NATIONAL BIODIVERSITY ASSESSMENT 2011:

Technical Report

Volume 4:

Marine and Coastal Component

SANBI
Biodiversity for Life

environmental affairs
Department: Environmental Affairs
REPUBLIC OF SOUTH AFRICA

agriculture, forestry & fisheries
Department: Agriculture, Forestry and Fisheries
REPUBLIC OF SOUTH AFRICA

NRF National Research Foundation | SAEON South African Environment Observation Network

NRF National Research Foundation | SAIAB South African Institute for Aquatic Biodiversity

Nelson Mandela Metropolitan University
for tomorrow

UNIVERSITEIT·STELLENBOSCH·UNIVERSITY
jou kennisvennoot • your knowledge partner

University of Cape Town · iYunivesithi yaseKapa · Universiteit van Kaapstad

CSIR
our future through science

UNIVERSITY of the WESTERN CAPE

International Ocean Institute Southern Africa

WWF NEDBANK GREEN TRUST
WWF

NATIONAL BIODIVERSITY ASSESSMENT 2011: Technical Report

Volume 4: Marine and Coastal Component

Kerry Sink[1], Stephen Holness[2], Linda Harris[2], Prideel Majiedt[1], Lara Atkinson[3], Tamara Robinson[4], Steve Kirkman[5], Larry Hutchings[5], Robin Leslie[6], Stephen Lamberth[6], Sven Kerwath[6], Sophie von der Heyden[4], Amanda Lombard[2], Colin Attwood[7], George Branch[7], Tracey Fairweather[6], Susan Taljaard[8], Stephen Weerts[8] Paul Cowley[9], Adnan Awad[10], Ben Halpern[11], Hedley Grantham[12] and Trevor Wolf[13]

1 South African National Biodiversity Institute
2 Nelson Mandela Metropolitan University
3 South African Environmental Observation Network
4 Stellenbosch University
5 Department of Environmental Affairs
6 Department of Agriculture, Forestry and Fisheries
7 University of Cape Town
8 Council for Scientific and Industrial Research
9 South African Institute for Aquatic Biodiversity
10 International Ocean Institute, South Africa
11 National Centre for Ecological Analyses and Synthesis, University of California, USA
12 University of Queensland, Australia
13 Trevor Wolf GIS Consultant
14 Oceanographic Research Institute
15 Capfish
16 Ezemvelo KZN Wildlife
17 KwaZulu-Natal Sharks Board

Other contributors: Cloverley Lawrence[1], Ronel Nel [2], Eileen Campbell[2], Geremy Cliff[17], Bruce Mann[14], Lara Van Niekerk[8], Toufiek Samaai[5], Sarah Wilkinson[15], Tamsyn Livingstone[16] and Amanda Driver[1]

This report can be cited as follows:
Sink K, Holness S, Harris L, Majiedt P, Atkinson L, Robinson T, Kirkman S, Hutchings L, Leslie R, Lamberth S, Kerwath S, von der Heyden S, Lombard A, Attwood C, Branch G, Fairweather T, Taljaard S, Weerts S, Cowley P, Awad A, Halpern B, Grantham H, Wolf T. 2012. National Biodiversity Assessment 2011: Technical Report. Volume 4: Marine and Coastal Component. South African National Biodiversity Institute, Pretoria. Pp 325

This report forms part of a set of six reports on South Africa's National Spatial Biodiversity Assessment 2011. The full set is as follows:

Synthesis Report

Driver, A., Sink, K.J., Nel, J.L., Holness, S., Van Niekerk, L., Daniels, F., Jonas, Z., Majiedt, P.A., Harris, L. & Maze, K. 2012. *National Biodiversity Assessment 2011: An assessment of South Africa's biodiversity and ecosystems. Synthesis Report.* South African National Biodiversity Institute and Department of Environmental Affairs, Pretoria.

Technical Reports

Volume 1: Terrestrial Component

Jonas, Z., Daniels, F., Driver, A., Malatji, K.N., Dlamini, M., Malebu, T., April, V. & Holness, S. 2012. *National Biodiversity Assessment 2011: Technical Report. Volume 1: Terrestrial Component*. South African National Biodiversity Institute, Pretoria.

Volume 2: Freshwater Component

Nel, J.L. & Driver, A. 2012. *National Biodiversity Assessment 2011: Technical Report. Volume 2: Freshwater Component*. CSIR Report Number CSIR/NRE/ECO/IR/2012/0022/A. Council for Scientific and Industrial Research, Stellenbosch.

Volume 3: Estuary Component

Van Niekerk, L. & Turpie, J.K. (eds). 2012. *National Biodiversity Assessment 2011: Technical Report. Volume 3: Estuary Component*. CSIR Report Number CSIR/NRE/ECOS/ER/2011/0045/B. Council for Scientific and Industrial Research, Stellenbosch.

Turpie, J.K., Wilson, G. & Van Niekerk, L. 2012. *National Biodiversity Assessment 2011: National Estuary Biodiversity Plan for South Africa*. Anchor Environmental Consulting, Cape Town. Report produced for the Council for Scientific and Industrial Research and the South African National Biodiversity Institute.

Volume 4: Marine Component

Sink, K.J, Holness, S., Harris, L., Majiedt, P.A., Atkinson, L., Robinson, T., Kirkman, S., Hutchings, L., Leslie, R., Lamberth, S., Kerwath, S., von der Heyden, S., Lombard, A.T., Attwood, C., Branch, G., Fairweather, T., Taljaard, S., Weerts, S., Cowley, P., Awad, A., Halpern, B., Grantham, H. & Wolf, T. 2012. *National Biodiversity Assessment 2011: Technical Report. Volume 4: Marine and Coastal Component*. South African National Biodiversity Institute, Pretoria.

