 80% of the commercial TAC. In the Eastern Cape there is a small resource that may be able to yield a few tons despite intense recreational fishing pressure and poaching in some areas. (Tarr, unpublished data)

Netfisheries

On the south-west and west Cape coasts, the harder resource is heavily utilised (Lamberth *et al.*, 1997). An experimental fishery is underway on the south-east Cape coast.

The subsistence and recreational fishery for molluscs

The abalone fishery is fully utilised (Tarr, unpublished data) with the limpets *Patella* spp., whelks and *Octopus* spp. considered to be under-utilised in some areas. Along the former Transkei coast where there is intense harvesting, all inter-tidal mollusc resources are considered to be over-utilised (Anon, 1996b).

Seals

The seal resource is considered under-utilised **(**SFAC, 1990**)**.

Bait fishery

Red bait, sand prawn, reef worm, and mole crabs are considered to be under-utilised. Mud prawn, blood worm and white mussel are considered to be either fully- or over-utilised in certain areas (Anon., 1996b; Robertson & Fielding, 1997; Oceanographic Research Institute, unpublished data; Marine and Coastal Management (MCM), unpublished data).

Seaweeds

Kelp (*Ecklonia. maxima*) is considered to be under-utilised, whilst the *Gracilaria* spp. resource is fully utilised (Anderson *et al.*, 1989, Levitt *et al.*, 1992).

Mariculture

There is considerable potential for mariculture in South Africa (Hecht & Britz, 1992). A recent study suggested that the carrying capacity for Saldanha Bay was 80 000 - 100 000 tons for mussels alone (Cook, 1998).

Non-consumptive resources

All non-consumptive resources, with the exception of guano collection, are considered to be under-utilised. The impact of ecotourism on the resources needs to be carefully examined.

Future prospects

There are few resources that appear to be under-utilised and therefore offer few prospects for further developments. Various pelagic and mesopelagic species such as horse mackerel (Barange *et al.*, 1998) and red-eye round herring (Roel and Armstrong, 1992) have been shown to be abundant on the south Cape coast and are obvious candidates for increased levels of harvesting, provided suitable gears are developed. Other under-utilised resources include various trawl bycatch species, deepwater fish species such as orange roughy (*Hoplostethus atlanticus*) and oreo dories (*Allocyttus* and *Neocyttus* spp.), seals, whelks, common octopus *Octopus vulgaris*, certain crab and prawn species (*Scylla seratta* and *Ovalipes trimaculatus*), red-bait and certain seaweeds. Poaching of patagonian toothfish (*Dissostichus elengoides*) by international fleets off the Marion and Prince Edward Islands is already putting the resource under severe pressure and the sustainability of the resource is questionable (MCM, unpublished data). The under-utilisation of various resources needs to be addressed from a regional perspective. Some of these species have been earmarked as potential subsistence candidate species (Anon., 1996b).

Utilisation of trawl bycatch resources is a necessary option, as bycatch utilisation and/or reduction are becoming increasingly important considerations within the trawlfisheries. There is a need to utilise these resources as almost all bycatch organisms die after capture. If the facilities to process these resources are not available then methods to reduce bycatch are necessary such as bycatch reduction or exclusion devices (Broadhurst & Kennelley, 1994; Booth *et al.*, 1999).

Mariculture has viable prospects in South Africa. There is a global trend towards developing mariculture potential in many countries, principally to meet current seafood demands. South Africa is no exception and the production of high value species is set to enter an exponential growth phase.

Whale and dolphin watching, particularly in the southern Cape, is an important non-consumptive resource and has high economic potential. Penguin watching at Boulder Bay, Cape Town is an important tourist attraction.

The development of Marine Protected Areas also needs careful consideration. They provide a mechanism to conserve biodiversity as they protect essential habitat, provide additional surplus fish to adjacent areas, seed adjacent and distant areas with eggs and larvae and promote ecotourism (see Conservation of Marine Biodiversity, this report).

Research needs

In general, marine resource research needs should be carefully reviewed and prioritised. An exercise of this nature has already been conducted for the linefishery (Van der Elst & Adkin, 1991) and is currently being updated. This exercise has provided valuable insight into priorities and has facilitated funding decisions. Workshops, therefore, need to be convened to address this issue for other resources and fisheries.

Inter-institutional collaboration with regards to the assessment and management of South Africa's living marine resources needs to be encouraged. In addition, most of the stock assessment research conducted is of a single species nature and an ecosystem and/or multispecies approaches need consideration.

Due to the lack of data on certain substrata (including areas of reef and hard grounds) and their associated resources, it is necessary for South Africa to take a full resource inventory. A comprehensive socio-economic analysis needs to be conducted on the utilisation of South Africa's resources, the communities that are benefiting, and the regulations that are in place to ensure sustainable harvesting.

Currently, it is perceived that all the trawl bycatch resources are under-utilised. The reality needs to be carefully assessed as only the basic biology of bycatch species has received attention (Booth, 1997; Walmsley, 1996; McPhail, 1997). Research also needs to be conducted on the development of alternative bycatch products and the establishment of suitable markets.

Management procedures and legislative efficiency

There has been considerable change within the marine resource management arena over the past two years (see International and national policies concerning marine and coastal biodiversity, this report). A new Marine Living Resources Act (Act 18 of 1998) has been approved that promotes equity of access to resources, resource sustainability and socio-economic stability. South Africa's marine living resources are considered to be a national asset, and as such, require management from a national level. There has also been significant restructuring within the Marine and Coastal Management (formerly the Sea Fisheries Research Institute), South Africa’s national management agency responsible for a significant proportion of fundamental and applied research pertaining to the status of South Africa's marine living resources. MCM is now tasked with the pressures of self-reorganisation together with having to implement the Act.

South Africa has a variety of resources and associated fisheries. These range in size from recreational fishers to technically advanced industrial fleets. As a consequence, their management needs are unique and careful consideration needs to be afforded to involving all stakeholders into the decision-making process. Further socio-economic studies need to be initiated to assess the various fisheries regulations and critically assess the strengths and weaknesses of alternative management scenarios.

South Africa is moving towards the development of Operational Management Procedures (OMPs). Those in operation are for the anchovy/pilchard complex (Bergh & Butterworth, 1987; Butterworth *et al.*, 1993), Cape hakes (Punt, 1994) and west coast rock lobster (MCM, unpublished data). OMPs are important, and industry needs to be fully involved in management decisions. OMPs are presently being developed for the linefishery (Penney *et al.*, 1997). Researchers involved in stock assessment are distributed throughout the country at government, private and educational institutions such as MCM, University of Cape Town, Rhodes University and the Oceanographic Research Institute.

Lastly, serious attention needs to be given to the efficiency of policing.

Potential threats

With South Africa's high population growth rate there is no doubt that there will be additional pressures on its marine living resources. Conflicts over access rights, increased levels of poaching and overfishing are inevitable. Proactive measures need to be implemented as a matter of urgency to ensure the resources are sustainably harvested and the social and economic security and stability of the fishers is maintained. Fisheries management must therefore strive to maintain biological functioning of ecosystems and ensure that the resource in question is sustainable over the long-term. Such an ecosystem-based management approach must be founded on sound scientific knowledge, and if absent, using the precautionary principle approach.

Overfishing is an obvious threat. As the current fisheries resources are mostly fully utilised, any increase in fishing effort must be viewed with caution. For those resources currently considered to be under-utilised, a fair and equitable system of access is needed to ensure long-term sustainability. The management system should consider the use of the resources in the interests of conservation and in the interests of current and potential users (Anon, 1996a; 1996b).

Political expediency, the control of fishing fleets and control of illegal fishing (poaching) are immediate threats to resource sustainability in South Africa. Enforcement in South Africa is poor and is primarily restricted to the large economically important industrial fisheries off the western Cape. Independent research has, however, shown that small-scale fisheries, and their associated industries, such as the linefishery, contribute significantly to the economic welfare of many towns and cities along the South African coastline. Resource sustainability is the critical link in the chain. If there is overfishing, there will be no incentive to fish commercially or recreationally and this will have serious economic impacts. The development of educational thrusts and review of resource-ownership issues, coupled with proactive monitoring and effective policing is therefore imperative.

The value of marine biodiversity

The effective monetary value of each fishing sector must include its processed value and the income generated by associated industries. In many cases the latter figure is unavailable. Within the South African trawlfishery in 1995, the demersal catch contributes the greatest revenue in terms of wholesale value (R805 million). Despite landing the greatest weight of fish, the pelagic fishery generates R403 million. The rock lobster and linefishing sectors contribute R185 million and R216 million, respectively. Other large contributors include the abalone fishery (R54 million) and the mariculture industry (R25 million). Overall, the wholesale value in 1995 for all commercial fishing sectors totalled R1.7 billion.

The potential value of non-consumptive resources as a source of income through ecotourism has only recently been recognised. Similarly, the value of recreational fishing lies not necessarily within the value of the fish caught (or processed) but in the associated industries that support them such as tackle and bait shops and boat-building enterprises. Data that are available suggests that the total South African linefishery generates R2.2 billion alone (McGrath *et al.,* 1997). This is in stark contrast to the processed value of the catch of R185 million, with the balance largely attributed to associated industries. Monetary values for the subsistence fishery are not available at present as the research is currently in progress.

Conclusion

In South Africa, most living marine resources currently harvested are fully utilised with only a few that can be considered to be under-utilised. Certain resources, such as the abalone and kob species, are severely overfished. Careful consideration must therefore be given to the current status of these stocks to foster rebuilding and avoid further over-fishing scenarios. For those consumptive and non-consumptive resources that are under-utilised, their potential needs to be recognised to provide considerable economic and social benefits for the future.

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CONSERVATION OF MARINE BIODIVERSITY IN SOUTH AFRICA

by C.L.Attwood, C.L. Moloney, J. Stenton-Dozey, L.F. Jackson, A.E.F. Heydorn and T.A. Probyn

The reliance of South Africa's increasing population on the ocean for food, recreation, transport and mineral extraction has subjected marine biodiversity to pressures that are changing the structure of marine communities. Human impacts on the marine environment differ substantially from those experienced in the terrestrial environment. Because the sea is a commonage and most of its features are hidden from human observation, many principles and ethics that apply to terrestrial resource management do not apply to the ocean. Indiscriminate dumping of substances, for example, is tolerated at sea to an extent that is generally not permitted on land. There is free access to the harvesting of wild marine organisms for recreation almost everywhere along South Africa's shores, whereas the practice of hunting on land is restricted and controversial. Resource husbandry is seldom developed in the marine environment. In contrast to South Africa's terrestrial biodiversity, its marine biodiversity is threatened primarily by the exploitation of wild organisms. Efforts to conserve the marine environment must consider the dispersive nature of the seawater-medium that links marine populations over vast areas and spreads pollutants to an equal extent.

The South African marine environment is showing symptoms of over-exploitation and degradation, and the pressures that bear on marine resources are likely to increase for the foreseeable future. This chapter reviews the major threats, the mechanisms for conservation, and the capacity for management of marine biodiversity in South Africa.

Major threats to marine biodiversity

Fishing

The definition of biodiversity includes genes, species, communities and ecosystems, their physical environment and all the abstract relationships among these various components. With such a wide definition, there is a multitude of human activities that can impact marine biodiversity. Many of these are likely to be regarded as threats, but none are considered to have had as great an impact as fishing (Boehlert, 1996). The total world fish catch, estimated at 100 million metric tons per annum, is causing disruptions to marine biodiversity at all levels by the removal of fish and the disturbance of the biological and physical environments.

The primary objective of fisheries management has been to ensure the sustained yield of fisheries, with less attention being paid to the effects of fishing on non-targeted species and the environment. But even in its narrow, primary objective, fisheries management around the world is failing (Clark, 1996; Roberts, 1997). The process of fishery management reduces fisheries to their component parts and assesses and controls each independently. Catch quotas are derived from estimates of the production of individual stocks, based on their size, structure and growth rate. The dependence of a fish population on other components of the ecosystem for maintaining its productivity is almost always ignored by managers. This oversight could have serious consequences if the ecological structure and processes that support stock production are impacted by the fishing activity itself, or by other human activities or natural phenomena.

Apart from direct effects of fishing on fish abundance (see Utilization of South Africa's marine living resources, this report), there are four major indirect effects on marine biodiversity:

(i) Alterations to the benthic environment

The impacts of trawls and dredges on the benthic habitat include scraping, ploughing and resuspension of substratum (Jennings & Kaiser, 1998). The effects of these impacts vary according to the fragility of the habitat and severity of natural disturbance. Coral reefs and deep-sea environments that are not accustomed to disturbance have been severely impacted (Jones, 1992). Preliminary investigations of the effects of trawling on the benthic environment of the South African west coast have not revealed signs of impact. This may be attributed to strong currents associated with upwelling along this shelf (R.W. Leslie, Marine and Coastal Management, pers. comm.). At the other end of the coast, South Africa's coral reefs have been totally protected from all forms of bottom fishing. There is, however, concern that bobbin-gear and tickler chains, once extensively used by local and foreign trawlers, have damaged temperate reef habitat on the Agulhas Bank while catching reef fish (e.g. Panga *Pterogymnus laniarius*) and flatfish (e.g. Monkfish *Lophius upsicephalus*), in a similar manner to damage caused to such environments in other parts of the world (Jennings & Kaiser, 1998). There are no base line data to test these possibilities locally. Experimental fisheries off southern Africa for orange-roughy and other deep reef species have the potential for destroying seamount fauna, which include many range-restricted species (Koslow *et al.*, 1999).

Trawl catch discards are dumped into the sea and sink to the bottom where they rot and reduce oxygen levels in the benthic layer. Such effects can make the habitat less suitable for many benthic organisms (Jones, 1992).

(ii) Changes to community structure

Fisheries are size and species selective, and have altered community structures substantially (Russ & Alcala, 1989; Bohnsack & Ault, 1996). The terms 'serial overfishing' (Bohnsack & Ault, 1996), and 'fishing down the foodweb' (Pauly *et al.*, 1998) describe the tendency of fisheries to deplete large top predators first and then to successively target the next largest species as previous targets become depleted. These changes can reduce the productivity of a food chain, if the effects filter down to primary producers (Babcock *et al.,* in press). South Africa has experienced this phenomenon, beginning with near extermination of fur seals, followed by targeting of reef-fish predators. Comparison of contemporary and historical records of South African linefish catches show that large piscivorous fish species have declined relative to smaller species over the course of the twentieth century (Attwood & Farquhar, in press; Griffiths, in press.).

(iii) Changes to gene pools

The selectivity of fishing gear affects the intra-specific diversity of fish populations by selecting against certain traits, such as large size and fast growth, aggression and schooling behaviour. Fishing mortality rates on South African marine fish range from 0.1 y^{-1} for demersal quota species to 1.0 y^{-1} for linefish species, implying that between 10% and 64% of a stock is removed by fishing gear annually. Such intense selection can change physical, physiological and behavioural attributes of wild stocks in a few generations, and impact on their fitness, production and catchability (Ryman, 1991).

(iv) Incidental mortality on non-target species

Despite the desired selectivity of fisheries, fishing hardware can seldom deliver the accuracy to match it (Roberts, 1997). Many species are caught despite the fact that they are not wanted, not allowed to be caught or because they cause damage to the gear. Bycatch rates in South Africa vary between five and 70% (Japp, 1997). The effect of fishing on bycatch species is seldom known, because these species are mostly not recorded in catches and not regulated by quotas. A serious bycatch issue is currently the mortality of sea-birds affected by long-line operations (Barnes *et al.*, 1997; Ryan *et al.*, 1997).

Mariculture

The decline in the availability of wild fish and the increase in the demand for sea-food products, has promoted the practice of mariculture. The culture of profitable species in or near the coastal zone has had a negative impact on marine biodiversity in many countries. Effects include mangrove deforestation, loss of native habitat, eutrophication, invasion of introduced species, and the spread of disease organisms (National Research Council, 1995; Cowley *et al.*, 1998). South Africa does not have a coastline suited to mariculture, and the few enterprises that have flourished are located in physically protected bays (e.g. Mediterranean mussels *Mytilus galloprovincialis* in Saldanha Bay and Port Elizabeth), estuaries (Pacific oysters *Crassostrea gigas* in Knysna Lagoon) or land-based impoundments with a pumped seawater supply (abalone *Haliotus midae* in Walker Bay). Even on a limited scale, these practices can present threats to marine biodiversity, unless properly managed. The Saldanha Bay farms have been the most intensively studied mariculture operation in South Africa. The threats to marine biodiversity by these farms are the removal of phytoplankton by the farmed mussels, which could affect the native planktivorous populations of the bay, and the smothering of the benthos underneath the rafts.

Abalone have been introduced at Port Nolloth as a ranching experiment, in a region that is beyond the current (but not historical) range of the species. This introduction was not considered to be problematic, because the species is slow-growing and vulnerable to exploitation (R. Tarr, Marine and Coastal Management, pers. comm.).

Mining

South Africa's marine and coastal environment is mined in the north-east for titanium, in the south for fossil fuel and in the north-west for diamonds, and exploration for phosphate is in progress along the southern and western coasts. An unavoidable consequence of mining is the disruption of the sediment, which ranges from extensive in the case of titanium to limited in the case of oil. With that disruption, there is a complete removal of the biological community, which may include dune vegetation, in-fauna and epi-fauna. With few exceptions, marine mining does not introduce anything into the natural environment, provided that mechanical structures and waste material are returned to land.