Acknowledgements

The authors of this report acknowledge and thank the South African marine science, conservation and management community for their participation in this assessment. Theressa Franz, Philip Ivey and Michelle Hamer (SANBI) provided comments and strengthened the key findings and priority actions identified during this assessment. Ernst Swartz from SAIAB and Ross Wanless from Birdlife South Africa assisted with specific queries. Neil Malan and colleagues from the Oceans and Coast Branch of the Department of Environment Affairs are acknowledged for refinement of key messages and assistance in determining priority actions to support integrated coastal management. Carl van der Lingen and Andy Cockcroft from the Department of Agriculture, Forestry and Fisheries (DAFF) are thanked for their assistance with specific elements of the climate variability and change component of this report. Deon Durholtz and Jean Glazer (DAFF) are acknowledged for providing information pertinent to the stock status, assessment methodology and management of hake and other resources. Ken Hutchings (Anchor Environmental Consulting) lent expertise to assist with the overview of the impacts of mariculture and in the development of priority actions for this sector. We thank Peter Chadwick (WWF South Africa) and Alan Boyd (Department of Environmental Affairs) for assistance in collating information for the Marine Protected Areas component of this report. We thank Professor Charles Griffiths (University of Cape Town) for reviewing an earlier draft of this report and for constructive comments that improved the revised version.

Funding for this work was provided to SANBI by the WWF Nedbank Greentrust through the Offshore Marine Protected Area Project and the SeaChange Project, and by the Global Environmental Facility through the C.A.P.E. Program. The National Research Foundation is also acknowledged for their contribution provided through funding received by Linda Harris, whose PhD research work focused on sandy beach conservation has contributed significantly to the coastal aspects of this assessment.

List of Workshop Participants

Aaniyah Omardien - WWF-SA
Alan Aldrin Meyer - CSIR
Alan Boyd - DEA: Oceans and Coasts
Albrecht Gotz - SAEON
Amanda Lombard - Consultant
Ane Oosthuizen - SAN Parks
Anneita Brahmin - CapeNature
Arne Purvis - City of Cape Town
Astrid Jarre - University of Cape Town
Belinda Reyers - CSIR
Bruce Mann - Oceanographic Research Institute
Carl van der Lingen - DAFF: Fisheries
Chantel Petersen - CSIR
Charles Griffiths - University of Cape Town
Christoph Sholtz - SANBI
Cloverley Lawrence - University of Cape Town
Colin Attwood - University of Cape Town
Colleen Moloney - UCT
Coral Birss - CapeNature
Craig Smith - DAFF: Fisheries
Dave Japp – CapFish
Deon Nel - WWF-SA
Erwann Lagabrielle - NMMU
Fahiema Daniels - SANBI
George Branch - University of Cape Town
Georgina Jones - SURG
Heather Terrapon - SANBI
Herman Oosthuizen- DEA: Oceans and Coasts
Jan Venter - Eastern Cape Parks
Jane Turpie - Anchor Environmental Consulting
Jean Githaiga-Mwicigi - DEA: Oceans and Coasts
Jean Harris - CSIR
Jeanne Nel - EKZN Wildlife
Juliette Hermes – SAEON

Kerry Sink - SANBI
Kim Prochazka - DAFF: Fisheries
Lara Atkinson - SAEON
Lara van Niekerk - CSIR
Larry Hutchings - DEA: Oceans and Coasts
Lebeau Labuschagne – DMR
Lesley Rochat – De Beers
Liesl Jansen - DEA: Oceans and Coasts
Lieze Swart - DEA: Oceans and Coasts
Linda Harris - NMMU
Lynn Jackson – Consultant
Lynne Shannon - University of Cape Town
Mandy Driver - SANBI
Mathieu Rouget – University of Pretoria
Maya Pfaff – UCT
Mbulelo Dopolo – SANParks
Michael Schleyer - Oceanographic Research Institute
Mike Roberts - DEA: Oceans and Coasts
Nadine A. Strydom – NMMU
Namhla Mbona - SANBI
Natasha Karenyi - NMMU
Neville Sweijd – CSIR
Nina Stefani - Consultant
Paddy Gordon – SANParks
Paul Sieben – SANParks
Peter Best – University of Pretoria
Peter Chadwick - WWF-SA
Peter Goodman – EKZNW
Peter Southwood - SURG
Philip Haupt - NMMU
Pierre de Villiers – CapeNature
Prideel Majiedt - SANBI
Risha Persad - DEA: Oceans and Coasts
Rob Anderson - University of Cape Town
Robin Leslie - DAFF: Fisheries

Rochelle Wigley - Council for Geosciences
Ronel Nel - NMMU
Ross Wanless - Birdlife-SA
Russell Stevens
Samantha Peterson - WWF-SA
Sarah Wilkinson - CapFish
Sediqa Khatieb - SANBI
Seshnee Maduray - DEA: Oceans and Coasts
Smiso Bhengu - SANBI
Sophie von der Heyden - Stellenbosch University
Stephen Holness - SAN Parks
Stephen Kirkman - DEA: Oceans and Coasts
Steve Lamberth - DAFF: Fisheries
Susan Taljaard – CSIR
Sven Kerwath - DAFF: Fisheries
Tammy Robinson - Stellenbosch University
Tammy Smith - SANBI
Tamsyn Livingstone - EKZN Wildlife
Thuli Wistebaar - SANBI
Toufiek Samaai - DEA: Oceans and Coasts
Tracey Fairweather - DAFF: Fisheries
Tracey Phillips - Consultant
Zuziwe Jonas - SANBI

List of workshops and key meetings

6 June 2008	National Marine Biodiversity Assessment Planning Workshop, Kirstenbosch Research Centre, SANBI (18 participants representing 8 organisations)
2 September 2008	Discussion workshop to support Marine Ecosystem Listing, Kirstenbosch Research Centre, SANBI (22 participants representing 7 organisations)
24 October 2008	Threatened marine species workshop, (26 participants representing 12 organisations)
27 August 2009	Reef Classification Workshop (19 participants representing 11 organisations)
22 September 2009	Workshop to plan for the Assessment of Marine Ecosystem Status, Centre for Biodiversity Conservation, Kirstenbosch, SANBI (22 participants representing 8 organisations)
27 July 2010	Pelagic Ecosystem Classification Review Workshop, Centre for Biodiversity Conservation, Kirstenbosch, SANBI (11 participants representing 6 organisations)
7 September 2010	Ecosystem-pressure matrix workshop (SANBI, DEA, SAEON, NMMU, DAFF).
30 November 2010	NBA Marine Component Review workshop, Kirstenbosch Research Centre, SANBI (22 participants representing 7 organisations)
5 January 2011	National Marine Biodiversity Assessment Review Meeting: KZN (ORI)
4 October 2011	Integrated Coastal Management discussion, Oceans and Coasts, Department of Environment (12 participants, DEA and SANBI)

Participating Organisations: South African National Biodiversity Institute; Department of Environmental Affairs; Department of Agriculture, Forestry and Fisheries; Council for Scientific and Industrial Research; South African Environmental Observation Network; South African National Parks; South African Institute for Aquatic Biodiversity; World Wildlife Fund; Birdlife; Ezemvelo KZN Wildlife; Natal Sharks Board; Iziko; Cape Nature; Oceanographic Research Institute; University of Cape Town; Nelson Mandela Metropolitan University; Stellenbosch University; University of the Western Cape; University of Pretoria; Natal Museum; City of Cape Town; Capfish; Anchor Environmental Consultants; Southern Underwater Research Group and Two Oceans Aquarium.

Executive summary

The marine and coastal component of the National Biodiversity Assessment 2011 is an assessment of the state of biodiversity and ecosystems in South Africa's marine and coastal environment. This report represents a milestone for marine biodiversity in South Africa. Major new contributions include the first national marine and coastal habitat classification and national habitat maps for the coast, ocean floor and the open ocean; a comprehensive review of pressures on marine and coastal biodiversity; and the first data driven assessment of ecosystem threat status and protection levels for 136 habitat types. An overview of the state of knowledge of marine taxonomy, a chapter on marine alien and invasive species and a review of marine genetic biodiversity are included for the first time. Knowledge gaps and research priorities are identified and a detailed set of priority actions are distilled to address the key findings of this assessment.

The area assessed extends 500 m inshore of the coastline and 200 nautical miles offshore to include the mainland Exclusive Economic Zone, excluding the Prince Edward Islands. Both spatial and thematic elements are included in the report which is structured in 17 sections nested within three broad divisions; the spatial assessment, the thematic component, and an overview of key findings, research priorities and recommended priority actions.

The spatial assessment includes three main sets of spatial input layers: habitat types, pressures and protected areas. A national marine and coastal habitat classification and map was developed that defined and mapped 136 marine and coastal habitat types. A total of 27 pressures on marine and coastal biodiversity were reviewed and mapped. A revised Marine Protected Area (MPA) map showing South Africa's 23 MPAs was produced.

The national marine and coastal habitat classification incorporates several key drivers of marine biodiversity pattern: terrestrial and benthic-pelagic connectivity, substrate, depth and slope, geology, grain size, wave exposure and biogeography. The habitat classification revises the bioregions and biozones used in the National Spatial Biodiversity Assessment 2004 to include six ecoregions (Benguela, Agulhas, Natal, Delagoa, Southeast Atlantic and Southwest Indian) and 22 finer scale ecozones that nest within these ecoregions. Each ecozone is considered to have distinct species assemblages that need to be considered in biodiversity assessments and in planning for a representative MPA network. The habitat classification identifies and maps a total of 136 habitat types including 37 coast types, 17 inshore (5-30 m) habitat types and 62 offshore (deeper than 30 m) benthic habitat types. In addition, a separate classification was undertaken to define 16 different offshore pelagic habitat types based on differences in sea surface temperature, productivity, chlorophyll, depth and the frequency of eddies, temperature fronts and chlorophyll fronts.

The National Biodiversity Assessment 2011 drew from recent efforts in mapping human use in coastal and offshore environments and produced 27 maps reflecting the relative intensity of 27 pressures or drivers of ecosystem change. These include 18 types of extractive marine living resource use (13 commercial fisheries, two types of recreational fishing, commercial kelp harvesting, subsistence harvesting and the shark control program), petroleum activities, diamond and titanium mining, shipping, coastal development, disturbance associated with coastal access, waste water discharge, mariculture, invasive alien species and the reduction of freshwater flow into marine ecosystems. An overview of each pressure was compiled drawing from more than 350 publications to report on the known and potential impact of each pressure in different habitat types.

The marine and coastal assessment did not undertake new analyses to determine priority areas for MPA establishment but draws from other initiatives to present spatial priorities. Offshore Marine Protected Areas, other types of offshore spatial management measures and an MPA in Namaqualand are priorities at a national scale. The proclamation of the Prince Edward Islands MPA remains an urgent national priority. Fine-scale systematic planning in KwaZulu-Natal and the Agulhas region identified several provincial or regional priorities for Marine Protected Area establishment there.