Titanium mines are restricted to coastal dunes, where the loss of biodiversity has been partly offset by the re-vegetation of mined dunes. Titanium-rich dunes fringe Lake St Lucia, South Africa's largest estuarine system. Application also has been made to mine the seabed in this area.

At present there is one active oil and gas well near Mossel Bay, with further exploration occurring widely on the Agulhas Bank. Oil and gas extraction does not cause major benthic disruption. The possibility of a spill is probably the greatest threat posed by this industry to marine biodiversity.

Diamond mining along the west coast disrupts the benthos, re-suspends sediment in a tail-plume and results in under-sea noise. The tail plumes contain heavy metals that may reach toxic concentrations (Lane & Carter, 1999). Concessions have been granted to a number of local and international companies, covering virtually all of the shelf, and much of the coastal zone, along South Africa's west coast, north of 33° S. Diamonds are confined to small pockets (ancient river mouths), and while only a small fraction of the concession areas will ever be mined, there is concern that diamond concentrations could occur in a particular habitat type with a unique fauna. If this is the case, there could be substantial disruption to such a community. A number of post-graduate studies have been completed on the species composition and recovery time of disturbed west-coast benthic communities (J.G. Field, University of Cape Town, pers. comm.). Other than these, there are few base-line data and no 'biodiversity maps' to assess the threat of future mining.

For all mining operations, there is the potential for conflict with fishing interests.

Pollution

Pollution originates from land-based sources (industrial, municipal, agricultural and run-off), shipping activity (accidental and deliberate discharges, garbage and dumping) and atmospheric gases (soluble gases). Pollutants can take on many forms, and might affect marine biodiversity in several ways:

(i) Toxicity.
Industrial waste is as diverse as industrial products: heavy metals, petroleum products, halogenated hydrocarbons, radioactive waste, etc. This broad range of toxins can lead to an increase in infections, tumours and diseases in marine fish (Vethaak & Rheinaldt, 1992). Heavy metals accumulate in food chains, poison top predators and render seafood unsafe for human consumption.

(ii) Eutrophication.
Effluent from sewage systems or food processing leads to increased concentrations of organic compounds in the marine environment. Bacterial counts are proportional to organic levels and organic loading can lead to unhealthy levels of bacteria, causing infections in marine life and humans. Excessive organic

loading can also lead to eutrophication and anoxia. Increased levels of nutrients promote primary production but often lead to a reduction in local diversity. A consequence of increased eutrophication is an increased frequency, duration and intensity of noxious red tides (National Research Council, 1995). The recent red tide bloom at Elandsbaai is possibly a consequence of anthropogenic eutrophication.

(iii) Sediment loading.

Increased erosion of soil can lead to increased levels of particulate matter in the water which in turn increases turbidity, reduces plant growth and clogs the filtering appendages of many organisms low down in the food chain.

(iv) Plastic pollution.

Plastics have a long half-life and their persistence in the marine environment poses a threat for marine organisms that ingest or become entangled in plastic waste. Sea-birds, seals and turtles are among the most affected. In South Africa, plastics contribute about 90% of marine litter, and the cost of cleaning beaches runs into millions of Rands (Ryan, 1990).

(v) Oil pollution.

Marine crude oil physically smothers intertidal organisms and fouls feathers and fur. The survival of the endemic African penguin *Spheniscus demersus* is threatened by oil spills (Crawford, 1998).

(vi) Aesthetic pollution.

Effluents may discolour coastal water, and impact on recreational usage. Garbage and plastics are also unsightly.

Invasion of alien species

South Africa has been fortunate in that its marine ecosystems have not been severely disrupted by invasive alien species, despite the great potential for seeding from ships. The two major invasions in South African waters are believed to have been introduced accidentally by ships or oil rigs. The European mussel *Mytilus galloprovincialis* has invaded the west coast (Grant & Cherry, 1996), where it has restructured intertidal communities. This species is also farmed commercially. The invasion of the European shore crab *Carcinus meanis* has been restricted to sheltered bays and harbours along the southwest coast, but the species has the potential to devastate populations of molluscs (Le Roux *et al.*, 1990). There is also a possibility of accidental or deliberate introduction of species for culturing which may establish them in the natural environment. Poor control of the mariculture industry has been blamed for the introduction of a South African Sabellid worm parasite to California where it has infected several abalone farms and has presented a potential threat to indigenous wild stocks (Lafferty & Kuris, 1996; Tegner, 1996).

South Africa has experienced episodic invasions of unicellular algae. *Oriococcus anophagesserens* bloomed in Saldanha Bay and threatened the mariculture industry there. It is a small alga that was noticed only when it bloomed. The occurrence of this same species along the American Pacific coast suggests that is may also be an invader from ships. *Gymnodinium cf. mikimotoi*, bloomed in False Bay in 1988, when it was recorded for the first time. It has since been recorded most years after that, which also suggests that it is an introduced species. It caused large invertebrate mortalities and presented a health hazard. Ship ballast water is the most common transport mechanism for invasive algal species (National Research Council, 1995).

Climate change

Pollution of the atmosphere is resulting in increased levels of UV radiation and a reduction in back-radiation from the earth. The former directly damages tissues of plants and animals. The latter is leading to a change in the heat balance of the globe, causing shifts in weather patterns and temperature regimes. The long-term direction of climate change is uncertain on a local scale, but at this stage there is agreement that changing temperature regimes in the marine environment will raise the sea-level and could severely alter species distribution patterns, reproductive success and production rates (de Fontaubert *et al.*, 1996).

Artificial reefs

Fishers and divers enhance their catches by providing additional hard substrata in the form of waste materials (e.g. tyres), derelict ships or purpose-designed concrete or fibreglass structures. This practice is controversial. The provision of reefs can provide additional sites for epilithic and reef-dwelling fish species. They can also serve to attract and concentrate long-lived reef fish to accessible and well-known areas frequented by line- and spear fishermen. The structures themselves may present a pollution threat. Artificial reefs have been created legally and illegally in South Africa.

Human pressure on the coastal zone

The underlying cause of most problems related to biodiversity is human population growth and the attendant pressure on natural resources. The coastal zone in South Africa is showing signs of over-use near metropolitan areas. Increased pedestrian and vehicle traffic on the shore is causing damage to dune plants and threatening the breeding success of coastal birds, like the African Black Oystercatcher *Haematopus moquini* (Hockey, 1997). Even non-consumptive activities, which are promoted in reserves, can cause damage to ecosystems. An overload of recreational divers, for example, has led to coral reef deterioration in some parts of the world (Dixon, 1993), including Sodwana Bay (M. Schleyer, Oceanographic Research Institute, pers. comm.).

South Africa has seen numerous developments in the coastal zone in the last decade to supply recreational (e.g. Port Alfred Marina, Harbour Island, Strand) and industrial markets (e.g. Richards Bay, Saldanha Bay). Many new developments are proposed (e.g. the Koega Harbour development in Algoa Bay). These facilities may facilitate economic development, but they also irreversibly change the coastline and serve to increase access to resources that previously may have been too remote to be harvested.

The major cause of estuarine degradation is through land-use changes and the anthropogenic manipulation of riverine flow, but residential, industrial and agricultural pollution is rapidly becoming a major problem (Whitfield, 1997). Fish which have been dangerously depleted as a result of alterations to riverine flow include estuarine pipefish *Syngnathus watermeyeri*, freshwater mullet *Myxis capensis*, and catadromous anguillid eels (Whitfield, 1997). In addition, some important linefish species have declined as a partial result of the degradation of estuarine habitat, e.g. white steenbras *Lithognathus lithognathus* (Bennett, 1993). Overfishing is also contributing to the decline in abundance of some fish species. It is evident that proper management and rehabilitation of estuaries can only be achieved through the management of water resources in entire catchments.

The greatest threat to estuarine biodiversity is arguably the uncertainty on the issue of which government agency is responsible for estuarine management. Prior to 1998, a mix of provincial and local government agencies assumed this function, although the management of river catchments was (and still is) affected by management policies of the directorates of Water Affairs and Forestry, and Agriculture. The release of the Marine Living Resources Act (MLRA) in 1998 effectively ceded the authority to manage the exploitation of estuaries to the Department of Environmental Affairs and Tourism, which, at the time, had no capacity in terms of research, monitoring or enforcement to do so. Estuarine management is currently (1999) in limbo. Provincial conservancies of the Western Cape and KwaZulu-Natal have requested that such responsibilities be returned to the provinces.