Thematic elements of the assessment address ecosystem services, species of special concern, alien and invasive species, climate variability and change, and the status of taxonomic and genetic knowledge. There is compelling evidence from multiple international sources showing that diverse and healthy ecosystems underpin ecosystem processes, resilience (including resistance, recovery and reversibility), and thus the sustainability of ecosystem services. In a global analysis of the value of ecosystem services, marine and coastal ecosystems had the greatest total global flow value and contributed the highest value compared to all other ecosystems. In South Africa, coastal resources make a significant contribution to South Africa's Gross Domestic Product, including nearly R2.5 billion from fisheries. The people of South Africa are in a strong position to benefit greatly from the many ecosystem services that are freely available from the rich marine and coastal ecosystems in this country. This is mainly because there are still opportunities to restore and protect most marine and coastal habitat types, and

South Africa is poised to expand and strengthen the MPA network, which in turn will enhance ecosystem service provision, with long-term sustainability.

Key findings

The key findings of the marine and coastal component of the National Biodiversity Assessment 2011 are highlighted below, including some of their implications. These findings form the basis for the key messages and priority actions that follow.

47% of marine and coastal habitat types are threatened

- Sixty-four of 136 (47%) marine and coastal habitat types are threatened, with 17% of all habitat types critically endangered, 7% endangered and 23% vulnerable.
- Many threatened habitat types have limited spatial extent, so more than 70% of South Africa's total marine and coastal area is least threatened.
- A higher proportion of coastal than offshore habitat types are threatened. In the offshore environment, there are more threatened benthic habitat types than threatened pelagic habitat types.
- All rocky shelf edge and island-associated habitat types are threatened.
- Along the coast, many habitat types in Namaqualand and the southwestern Cape are threatened. Offshore, the Southern Benguela and Agulhas ecoregions have the most threatened habitat types, including productive habitats that support important commercial fisheries.

40% of marine and coastal habitat types have no protection

- Fifty-four (40%) marine and coastal habitat types are not represented at all in South Africa's MPA network.
- Most of these unprotected habitat types are offshore, reflecting the fact that almost all of South Africa's existing MPAs extend only a short distance from the shore.
- Along the coast and inshore, habitat types with no protection include five in Namaqualand and two in the Natal ecoregion.
- A total of 13 habitat types are both critically endangered and have no protection, suggesting that these habitat types are priorities for improved management as well as representation in the MPA network, to reduce human impacts.

Only 6% of marine and coastal habitats are well protected

- Only 9% of coastal and inshore habitat types are well protected.
- Most coastal habitat types are moderately protected, reflecting the fact that in many MPAs there is insufficient protection from fishing (i.e. insufficient representation in no-take zones).
- Only 4% of offshore habitat types are well protected.
- There is poor awareness of the role of MPAs in biodiversity conservation, fisheries management, climate change adaptation and delivery of socio-economic benefits.

Fishing remains the greatest pressure on marine biodiversity

- Fishing is a key driver of change in marine and coastal ecosystems and has the highest impact score in 10 of 13 broad ecosystem groups.
- Key challenges include overexploited resources, substantial and unmanaged bycatch in some sectors, incidental seabird mortalities, habitat damage, concerns around food supply for other species and other ecosystem impacts of fishing.
- Poaching continues to threaten marine biodiversity, resource sustainability and the livelihoods of legitimate fishers.
- The division of the former Marine and Coastal Management branch in the Department of Environmental Affairs into a fisheries branch within the Department of Agriculture, Forestry and Fisheries and the Oceans and Coasts Branch within the Department of Environmental Affairs in 2009 makes the implementation of the Ecosystem Approach to Fisheries management more difficult and costly.

Coastal development is the greatest pressure on coastal biodiversity

- 17% of South Africa’s coastline has some form of development within 100 m of the shoreline.
- Coastal ecosystems provide key ecosystem services including:
  - protection from large waves associated with extreme weather events
  - provision of a reserve supply of sand in the dunes to maintain beaches
  - water filtration and nutrient cycling
  - provision of critical nursery areas for important fish species
  - valuable tourism asset.

- The interacting pressures of coastal development and climate change (coastal squeeze) threaten beaches, dunes, other coastal habitats and their underlying processes. This can disrupt critical ecosystem services.
- Inappropriate coastal development compromises ecosystem services and hampers our ability to adapt to climate change.

Freshwater flow reduction impacts marine, coastal and estuarine ecosystems

- Approximately 40% the flow from South Africa's 20 largest catchments no longer reaches the estuaries concerned.
- Freshwater flow reduction can uncouple critical ecological linkages between terrestrial and marine environments and disrupt ecological processes needed to maintain marine habitats, resources and ecosystem services.
- The impacts of reduced freshwater input on marine biodiversity and resources include those on physical habitat, reduced nutrient inputs and alterations to important ecological processes such as nursery functions, foodwebs and energy flow.
- Impacts have occurred along the entire South African coast but are expected to be more severe in the oligotrophic marine environment of the east coast.
- Freshwater input has been linked to marine resource abundance including linefish such as slinger and kob more than 40 km offshore on the Thukela banks in KwaZulu-Natal.

The majority of marine resources are overexploited and several marine and coastal species are threatened

- More than 630 species are caught by commercial, subsistence and recreational fisheries in South Africa.
- Stock status is reported for approximately 6% (41) of these species.
- Of these, 61% (25 of 41) are overexploited.
- Overexploitation and fishing impacts, freshwater flow reduction and the poor state of South Africa's estuaries, pollution and climate change are key threats at the species level.
- South Africa has at least 23 threatened marine species but needs to invest in conservation assessments (such as Red Lists) to systematically and comprehensively assess the status of marine species and prioritises conservation action.
- Several elasmobranchs and linefish are threatened.