Scientific and commercial specimen collecting and bioprospecting

A potential threat to rare species is caused by collections for scientific investigations and the aquarium trade. The rarer the organism the greater its value, and hence its vulnerability. In southern Africa, collectors threaten populations of the coelacanth *Latimeria chalumnae* (Bruton & Stobbs, 1991). The Knysna seahorse *Hippocanthus capensis*, pansy shell *Echinodiscus bisperforatus* and estuarine pipefish *Syngnathus watermeyeri* are other range-restricted species whose survival might be threatened by collectors.

Systematic searches for potentially usable biochemical compounds in marine organisms, termed bioprospecting, have been undertaken by a few pharmaceutical companies in South Africa's waters. Organisms are screened for compounds that may be of use in medicine (e.g. the cure for cancer), traditional healing (e.g.

fertility enhancers) and industrial applications (e.g. bio-adhesives). The marine bioprospecting industry is poorly regulated in South Africa. Some collection programmes have had positive spin-offs for scientific studies. Collections off the eastern Cape, for example, have lead to the discovery of ecological relationships and improved taxonomic records (M. Davies-Coleman, Rhodes University, pers. comm.).

Mechanisms for conservation and their effectiveness in South Africa

Preserving marine biodiversity in marine protected areas

There is virtually no part of the marine environment that is totally unaffected by human activities. Fishers are now targeting remote populations of fish in deep water and far outside territorial waters. In coastal environments, natural refuges are becoming rare as human access to the sea is improved, and new technology is used to locate organisms with great precision. The proclamation of marine protected areas (MPAs), where some or all forms of human activity are stopped or reduced, has become widely accepted as a necessary measure to counter the extensive exploitation, disturbance and pollution of marine ecosystems (Gubbay, 1995; Clark, 1996; Attwood *et al.*, 1997a). One of the major functions of MPAs is the preservation of representative communities in their natural state. MPAs can serve the conservation of biodiversity directly by providing a refuge for marine life, and also by providing undisturbed sites for research and monitoring. Other functions include education and tourism, which are also important for the popular and financial support of biodiversity conservation.

South Africa has thirteen marine protected areas, eleven general restricted areas, nineteen fishery sanctuaries, twenty-three estuarine protected areas and four National Parks in the marine environment and many additional coastal reserves (Hockey & Buxton, 1989; Robinson & de Graaf, 1994; Attwood *et al.*, 1997b). Their effectiveness at biodiversity and fishery protection can be examined from a number of perspectives. The conservation of biological diversity requires that representative areas of each biogeographic zone are included in MPAs. The maintenance of undisturbed ecosystems requires that each habitat type be represented in MPAs. The conservation of threatened species and the maintenance of fishery yield requires that relevant species are included in sufficient MPAs to provide protection throughout their range. It is also necessary to examine the regulations that accord protection and the adequacy of enforcement. Not all MPAs provide legal protection from harvesting, however, and poaching can further impact on the status of the resources.

(i) Biogeographic zones

South Africa has three major marine biogeographic zones: the cool temperate west coast, the warm temperate south coast and the subtropical east coast. Boundaries occur in the regions of Cape Point and the East London/Port St Johns area, and the subtropical east coast can be split further into two sub-provinces in the vicinity of Durban (Emanual *et al.*, 1992). Two of these zones are poorly protected. Besides a 12 km stretch in the extreme south and the Langebaan Lagoon, the cool temperate west coast has no MPA in which representative habitats are protected. The need for a MPA on the west coast was noted as early as 1977 (Attwood *et al.*, 1997b). A 50 km stretch of coast between the Groen and Spoeg River estuaries is about to be proclaimed as a National Park, and should adequately fulfil the need for representative west coast protection. The southern part of the subtropical east coast has no MPA in which representative habitats are protected. The Trafalgar Marine Reserve was established to cover the southern KwaZulu-Natal coast, but this MPA is small (less than five kilometres shoreline length) and shore-angling is permitted there. The warm temperate south coast and the northern subtropical east coast, however, seem to be adequately represented in MPAs.

South Africa has possession of the Prince Edward Islands, which have fallen within the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) protectorate since 1980 (Miller, 1991). South Africa’s ability to defend its remote economic exclusion zone against foreign fishing and the efficacy of the CCAMLR protocols were found wanting when international fleets discovered Patagonian Toothfish *Dissostichus eleginoides* in the Southern Ocean in the mid-1990’s. Regulatory and compliance methods have since been improved. The islands are strongly protected, largely for the conservation of sea-birds and unique island flora that is susceptible to alien plant invasions. The seamount community has a high degree of endemism, including an endemic kelp (Hay, 1986).

(ii) Habitat types

South Africa has five major marine ecotypes that should be considered for protection: rocky shores, sandy shores, offshore reefs (including coral reefs of Zululand), offshore soft sediment and estuaries. Breeding sites of sea-birds, seals and turtles are also an important focus for conservation.

a) Intertidal habitats (see Ecosystem functioning: Rocky shores, and Sandy beaches and dunes, this report)
Rocky and sandy shores have an equal share of MPA coastline (Hockey & Buxton, 1989); on average MPAs include 8.1 km of rocky-shore and 8.0 km of sandy-shore. Considering only the 'no-take' MPAs, the split is in favour of rocky shores, with 82% coverage. Mixed rock and sand shorelines are protected in the De Hoop, Goukamma, Sardinia Bay, Mkambati, Hluleka, Trafalgar and St Lucia MPAs, whereas exposed rocky-shore communities are protected in Cape of Good Hope, Bettys Bay, De Hoop, Tsitsikamma, Robberg and St Lucia MPAs. The major sandy-beach ecosystems of the Eastern Cape are not protected.

b) Offshore reefs (see Ecosystem functioning: Subtidal hard substrata, this report)
Millers Point, De Hoop, Goukamma, Tsitsikamma, and all MPAs further east include prominent offshore reefs that are the habitat for commercially important, and endemic, fish species. Tsitsikamma is a prominent and effective refuge for deep reef communities. The three eastern Cape 'Wildcoast' MPAs extend six nautical miles seaward and include important offshore habitat in a transitional biogeographic zone. The southern KwaZulu-Natal coastline is the only area where additional offshore reef protection is required. The hard corals that occur only on the northern coast of KwaZulu-Natal are protected in the large St Lucia and Maputaland Reserves.

c) Soft sediment benthos (See Ecosystem functioning: Soft subtidal substrates, this report)
Soft sediment areas are among the "biotically less diverse" habitats of the ocean, but are important feeding and breeding grounds for exploited demersal species, such as hake *Merluccius* spp., kingklip *Genypterus capensis*, and east coast sole *Austroglossus pectoralis*. The threat to these environments is primarily from the effect of trawling gear on the structure of the sediment and macro-benthos. Thirteen trawling-restricted areas include soft-sediment benthic communities. These areas are generally small and close inshore, or include reefs, which make trawling hazardous. Whether or not these trawling reserves provide adequate protection to representative benthic communities is unknown.

d) Estuaries (See Ecosystem functioning: Estuaries, this report)
South Africa has about 250 'functional estuaries', of which 23 are protected in one way or another (Attwood *et al.*, 1997b). The protection of estuaries is regarded as inadequate because most of the protected estuaries are small, insignificant systems (e.g. those within the Tsitsikamma National Park), the protection within an estuary is limited (e.g. Keurbooms, Gamtoos and Mgeni), or for the protection of birds only (e.g. Orange and Seekoei). Most large estuaries have been substantially impacted by building developments, water abstraction, pollution and exploitation (Harrison *et al.*, 1998). Whitfield (1997) notes that it would be difficult to choose two worse 80 km stretches of coast for reserves from an estuarine perspective than the Tsitsikamma National Park and St Lucia Marine Reserve. The 50 km De Hoop Nature Reserve also includes no substantial estuary. With the exception of the tiny Tsitsikamma estuaries, fish are not protected from exploitation in any South African estuary.

e) Breeding sites (see, in part, the Ecosystem functioning: Coastal islands, this report)
The breeding sites of sea-birds and seals on offshore islands are protected by the 'Sea Birds and Seals Protection Act'. Some species of sea-birds breed on the mainland and these are areas of concern for provincial conservation agencies. The endangered Damara tern *Sterna balaenarum* and the African black oystercatcher *Haematopus moquini* are protected in reserves, which have a marine and terrestrial component (e.g. De Mond and Cape Point Marine Reserve). African penguins breed in two mainland colonies near the high-water mark, one of which falls within the Bettys Bay MPA, and the other is now under the protection of the National Parks Board. Protection of turtle breeding sites is an important function of the St Lucia/Maputaland Reserve.