Marine alien and invasive species are an emerging pressure

- New research has shown a large increase in the number of known introduced marine species.
- Introduced microbes, parasites and pathogens are an emerging concern that threatens biodiversity, the developing mariculture industry and human health.
- Some harmful algal blooms (HABs) are caused by alien species and these can have severe consequences for human health, fisheries resources and the mariculture industry. Proper ballast water management can reduce the risks associated with HABs.
- There are eight known marine invasive species that are impacting marine and coastal biodiversity and driving up management costs in mariculture facilities.
- The main pathways of introduction include shipping, mariculture and petroleum activities.

Climate change has ecological, fisheries, resource management and socio-economic implications

- Clear climate change trends are difficult to detect and predict, particularly at a local scale, but it is recognised that climate change adds uncertainty and variability, which in turn increases the complexity of research and management in the marine and coastal environment.
- The following changes have been observed in South Africa:
    - Changes in sea temperature
    - Shifting distributions of rock lobster and small pelagic fish have led to social, ecological and economic impacts. These impacts complicate resource management.
    - Increased frequency and extent of coral bleaching
    - Sea-level rise
    - Increased coastal erosion linked to increased frequency and severity of storms
- The 17% of South Africa's coastline with some development within 100 m of the shoreline is particularly vulnerable to climate change impacts.

Key messages and priority actions

The messages and recommendations below follow from the key findings of the National Biodiversity Assessment 2011. Strategic objectives and priority actions for managing and conserving South Africa's biodiversity are set out in the National Biodiversity Strategy and Action Plan (NBSAP) and the National Biodiversity Framework, both of which are due to be reviewed shortly. Priority actions suggested by the results of the National Biodiversity

Assessment 2011 should feed into the review process. They are intended not to pre-empt the process of revising the NBSAP and National Biodiversity Framework but rather to provide science-based input to strengthen the process.

Many opportunities exist to secure South Africa's marine and coastal habitats

Although 47% of South Africa's marine and coastal habitats are threatened, there are still opportunities to restore impacted habitats, secure remaining healthy habitats, prevent further damage and improve marine biodiversity management. South Africa can constrain key emerging pressures through pro-active integrated spatial planning and effective regulation that accounts for sensitive and threatened ecosystems. Sensitive areas and critical habitats for the recovery of key marine and coastal resources should be identified and secured. Marine and Estuarine Protected Areas, Integrated Coastal Management, Fishery Management Areas and other types of ecosystem-based spatial management measures (such as seabed protection zones) are key tools for securing marine and coastal habitats. Collaborative mainstreaming initiatives in the fisheries and mining sectors offer opportunities for improved marine biodiversity management.

South Africa is poised to expand its Marine Protected Area network

South Africa is a global leader in systematic biodiversity planning and has identified several strategic geographic priority areas for the establishment of new Marine Protected Areas and other types of spatial management measures. These include priority areas in KwaZulu-Natal and the Agulhas ecoregion as determined from fine-scale plans and focus areas for offshore protection based on a national analysis. Many of South Africa's most productive offshore habitats that support fisheries are not included in the current MPA network. The Prince Edward Islands MPA is ready for declaration and a coastal MPA in Namaqualand is an urgent priority.

MPAs are valuable national assets that deliver ecosystem services and socio-economic benefits

South Africa's Marine Protected Area (MPA) network plays a key role in protecting marine and coastal habitats and sustaining fisheries. Coastal protected areas can support rural livelihoods and local economic development through providing jobs and opportunities for ecotourism and conservation-related industries. Protected areas attract foreign and domestic tourists, provide ecosystem services, and safeguard the environment for future generations. Fully protected MPAs help sustain fisheries by protecting breeding resources and by seeding adjacent areas with eggs, larvae or young and adults. South Africa has the opportunity to improve the delivery of ecosystem services from the existing MPA network by implementing new no-take zones, increasing benefits through diversified non-consumptive tourism activities and improving monitoring and management effectiveness. The strengthening of South Africa's MPAs will depend on resolving current resource-use conflicts, reducing current impacts inside existing MPAs (especially fishing) and strengthening management capacity. Building public awareness of the role of MPAs in protecting biodiversity and sustaining fisheries is a priority. Capacity, processes and arrangements are needed to allow stakeholders to participate in MPA design, planning and management.

Overexploited fish stocks can recover and provide long-term food and job security

Although many resources are overexploited, management action can lead to stock recovery. Key elements in securing resource sustainability in the long term include robust stock assessments, effective data management and science-based management action grounded in the realities of resource abundance. The implementation of the Ecosystem Approach to Fisheries management can contribute to resource recovery through protection of spawning and nursery areas and the maintenance of other essential fish habitats. Improved bycatch management offers opportunities to reduce waste and derive benefits from non-target species, through value adding activities that support job creation. Credible third party eco-certification provides an incentive for responsible fisheries and can deliver additional socio-economic benefits through improved market access and security. Current levels of poaching should be reduced to ensure recovery of key resources and to secure livelihoods of legitimate fishers and their dependent communities.

Integrated coastal management supports key ecosystem services and climate change adaptation

Integrated coastal management (ICM) is the process by which multiple uses of the marine and coastal environment are managed so that a wide range of needs are catered for, including both biodiversity protection and sustainable use, allowing all stakeholders to participate and benefit. The relatively high proportion of threatened coastal habitat types (62%) highlights the need for integrated management of the coastal environment, reinforcing the importance of the ICM Act and the tools it has introduced for coastal management. The implementation of ICM can constrain impacts in the sensitive coastal zone and ensure continued delivery of key coastal ecosystem services. These services include protection and buffering from sea-level rise, severe storms and tsunamis. ICM is essential in the wise development and optimal use of South Africa's coastline, including our beautiful beaches, an important investment that is critical to successful coastal tourism.