(iii) Species representation in MPAs

MPAs collectively cover 17% of the South African coastline, but only 4.9% of the coastline has all forms of exploitation prohibited. (This percentage is considerably smaller if the area of the shelf is considered.) A few MPAs are entirely 'no-take'. The three National Parks in the Cape Provinces and the St Lucia/Maputaland Reserve are zoned to include core preservation areas, where all exploitation is forbidden, and to prevent mutually exclusive human activities from impinging upon one another. Some MPAs allow angling from the shore, some also allow exploitation of invertebrates, and the single-species restricted areas protect either abalone or rock lobster and nothing else. Attwood *et al.* (1997b) has tabled and discussed the occurrence and status of marine species in South African MPAs. A summary of this discussion is presented below.

The higher vertebrate taxa are protected throughout South African waters in terms of the Marine Living Resources Act and the Seabirds and Seals Protection Act. The presence of these animals in MPAs might not always improve their conservation status, because of their wide-ranging habits, but it could contribute to marine conservation in general by promoting tourism activities in MPAs. Many MPAs include cetacean species and some, like De Hoop Marine Reserve, have capitalised on their presence as a tourist-attraction. Most sea-birds breed on islands only, although they may forage in several MPAs. Sea-birds are protected on all offshore islands.

Most economically important fish species are well represented in MPAs, but the status of their populations is regarded as critical (see Griffiths 1997 for linefish), suggesting that protection is not very effective. Estuarine fish are not protected from fishing anywhere. Fishing has been allowed in some MPAs as a compromise to fishers who have questioned the rationale for protecting harvestable stocks. Decisions to allow exploitation at MPAs at Bettys Bay and Goukamma, for example, were at odds with stock assessments that suggest the fish species have been exploited beyond the point commonly regarded as a 'safe' threshold (Griffiths, 1997). The consensus among fishery scientists is that at least 20% of the range of an exploited fish population should be included in MPAs, to reduce the risk of recruitment failure (Plan Development Team 1990).

Sandy beach invertebrates, such as shoveller crayfish *Scyllarides elizabethae* and white mussel *Donax serra* are poorly represented in MPAs. On a regional basis, invertebrates are not well represented in MPAs on the west coast. Abalone *Haliotis midae* are critically depleted in the south-western Cape. The Bettys Bay MPA has the least disturbed abalone beds, but these have been impacted by poaching (R. Tarr, MCM, pers. comm.). Likewise, the critical status of inter-tidal rocky-shore organisms of the Eastern Cape is cause for concern. Of the primary producers, the critical groups are dune vegetation and mangroves, but all taxa are well represented in MPAs.

The weakness of South African MPAs lies in their management. Provincial enforcement agencies that are charged with MPA management lack sufficient capacity to enforce offshore resources, because of their terrestrial bias. Marine organisms are poached to varying degrees by all fishing sectors. Recreational shore-anglers commonly poach bait organisms from MPAs where shore-angling is permitted. Traditional subsistence harvesters have frequently removed inter-tidal resources from the 'Wild Coast' MPAs. Along the south coast, commercial vessels have been observed to violate MPAs by squid-jigging, trawling, long-lining and linefishing within the boundaries. Poaching in the south-western Cape is targeted largely at lucrative stocks of abalone and rock lobster.

A further problem relates to the lack of management plans, and goal-directed decision-making. The primary concern here is that MPA management is seldom strong enough to withstand public pressure to gain access to MPAs. Ironically, the pressure to exploit MPAs stems from the poor state of resources in exploited areas. Only two MPAs have drafted management plans to date.

Control of the effects of fishing

Many countries are now attempting to incorporate 'ecosystem' considerations into fishery management procedures to prevent deleterious impacts on ecosystems, which may lead to reduced productivity or biodiversity loss. South Africa's Marine Living Resources Act recognises the importance of conserving biodiversity, and maintaining the populations of all species at levels consistent with their roles in the ecosystem. Article III of CCAMLR has attempted to put these ideas into practise, by, among others, specifying that fisheries will not be allowed to impact on the food sources of other components of the ecosystem (Miller, 1991). Mathematical tools such as multi-species VPA and ECOPATH have been developed to model the effects of fishing on community structure. South Africa has not yet developed fisheries operational management plans that aim to reduce risks to any component of the ecosystem other than the species being targeted. Difficulties in this regard stem from poor understanding of ecosystem processes and inadequate or low-quality data.

In practise, fisheries management in South Africa is a single-species approach with occasional provision being made to reduce bycatch, dumping and incidental mortality. Bottom-trawl fisheries account for the greatest bycatch and discard rates of all South African fisheries (Japp, 1997). The prawn trawls and south coast inshore trawlers operate in areas of high diversity and their catches include many unmarketable species. Prawn trawls are now fitted with bycatch excluders that reduce the catch of finfish to some extent. For all other trawl fisheries, restrictions that minimise bycatch are limited to mesh sizes, which serve the primary function of allowing undersized targeted species a chance of escape. Trawls are poorly selective and the extent to which minimum mesh size reduces mortality on unwanted and undersized species is questionable. Fishers circumvent the regulation to some extent by using chokers that prevent the net from opening to its full mesh size.

Long-lining is an alternative to trawling which delivers a superior product and takes less bycatch, but impacts on sea-bird populations (see Utilization of South Africa’s living marine resources, this report). In its first year, the experimental long-line fishery for hake killed an estimated 8000 white-chinned petrels *Procellaria aequinoctialis* in South African waters (Barnes *et al.*, 1997). Albatross mortalities are common during long-lining operations directed at Patagonian toothfish around the Prince Edward Islands (Ryan *et al.*, 1997). Because these birds are long-lived and have low rates of reproduction, their populations cannot withstand this high rate of additional mortality. There is now considerable pressure to enforce a set of regulations aimed at reducing the impact of long-line mortality on sea-birds.

Control of mariculture

The control of mariculture should aim primarily to prevent the establishment of foreign species in local water, the over-stocking of natural bays and the incubation and propagation of diseases. Mariculture in South Africa is practised under permit only. All mariculture proposals are evaluated by a working group of scientists at MCM, who also commission research into existing mariculture operations. Research at Saldanha Bay was aimed at setting a limit to the number of farms, to prevent over-utilisation of phytoplankton resources (Grant *et al.*, in press). Current research is directed at refining the estimates of the carrying capacity of the bay.

Estuaries offer potential for mariculture, but many of these may not be able to sustain such industries, or may not be suitable for other reasons. Cowley *et al.* (1998) has examined all South African estuaries, and identified those that are suitable for mariculture using a system of site-selection criteria, including estuary type, available scientific information of the system, its protected status and water quality parameters.

Control of mining industry

All mining operations are undertaken on the authority of the Department of Mineral and Energy Affairs, in terms of the Minerals Act of 1991. Applicants are required to draft Environmental Management Programmes (EMPs), which are then subject to review. Guidelines for such EMPs have been made available for the oil and gas industry (DME, 1996). A protocol for EMP approval has been established by the Department of Mineral and Energy Affairs and involves an extensive evaluation and revision process. A generic EMP (G-EMP) for diamond mining on the west coast has been drafted by consultants at the request of several mining companies (Lane & Carter, 1999). This G-EMP has drawn widely on the experience of scientists to establish a procedure to eliminate or reduce undesirable effects of mining on the environment. There is concern that Environmental Impact Assessments have concentrated too much on prediction of effects with insufficient attention to implementation. The G-EMP has recognised this short-coming and includes details on every aspect of the mining operation, with procedures for standardised monitoring and review, based on the ISO 14001 protocol. Over 90% of the recommendations of this G-EMP are already prescribed in law.

The Departments of Mineral and Energy Affairs and Environment Affairs and Tourism appear to be poorly co-ordinated with respect to planning, as fishing rights and mining rights are being issued for the same areas without consideration of the potential of incompatible activities.

Coastal zone management

Two important elements of coastal zone management are coastal land-use planning and review of development projects. Land-use planning determines the form and purpose of development for sections of the coastline. Project review ensures that proposals are in keeping with the land-use designations and the aesthetic and cultural character of the region. Most review systems incorporate the principles and procedures of Environmental Impact Assessment (Sowman, 1993). 'Limited Development Areas' have been established to protect sensitive or unspoilt coastal areas.

A considerable body of legislation applies to the control of the South African coastal zone (see International and national policies regarding marine and coastal biodiversity, this report), but a number of short-comings in the implementation of coastal zone management (CZM) require attention if the country's coastal resources are to withstand increasing human pressure (Heydorn *et al.*, 1992; Sowman, 1993). The major problems are (Heydorn *et al.*, 1992):

- A plethora of state legislation and fragmented, uncoordinated administration;
- Staff shortages and limited environmental expertise;
- Inadequate control over actions of provincial and government departments;
- Legislation not specifically aimed at promoting effective CZM;
- Dominance of private rights over public rights.