Healthy natural ecosystems increase society's resilience to the impacts of climate change and ICM is therefore a key element in South Africa's climate change adaptation strategy. Coastal Management Programmes, coastal set-back lines, extending coastal public property, and refining the delineation of the coastal protection zone are required in terms of the Act and will support resilience to climate change. Other tools such as demarcating coastal hazard areas, use of coastal vulnerability indices and coastal land-use planning will further support climate change adaptation. Further coastal ribbon development should be avoided in favour of nodal development, appropriately placed behind scientifically determined set-back lines. This will ensure that coastal impacts are mitigated and managed and allow sections of the coast to remain natural, supporting long term delivery of key ecosystem services and buffering human settlements and activities from climate change impacts.

Fresh water flowing into the sea is not wasted and is critical for ecosystem functioning

Fresh water (including groundwater) flowing into the estuaries and the sea maintains important ecological processes that keep marine resources healthy. Catchments, rivers, estuaries, groundwater and the ocean are linked through freshwater flow and this essential connectivity depends on maintaining these links. Freshwater flow provides nutrients, sediments that form important habitats, and underlies critical ecological processes. These processes include 1) the nursery function of estuaries and areas offshore of rivers and 2) natural environmental cues needed for spawning, migration and recruitment of key resource species. Freshwater inputs have been shown to affect linefish resources more than 40 km offshore in South Africa. A certain amount of water is needed to scour the mouth of most estuaries – without this scouring effect, sediments build up at the mouth increasing the risk of back-flooding during storms. Artificial breaching of an estuary mouth to minimise this risk is expensive and damages estuarine ecosystems. Water running out to sea should not be considered wasted but instead is essential for maintaining a range of coastal and marine ecosystem services.

Early detection, risk assessment and quick management action can prevent future invasions by alien species

South Africa can avoid the ecosystem damage and economic impacts associated with new invasive species through finalisation and effective implementation of the Alien and Invasive Species regulations in terms of the National Environmental Management: Biodiversity Act (Act 10 of 2004), a dedicated monitoring programme to enable early detection, and effective management. Effective management will depend on adequate planning, co-ordination and resources to support preventative management action and early response mechanisms. The developing mariculture industry should be supported to ensure that further invasive species are not introduced and that the management of existing invasive species reduces their economic impacts in this sector. Increased awareness of the risks, impacts and management options for invasive species is needed within the mariculture sector. Co-ordinated cross-sectoral management for ballast water and biofouling vectors is critical to prevent further introductions of alien and invasive species.

Priority actions suggested by the key findings and messages above include the following. As explained earlier, these priority actions should support the upcoming revision of the National Biodiversity Strategy and Action Plan and the National Biodiversity Framework.

Priority Action: Minimise impacts on priority ecosystems

- Prevent further degradation of critically endangered and endangered marine and coastal habitat types.
- Ensure that the refinement of boundaries of the coastal protection zone and coastal public property takes ecological factors into account, in support of the implementation of the ICM Act.

- Develop a map of coastal ecosystem priority areas based on a systematic biodiversity plan that integrates terrestrial, freshwater, estuarine, and marine aspects. This national coastal biodiversity plan should cover the whole coastal protection zone as well as the terrestrial and near-shore areas of coastal public property. The coastal biodiversity plan should identify coastal areas where it is critical to keep natural habitat intact to assist with adapting to the impacts of climate change.
- Identify marine ecosystem priority areas including sensitive habitats and key areas for resource recovery.
- Support the use of coastal and marine ecosystem priority areas in integrated planning, management and decision making across all sectors that impact on marine and coastal ecosystems and their relevant government departments. These include fisheries and mariculture, mining and alternative energy, coastal development, and water resource management.
- Determine and implement the most appropriate tools to manage and conserve coastal ecosystem priority areas. Mandatory tools include Coastal Management Programmes, coastal set-back lines, the extension of coastal public property and refining the delineation of the coastal protection zone. Other potential tools include MPAs, Special Management Areas, demarcating coastal hazard areas, the use of coastal vulnerability indices, coastal land-use planning, and listing of threatened or protected coastal ecosystems in terms of the Biodiversity Act.
- Determine and implement the most appropriate tools to manage and conserve marine ecosystem priority areas. Potential tools include MPAs, Fishery Management Areas, listing of marine ecosystems and collaborative management with offshore industries.
- Explore alternative management mechanisms for biodiversity conservation other than direct regulation (e.g. MPAs), such as incentive-based mechanisms, market-based mechanisms (e.g. eco-certification), awareness initiatives and payment for ecosystem services.

Priority Action: Expand and strengthen the Marine Protected Area Network

- Expand South Africa's MPA network to include currently unprotected habitat types, including proclamation of Offshore MPAs and an MPA in Namaqualand.
- Increase the delivery of the existing MPA network by
  - implementing more no-take zones to contribute to the sustainability of fisheries
  - increasing benefits through diversified non-consumptive tourism activities and
  - improving monitoring and management effectiveness.
- Improve the science base for South Africa's MPAs through species inventories, fine-scale habitat mapping, and coordinated monitoring initiatives. MPAs provide significant research opportunities for scientists, including potential to strengthen stock assessments for linefish.
- Transboundary MPAs between South Africa, Namibia, Mozambique and our neighbours in the Southern Ocean should be pursued and would need clear management agreements.
- Build public awareness of the role of MPAs in marine biodiversity conservation and fisheries management through targeted awareness initiatives, collaborative research and co-management.

Priority Action: Support the recovery of overexploited resources and threatened species

- Ensure that fishing quotas and fishing effort allocations (e.g. number of fishers or vessels) are grounded in the realities of resource abundance.
- Invest in the management of critical data sets (e.g. fisheries research and commercial catch and effort data and observer data) to support fisheries management. Dedicated data managers, better electronic systems for capturing, storing, validating and disseminating data and improved fisheries data with finer spatial resolution will improve place-based resource and ecosystem management. Advanced data policies and adequate resources will need to be developed and secured to achieve this priority.
- Develop and implement resource recovery plans for overexploited species.
- Cap effort on shark fishing and protect shark nursery grounds.
- Identify critical habitats for the recovery of key resources (e.g. spawning and nursery areas, key foraging areas).
- Secure critical habitats through the implementation of spatial management measures including Fishery Management Areas and Marine Protected Areas.
- Manage incidental mortality of seabirds and secure important offshore bird areas.
- Fortify compliance efforts and reduce poaching especially for rock lobster, abalone and linefish.

- Develop and implement a strategy to prioritise and catalyse southern African or national conservation assessments (Red Lists) for marine species.
- Build public awareness about threatened species, with a focus on linefish such as white steenbras and dusky kob.

Priority Action: Prevent further introduction and spread of invasive species

- Prevent future introductions of invasive species introductions through finalising and implementing the Alien and Invasive Species Regulations, including ensuring that all relevant marine species are listed.
- Review South Africa's adherence to international protocols, capability to deal with existing and emerging invasive species and enforcement of law to prevent new invasions.
- Build scientific and management capacity to support the identification of potential marine invasive species, assess risks and develop and implement appropriate management action. Additional capacity will also be needed to enforce regulations.
- Develop capacity and resources to make use of DNA barcoding to identify invasive species.
- Publish and publicise existing lists of known marine invasive species found in the South African marine environments.
- Establish co-ordinated monitoring initiatives to allow early detection of potential invasive species. Such monitoring initiatives need to include a focus on mariculture facilities, offshore oil and gas infrastructure, ports and harbours.
- Secure resources and develop capacity to enable rapid management action to prevent potential invasive species from becoming established when detected through monitoring programmes.
- Explore methods and potential for eradicating the European shore crab *Carcinus meanus* (currently confined to two harbours) and the black sea urchin *Tetrapygus niger* (currently confined to maricuture facilities).
- Ensure that the national strategy for invasive species that is currently being initiated addresses the marine environment comprehensively.
- Support the Department of Transport in the co-ordinated implementation of the conditions of the International Maritime Organisation Ballast Water Management Convention to ensure South Africa's readiness when the convention comes into force.
- Develop technical and management capacity to support the implementation of the conditions of the Ballast Water Management Convention.

- Promote South Africa's work in support of the International Maritime Organization as related to management of ballast water and biofouling. Develop case studies to report on port surveys and management of marine invasive organisms.

Priority Action: Support good environmental practice and effective regulation of the emerging mariculture sector

- Apply global lessons and good practice guidelines in avoiding and mitigating the environmental impacts of mariculture to ensure that wild fish populations and marine ecosystems are not further threatened by this emerging sector.
- Locate mariculture on land, or in ocean areas that have sufficient depth and flushing rates to minimise habitat impacts. Mariculture should be avoided in biodiversity priority areas including Critical Biodiversity Areas, Marine Protected Areas, Estuaries, Fresh Water Ecosystem Priority Areas (including estuaries), critically endangered and endangered ecosystems and other sensitive biodiversity areas.
- Select species for mariculture with full consideration of potential impacts on indigenous species, ecosystems and fisheries. In keeping with the Biodiversity Act, a comprehensive risk assessment and contingency plan should be conducted for all mariculture operations proposing to farm alien or translocated species. For improved cooperative governance, the biodiversity sector should be represented in the mariculture working group.
- Ensure effective management and husbandry of stock, food and feeding, disease control, effluent, waste and interactions with wild stocks and predators to minimise impacts on indigenous species and ecosystems and prevent negative impacts on existing fisheries and other activities (e.g. ecotourism).
- Control incidental introductions with stock or spat of introduced species.
- In order to prevent the introduction of microbes, parasites and pathogens to wild populations, effluent from land-based farms should be filtered and sterilised and sea-farmed stock should be certified disease free prior to stocking. This should also apply to the transport medium for mariculture species, irrespective of whether animals are moved within or imported from outside South Africa's borders.
- To avoid potentially damaging genetic impacts, ensure that the genetic variability of broodstock resembles the genetic profile of the surrounding wild populations.
- Raise awareness about the potential impacts of mariculture and develop management capacity within the mariculture industry sector through increased training in responsible aquaculture methods and best practices.

- Develop capacity for effective regulation of the mariculture sector and to ensure compliance with environmental management plans developed for mariculture enterpises. Regular, inspections of all mariculture enterprises by suitably qualified biodiversity and animal health experts are needed to minimise the risks of the introduction of disease and invasive species into marine and coastal ecosystems.

Priority Action: Strengthen climate change resilience

- Conserve, manage and where appropriate rehabilitate natural ecosystems that play a critical role in climate change adaptation. For example, beaches, dunes, estuaries, mangroves and kelp forests should be maintained in an ecologically healthy and functioning state as they play a critical role in helping humans cope with the impacts of climate change.
- Implement integrated ecosystem-based management including Integrated Coastal Management and the Ecosystem Approach to Fisheries management.
- Ensure MPAs support resilience to climate change through adequate representivity and connectivity by expanding and consolidating the MPA network.
- Improve the knowledge base to support the understanding of climate change in South Africa. Long-term monitoring is a key element in research to understand climate variability and change.
- Further develop scientific capacity to detect and predict changes and provide science-based advice to support climate change adaptation and mitigation.
- Develop adaptive management capacity including enhanced management flexibility to adapt to a changing environment.
- Ensure policies encourage diversification of resource use and income generation to enhance social resilience in the face of uncertainty and variability. This is especially important for the most vulnerable coastal and fisher communities.