To address these short-comings, a White Paper on the coastal zone has been developed through an extensive public participation process. The theme of the policy is 'sustainable coastal development' and it includes provision for coastal protected areas. The policy has not yet given rise to new legislation.

Pollution control

South Africa is a signatory on a number of international marine pollution protocols (of which MARPOL is the main one) that are legally binding on participating states. The relevant South African legislation is the Marine Pollution (Control and Civil Liability) Act 6 of 1981, and the Marine Pollution (Prevention of Pollution from Ships) Act 2 of 1986. These provide for, among others, the control of quantity and location of oil and other noxious discharges, tank cleaning procedures and the disposal of garbage.

A Coastal Sensitivity Atlas was compiled to identify priority areas for protection from oil spills (Sowman, 1993), and oil spill contingency plans have been prepared for the entire coastline. These plans have been used to great effect in cleaning oil from recent spills. Implementation of legislative control of ship-based pollution (two acts listed earlier) is the task of the Department of Transport, whereas the Directorate of Environmental Quality and Protection (Department of Environment Affairs and Tourism) is charged with the responsibility of removing spilled oil. Some difficulties have been experienced with the enforcement of the ship-based pollution legislation, namely the difficulty of proving the origin of pollutants and distinguishing between accidental and deliberate discharges.

All industrial, sewage and stormwater discharges are permitted by the Department of Water Affairs and Forestry, and all discharges are monitored for chemical and bacterial contents. Provisions in the National Water Act 36 of 1998 allow for the control of water quality entering the sea via rivers. Standards are set for the quality of effluent discharged into rivers. There is no direct control over the quality of water runoff from non-point sources.

The biggest problem regarding dumping of garbage at sea and littering is education and the development of an ethic among recreational and industrial sectors. Education campaigns launched by provincial conservancies and the Department of Environmental Affairs and Tourism to counter pollution have achieved limited success.

Pollution in the sea is monitored:

- around the Cape Peninsula by the Mussel Watch Programme that records concentrations of trace metals in the tissue of the filter feeders;
- around industrial discharges at Saldanha Bay and off the KwaZulu-Natal coast;
- by coastal municipalities who check for public health hazards.

Prevention of introduction of alien species

Precautions can be taken to minimise the likelihood of accidental introductions. The Marine Environmental Protection Committee of the International Maritime Organisation (IMO) has adopted a set of voluntary guidelines: Guidelines for Preventing the Introduction of Unwanted Aquatic Organisms and pathogens from Ships' ballast water and Sediment Discharges. IMO member states are urged to adopt the guidelines until better controls are passed as an annexe to MARPOL.

South Africa has not yet implemented these guidelines, but is working towards a strategy for the prevention of accidental invasions. A practice that has been banned in some countries, but not in South Africa, is the cleaning of ships' hulls at sea, which releases organisms into the water.

The introduction of alien species for mariculture and the aquarium trade is another area of concern. The policy governing the import of live alien species, includes the following checks:

- The country of origin must approve the collection of the species and their export from that country;
- The import should fall within the terms of the CITES agreement;
- A species may be imported provided it is known not to be an invasive alien species, an aggressive predator, or problematic in any other way, and there is no closely related native species that is important to the local fishing or mariculture industry.

This policy is implemented by DEA&T. The import of live alien species is, however, poorly monitored and tighter control on deliberate and accidental species introductions is needed.

Precautionary principle

The Precautionary Principle is applied to decision-making processes to swing the balance of decisions in favour of a conservative approach to managing biodiversity. The principle applies in instances where ignorance or ambiguity prevail over the state of a resource or the effect of any activity on the resource.

The Precautionary principle has been adopted by the Marine Living Resources Act and the Biodiversity Policy, and it is also an integral part of the United Nations Food and Agricultural Organization (FAO) Code of Conduct for Responsible Fishing (FAO, 1996). At present, MCM uses the principle in working group deliberations to justify conservative recommendations, but a greater commitment to the application of the principle is needed, for example, by incorporating it into fishery operational management procedures.

Capacity for conserving marine biodiversity: Strengths and Weaknesses

Research

Research into marine biodiversity covers virtually every aspect of marine biology. South Africa has a diverse and active marine science community, with areas of excellence in ecology and fisheries biology. Active laboratories exist in Cape Town (MCM, the Universities of Cape Town and Western Cape, Council for Scientific and Industrial Research, and the South African Museum), the eastern Cape (JLB Smith Institute of Ichthyology, the Universities of Rhodes, Port Elizabeth, Fort Hare, and Transkei, and the Port Elizabeth Museum) and KwaZulu-Natal (Universities of Zululand and Durban-Westville, the Natal Sharks Board, and the Oceanographic Research Institute). The majority of these serve as training institutions as well as research centres.

One weakness in South Africa's marine biological research capacity is in the field of taxonomy (see Taxonomy/Species section, this report). Marine science in this country reflects a worldwide trend in the decline of taxonomic expertise (National Research Council, 1995). This makes biodiversity management difficult, because the accurate identification of species is one of its most basic requirements. There are large areas of South Africa's marine environment where the biological communities are poorly described at the species level. Marine biodiversity audits, the control of invasive species, and the identification of rare, endemic species all require taxonomic competence. Unfortunately, taxonomy has not been promoted as an attractive career option, in comparison with ecology, fisheries biology or mariculture, which are perceived to be more 'applied' and as having greater employment prospects.

Marine research projects could be more coordinated to address 'biodiversity' problems. Areas of focus need to be identified (e.g. MPA auditing, fishery bycatch, alien species spread, pollution effects, etc.) and researched consistently across the country. Not all the impacts of fisheries are equally understood and not all the communities in MPAs are sufficiently documented.

Management of resources

Marine resource management consists of three basic components: monitoring (or assessment), regulation and enforcement.

(i) Biodiversity monitoring

A monitoring programme should be able to detect shifts in biogeographic patterns at a range of scales: macro (ocean basin), regional (biogeographic province), metapopulation or community, and patch (uniform habitat). Observation at all these scales should reveal changes caused by climate change, fishing, habitat deterioration, disease, etc. South Africa does not have such a comprehensive monitoring system, although there are numerous monitoring projects in operation, including ones focussing on top predators, targeted fish species, coral reefs, rocky shore communities, etc. Many of these are research projects, which have specific short term objectives and funding. There are also a number of databases that hold fishery-dependent information (e.g. National Marine Linefish System, pelagic database, demersal database). These data sources can be used to develop a spatial database (a full G.I.S. might be warranted) of exploited resources.

(ii) Regulation

The most persistent criticism of the management of the coastal environment in South Africa is the lack of integrated and co-ordinated decision-making, both within and across government structures (Heydorn *et al.*, 1992; Hockey & Buxton, 1989). Conflicts arise between the applications of different legislation regulating activities on the same resources, for example, mining versus fishing, the use of personal water craft in MPAs or areas with tourism potential, water abstraction versus estuarine management, etc. Legislative authority over living marine resources below the high-water mark is assigned to National Government, but there are numerous national, provincial and local-government laws that apply to the coastal zone. In the sea, provincial legislation has been used by KwaZulu-Natal, but very rarely by the Cape Provinces. Hockey & Buxton (1989) cite this as a possible area for improvement, because the provincial legislation is in many respects more powerful for declaring nature reserves than the Marine Living Resources Act. The latter however is upheld should there be a conflict between it and any other act, except the constitution. For this reason, new regulations in the marine environment are likely to be passed in terms of this act. Local and regional authorities commonly pass bylaws to control activities in the coastal zone, but because of the parochial nature of their problems, their decisions are often at odds with national attempts to conserve marine biodiversity. Typical examples include the breaching of estuaries, and the use of off-road vehicles.

(iii) Enforcement

Enforcement of regulations in the coastal zone is accomplished by a variety of government departments. South Africa is in the unfortunate position of having a severe enforcement problem with regard to living marine resources (Attwood *et al.*, 1997b; Griffiths, in press). The capacity for enforcement around the coastline appears to be uneven. Enforcement in KwaZulu-Natal, for example, is better than in other provinces, where provincial conservancies have very limited marine enforcement capacity. MCM directs its enforcement effort primarily at controlling large-scale commercial fisheries, with less attention being paid to coastal resources. Staff and budgetary limitations are the principal reasons. Applications for new fisheries and MPAs have been turned down because of the inability to police these developments. The lack of enforcement capacity is therefore costing South Africa in terms of marine biodiversity and lost opportunity. A recent promising development has been an alliance (SEAPACC) between Marine and Coastal Management, the Navy and Police Waterwing to provide a united effort to counter poaching. Marine and coastal enforcement is currently under review as part of the development of a new strategic plan.

In a few instances, civil society has taken matters into their own hands. Trusts have been established for the major purpose of law enforcement. Organisations like Seawatch, Overberg Coastal Trust, Breede River Trust, Foundation for Outeniqua and Baywatch work closely with police, local government and marine inspectors. Some of these groups have assisted with the apprehension of offenders (McKenzie, MCM, pers. comm.).

Management of MPAs

A policy adopted in 1977 declared that the management of a marine reserve should be assigned to one competent authority (Attwood *et al.*, 1997b). In practise, provincial conservancies have assumed this role. However, some MPAs and most restricted areas are not managed by any authority. Provincial authorities have a strong terrestrial bias in terms of staff training and equipment, and the management of MPAs can rarely be described as satisfactory, except in KwaZulu-Natal where legislative authority over marine matters has engendered a capacity for marine management. The National Parks Board is similarly well equipped to manage their MPAs. Only two MPAs have drafted comprehensive management plans: St Lucia and Goukamma. The major deficiencies with MPA management are:

- The absence of a national MPA coordinating body;
- Shortage of staff;
- Inadequate monitoring programmes;
- Lack of public awareness;
- Shortage of funds.

Future action

A marine science biodiversity initiative aimed at understanding and predicting the impacts of human activities on biodiversity should promote studies spanning a broad range of processes and spatial scales. Much of the research capacity already exists, and the aim of the initiative should be to direct research to the following areas.

- A marine biodiversity audit will improve our understanding of the magnitude and distribution of marine biodiversity. Some sites should be sampled regularly as part of a monitoring programme that can detect community changes and alien species invasions. A centralised repository for spatially-referenced data should be established. Such a data-bank could be accessed when information is needed to assess the likely impacts of human activities and the representativeness of MPAs.
- Impact studies, including the provision of base-line information, are required for the management of fishing activities, mining operations, and coastal zone developments. Such studies would include comparisons between treatments (e.g. fished versus not fished), experimentation, time-series analyses, literature reviews, etc. The results of these studies should feed directly into operational management procedures, of the type that have been developed for some mining operations. Thus far, fishery management procedures have rarely gone beyond single-species considerations.
- Environmental planning is needed, otherwise resource control will always be a reactionary, rear-guard action that attempts to preserve the last remaining example of a biological community. It is essential that biological, social and economic sciences collaborate, perhaps on a regional basis, to establish long-term plans. The Spatial Development Initiatives (e.g. Lubombo SDI) provide a framework for such planning. A spatial approach is needed to ensure that each segment of coast is adequately protected and that all kinds of resource users are allowed fair and controlled access to resources.

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INTERNATIONAL AND NATIONAL POLICIES CONCERNING MARINE AND COASTAL BIODIVERSITY

by R. Wynberg

International policies

Mounting concern about the impacts of human activities on marine and coastal biodiversity is reflected in numerous international, regional and national policies. The past twenty years in particular have seen a rapid increase in the number of international instruments aimed at addressing the threats to marine and coastal biodiversity, and protecting, understanding and using marine resources sustainably (see Box 1). The most comprehensive and significant of these is the legally binding United Nations Convention on Biological Diversity (CBD). Signed at the United Nations Conference on Environment and Development in 1992, the treaty came into force in December 1993 and has 175 member countries as parties (as of 15/1/99), including South Africa. Its three objectives, all of which have relevance to marine and coastal biodiversity, are:

1. the conservation of biological diversity;
2. the sustainable use of its components; and
3. the fair and equitable sharing of benefits arising from the use of genetic resources.

These objectives are to be met through the enactment of a number of measures at both international and national levels. These include:

- the development of national strategies;
- the integration of biodiversity considerations into sectoral and cross-sectoral plans;
- the establishment of monitoring programmes;
- extensive measures for *in-situ* and *ex-situ* conservation (e.g. establishing protected areas, controlling alien organisms, restoring degraded ecosystems);
- the adoption of incentive measures;
- the establishment of research and training programmes;
- public education and awareness-raising activities; and
- the introduction of measures to facilitate access to genetic resources and benefit-sharing.

The Convention advocates an ecosystem approach in fulfilling these measures. This is especially pertinent to the marine context, and the Convention explicitly provides for implementation to be consistent with the Law of the Sea.

A noteworthy development is the adoption in 1995 by the second Conference of Parties to the CBD of "The Jakarta Mandate on Marine and Coastal Biodiversity". This declaration articulates a programme of action for implementing the CBD with respect to marine and coastal biodiversity, and singles out the following issues for special attention:

- integrated marine and coastal area management;
- marine and coastal protected areas;
- sustainable use of marine and coastal living resources;
- mariculture; and
- alien species.

The Jakarta Mandate is significant in that it provides - within the legal context of the CBD - an overarching political and scientific framework within which to address concerns relating to marine and coastal biodiversity. Implementation of the Mandate has subsequently been considered by a meeting of experts, including a representative from South Africa, and a programme of work has been adopted for 1998-2000 (UNEP 1998). The programme of work (see Box 2) identifies key operational objectives and priority activities within the five programme elements described above, as well as a general programme element to encompass the coordination role of the Secretariat to the Biodiversity Convention, and the effective use of experts. A key task in relation to these programmes will be to consider the wide range of existing multilateral instruments concerning the marine environment. Thus it is intended for the CBD to build on and strengthen aspects in other agreements that relate to marine and coastal biodiversity.

Box 1. International agreements having relevance to the conservation and sustainable use of marine and coastal biodiversity[2]

- Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks, 1995[3]
- FAO Compliance Agreement and Code of Conduct for Responsible Fisheries, 1995[4]
- United Nations Convention on Biological Diversity, 1992
- United Nations Framework Convention on Climate Change, 1992
- Agenda 21, 1992
- Rio Declaration, 1992
- Montreal Protocol on Substances that Deplete the Ozone Layer, 1987
- Convention on the Protection, Management and Development of the Marine and Coastal Environment of the Eastern African Region (Nairobi Convention), 1985[5]
- Convention for Cooperation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region (Abidjan Convention)[6]
- United Nations Convention on the Law of the Sea, 1982 (UNCLOS)[7]
- Convention on the Conservation of Antarctic Marine Living Resources, 1980 (CCAMLR)
- Convention on International Trade in Endangered Species, 1973 (CITES)
- International Convention for the Prevention of Pollution from Ships, 1973-1978 (MARPOL)
- London Convention on Prevention of Marine Pollution by Dumping of Wastes, 1972
- Convention Concerning the Protection of the World Cultural and Natural Heritage, 1972 (World Heritage Convention)
- Convention on Wetlands of International Importance Especially as Waterfowl Habitat, 1971 (Ramsar Convention)
- International Convention for the Regulation of Whaling, 1946

Box 2. Implementing the Jakarta Mandate. Programme of work on marine and coastal biological diversity 1998-2000

Implementation of Integrated Marine and Coastal Area Management (IMCAM)

- Review existing instruments relevant to IMCAM and their implication for the implementation of the CBD
- Promote development and implementation of IMCAM at local, national and regional level.
- Develop guidelines for ecosystem evaluation and assessment

Marine and Coastal Living Resources

- Promote ecosystem approaches to the sustainable use of marine and coastal living resources for the purpose of assessing and monitoring the conservation and use of biodiversity
- Make available information on marine and coastal genetic resources, including bioprospecting

Marine and Coastal Protected Areas

- Facilitate research and monitoring activities related to the value and effects of marine and coastal protected areas on sustainable use of resources
- Develop criteria for the establishment and management of marine and coastal protected areas

Mariculture

- Assess consequences of mariculture for marine and coastal biodiversity and promote techniques which minimise adverse impacts

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[2] Unless indicated otherwise, South Africa is a party to all of the listed agreements.
[3] South African ratification of this Agreement has been approved by Cabinet and is in the process of being submitted to Parliament for final acceptance and signing.
[4] These Agreements have been submitted to Cabinet for consideration.
[5] South Africa is in the process of acceding to this Convention and its Related Protocols on (a) Protected Areas and Wild Fauna and Flora; and (b) Combating Marine Pollution in Cases of Emergency.
[6] South Africa is in the process of acceding to this Convention and its Related Protocol on (a) Combating Pollution in Cases of Emergency.
[7] Ratified by South Africa on 23 December 1997.

Alien Species and Genotypes • Achieve better understanding of the causes of the introduction of alien species and genotypes and impact of such introductions on biodiversity • Identify gaps in legal instruments, guidelines and procedures to counteract introduction and adverse effects of alien species and genotypes and collect information to address these problems • Establish an "incident list" on introductions of alien species and genotypes

National policies

At the national level, policies to conserve biodiversity have historically focused upon the terrestrial environment, and marine and coastal biodiversity has been relatively neglected. Although a substantial body of law exists which has application to marine conservation (see Box 3), its efficacy is hindered by a number of factors.

Chief amongst these is an extremely high degree of fragmentation, resulting from legislation being spread across many different government departments, at both provincial and national levels. Additionally, there has been no coherent policy or strategy to ensure the conservation and sustainable use of marine and coastal biodiversity, and inadequate attention has been given to the comprehensive and holistic approach so critical to addressing marine conservation effectively. Instead, initiatives have been piecemeal and largely uncoordinated, resulting in the *ad hoc* establishment of marine protected areas and a predominantly species-orientated approach towards resource management. A further problem is the enforcement of legislation, rendered ineffectual by inappropriate penalties, the lack of an appropriate incentive system to reward good practice, and insufficient capacity within government agencies to monitor infringements.

These concerns are well recognised, and the past two years have seen the development of an impressive array of new policies and laws to develop a stronger and more integrated framework for environmental management in general, and for marine resources in particular. These include: -

- ***A new Constitution***, which provides for environmental protection and conservation within its Bill of Rights (Sections 24 and 25) and, importantly, allocates marine resources as an exclusive national competence (Schedule 4);
- ***A White Paper on an Environmental Management Policy for South Africa***, which gives effect to the environmental rights embodied in the Constitution and provides an overarching framework policy that sets out the general vision, principles, goals and regulatory approach for environmental management in South Africa;
- ***A National Environmental Management Act***, which provides for "cooperative environmental governance by establishing principles for decision-making on matters affecting the environment, institutions that will promote cooperative governance and procedures for coordinating environmental functions exercised by organs of state";
- ***A White Paper on the Conservation and Sustainable Use of South Africa's Biological Diversity***, which articulates South Africa's response to the requirement of the Convention on Biological Diversity to develop national strategies to address the agreement's provisions;
- ***A White Paper on a Marine Fisheries Policy for South Africa***, and a ***Marine Living Resources Act*** which spell out new approaches towards the management of marine resources in South Africa; and
- ***A White Paper on a National Water Policy for South Africa***, and a ***National Water Act*** which contains important provisions relating to the control of marine pollution; and
- ***A Draft White Paper for Sustainable Coastal Development,*** which will shortly be submitted to Cabinet for approval. The key thrust of this policy is on maximising opportunities for economic and social development connected with coastal resources through maintenance of the health, diversity and productivity of coastal ecosystems.

Other initiatives include the development of a policy on integrated pollution control and waste management, and the establishment of a Marine Biodiversity Working Group, as part of the work of the Chief Directorate: Marine and Coastal Management, Department of Environmental Affairs and Tourism.

The introduction of this array of policies has significant implications for the conservation and use of marine and coastal biodiversity, especially with the enactment of new legislation. Important new approaches have been introduced through these policies and laws, the most notable being that for the first time in South Africa, policies concerning biodiversity have been developed in a participatory manner and enjoy widespread support. There is also a significant shift towards stronger environmental protection, and balancing such protection with the reconstruction and development of South Africa and the needs of her people.

Both the Biodiversity and Marine Fisheries White Papers (and the related Act on Living Marine Resources) recognise the need to protect ecosystems, as well as target and non-target species, and advocate a precautionary approach where there is a threat of significant reduction or loss of biodiversity. Provision is made in the Marine Living Resources Act to establish and control marine-protected areas, and to restrict certain fishing activities that may be detrimental to biodiversity. Additionally, the Minister may regulate on a number of activities that may threaten biodiversity (e.g. marine pollution, mariculture, fishing methods), and enforcement is made more effective through increased powers for law enforcement officials and more severe penalties.

Within the Biodiversity White Paper, most provisions apply generally to both terrestrial and marine and coastal biodiversity. Specific attention however is given to marine and coastal areas and to the need to adopt a cross-sectoral approach that treats the hydrological cycle as an integrated unit and governs actions on land as well as in the sea. The strengthening and rationalisation of South Africa's protected area system, including marine protected areas, is considered to be a priority action. Additional priorities refer to the urgency of establishing legislative and administrative mechanisms to control access to genetic resources ("bioprospecting") and ensure equitable benefit-sharing, and of instituting a national biodiversity education and awareness plan.

A concern often expressed is that South Africa does not have adequate capacity to monitor and manage its extensive coastline and marine resources, nor sufficient knowledge and understanding to conserve its biodiversity effectively. Noteworthy among many of the emerging policies is the emphasis given to approaches that enhance existing capacities, co-ordinate ongoing initiatives (e.g. the collection of data and information), and recognise the importance of incentives and public education. The importance of biological inventory work is likewise underscored, including the adoption of creative approaches to capacity problems such as the development and training of "parataxonomists". Research that is multi-disciplinary, that integrates socio-economic considerations, that informs decision-making, and that is based upon gaps in knowledge and the identification of conservation and management priorities is accorded a high priority. To guide such research, the Biodiversity White Paper proposes the development of a multi-disciplinary research plan.

This initiative to develop a status report on coastal and marine biodiversity represents an important opportunity to develop such a plan, and to identify the required capacity to effect the research. The recent establishment of the National Research Foundation provides an important supporting environment within which such multidisciplinary work can take place. This, together with a powerful package of new policies and laws, places South Africa uniquely to meet the challenges of the new century in ensuring the conservation and sustainable use of our magnificent coastal and marine heritage.

Box 3. Key South African national policies and legislation having relevance to the conservation and sustainable use of marine and coastal biodiversity.

Completed Policies

- The Constitution of South Africa, 1996
- White Paper on a Tourism Policy for South Africa, 1996
- White Paper on Environmental Management Policy for South Africa,1997[8]
- White Paper on the Conservation and Sustainable Use of South Africa's Biological Diversity, 1997[9]

[8] The policy has been accepted by Cabinet, and following minor changes will shortly be adopted by Parliament.

- White Paper on a Marine Fisheries Policy for South Africa, 1997
- White Paper on a National Water Policy for South Africa, 1997
- Draft White Paper on Integrated Pollution and Waste Management for South Africa, 1998
- Draft White Paper for Sustainable Coastal Development, 1999

Policy Processes Underway

- Policy on Climate Change
- Policy on Environmental Education

Relevant Legislation

- Sea Shore Act 21 of 1935
- Prince Edward Islands Act 43 of 1948
- Sea Birds and Seals Protection Act 46 of 1973
- Lake Areas Development Act 39 of 1975
- National Parks Act 57 of 1976
- Dumping at Sea Control Act 73 of 1980
- Combating of Pollution of the Sea by Oil Act 6 of 1981
- International Convention for the Prevention of Pollution from Ships Act 2 of 1986
- Environment Conservation Act 73 of 1989
- Minerals Act 50 of 1991
- Constitution of the Republic of South Africa, Act 108 of 1996
- National Environment Management Act 107 of 1998
- Marine Living Resources Act 18 of 1998
- Water Act 36 of 1998
- Various Provincial ordinances containing provisions *inter alia* to control development, overexploitation, pollution, and the introduction of alien species.

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[9] The policy has been accepted by Cabinet and is likely to be considered by Parliament following adoption of the Policy on Environmental Management.

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GLOSSARY

Benthic Organisms living on the bottom of the sea.

Bycatch Bycatch includes species caught incidentally whilst fishing for a specific target species. Bycatch species are either discarded at sea or landed. Discarding according to the new Marine Living Resources Act of 1998 is now illegal.

Cod End The mesh size of the cod-end determines the size of organisms retained.

Demersal Living on the sea floor or just above it.

Gill-nets Gill-nets entangle fish. The nets are comprised of panels of multifilament- or monofilament panels with a stretched mesh size that capture fish by either lodging behind their gill-covers or by entangling their spines.

Intertidal the shore area between the high-tide and the low-tide levels.

Longline Fishery The long-line fishery deploys a mainline (up to50 km long) either on the substrate (e.g. kingklip directed), just above the substratum (e.g. hake directed) or mid-water (e.g. tuna/swordfish directed), onto which numerous individual shorter lines with baited hooks are attached.

Pelagic Swimming in the water column of the open sea.

Purse-seine A large net, suspended from floats, that is used to encircle shoals of surface and sub-surface dwelling fish species and 'pursed' to be retreived by a sea-going craft.

Plankton Small organisms largely dispersed by water movements. Includes animals (zooplankton) and plants (phytoplankton).

Seine-net A net, suspended from floats, that has a central bag and equal sixed wings, which is deployed around fish.

Squid jigging The jigging technique uses either predominantly hand-held or in some case machine operated lines with one or more jigs – plastic or painted lead lures with rosettes of barbless hooks.

Subtidal Shore below the lowest level reached by the tides.

Trawlfishery Trawl fishing is conducted by towing a net behind a vessel. The net is spread open by steel doors, which either scrape along the bottom in the demersal fishery or fly mid-water in the mid-water fishery.

Upwelling An occurrence of cold, nutrient rich, waters rising to the surface.