Priority Action: Ensure sufficient freshwater flow to the coastal and marine environment

- The needs of coastal and marine ecosystems (water quantity, water quality & sediment) should be taken into account in determining and implementing ecological water requirements for estuaries.

Priority Action: Strengthen institutional arrangements to facilitate integrated ecosystem-based management

- Develop effective institutional arrangements to underpin co-operative governance to support ecosystem based management (including the Ecosystem Approach to Fisheries management) and integrated strategic planning and management (including Integrated Coastal Management).
- Consider the development of an Inter-Departmental Liaison Committee for Marine Ecosystems, similar to the recently established Inter-Departmental Liaison Committee for Freshwater Ecosystems. This could provide opportunities for the various key role-players in marine ecosystem management and conservation to establish shared objectives and to collaborate actively, and to clarify respective roles and responsibilities.
- Strengthen collaboration between DEA and DAFF around the management, sustainable use and conservation of marine ecosystems. Formal co-operation with clear roles and responsibilities is needed to support Marine Protected Area establishment and management, Integrated Coastal Management and other types of effective spatial management. The multiple objectives of MPAs including both biodiversity conservation and fisheries sustainability should be recognised and inter-departmental co-operation is critical to the success of MPAs.

Priority Action: Invest in the knowledge base to support biodiversity assessment and management

- Refine the marine and coastal habitat classification and map based on testing the validity of the current classification, high resolution bathymetric mapping, and systematic marine biodiversity surveys across broad ecosystem groups.
- Collate information and conduct dedicated sampling to develop descriptions of habitat types.
- Establish long-term in-situ monitoring sites across broad ecosystem groups to calibrate the assessment of ecosystem condition and inform responses to emerging impacts.
- Invest in improved baselines through the capture, analysis and management of historical datasets.
- Re-instate and secure the scientific observer program in the long term to improve the knowledge base that supports fisheries management, identification of key biodiversity impacts of fisheries and the development of appropriate mitigation measures.
- Secure resources for, develop and implement a marine biodiversity information strategy. This should support the development and management of appropriate co-ordinated

specimen, species and genetic databases and address taxonomic priorities, support conservation assessments and the identification of invasive species.

- Improve co-ordination and collaboration in the collation and management of marine biodiversity data. Encourage data sharing to catalyse increased benefits, application and data security.
- Develop opportunities for all stakeholders to contribute to the assessment and conservation of marine biodiversity. Collaborative mainstreaming initiatives, participatory research, citizen science initiatives & co-management arrangements can help to improve public participation.

List of acronyms

ASCLME	Agulhas Somali Current Large Marine Ecosystem
DEA	Department of Environmental Affairs
DAFF	Department of Agriculture, Forestry and Fisheries
EAF	Ecosystem Approach to Fisheries
EEZ	Exclusive Economic Zone
GDP	Gross Domestic Product
GEBCO	General Bathymetric Chart of the Oceans
GIS	Geographic Information Systems
ICES	Council for the Exploration of the Sea
IMO	International Maritime Organisation
IUCN	International Union for Conservation of Nature
KZN	KwaZulu-Natal
MAR	Mean Annual Runoff
MPA	Marine Protected Area
NBA	National Biodiversity Assessment
NEMBA	National Environmental Management: Biodiversity Act
NLC	National Land Cover
PAH	Petroleum hydrocarbons
QDS	Quarter Degree Square
SANBI	South African National Biodiversity Institute
SAN Parks	South African National Parks
SST	Sea Surface Temperature
TAC	Total Allowable Catch
TNPA	Transnet National Port Authority
UNEP	United Nations Environment Programme

Table of Contents

List of Figures:

List of Tables

1 Introduction

1.1 What is the National Biodiversity Assessment?

The National Biodiversity Assessment (NBA) 2011 follows the first National Spatial Biodiversity Assessment (NSBA), led in 2004 by the South African National Biodiversity Institute (SANBI).

The NSBA 2004 was the first comprehensive national spatial assessment of the state of biodiversity, covering terrestrial, freshwater, estuarine and marine environments. It introduced two new headline indicators for assessing the state of South Africa's biodiversity: ecosystem threat status (referred to as ecosystem status in 2004), and ecosystem protection level. Ecosystem threat status tells us how threatened our ecosystems or habitat types are, and ecosystem protection level indicates how well- or under-protected our ecosystems or habitat types are. For the first time, these indicators were comparable across aquatic and terrestrial environments. These indicators are primary indicators that provide an overview of ecosystem state.

SANBI's mandate includes reporting on the state of biodiversity in South Africa. For this reason, the decision was made to broaden the National Spatial Biodiversity Assessment to incorporate non-spatial or thematic elements, and to produce a National Biodiversity Assessment. The intention is to review the National Biodiversity Assessment at five to seven year intervals.

The primary purpose of the NBA is to provide a regular high-level summary of the state of South Africa's biodiversity, with a strong focus on spatial assessment. The NBA is intended for decision-makers both inside and outside the biodiversity sector. It feeds into and links with other policy-related processes such as state of environment reports, identification of threatened ecosystems for listing in terms of the Biodiversity Act, the National Protected Area Expansion Strategy, and the National Biodiversity Strategy and Action Plan.

The NBA 2011, like the NSBA 2004, was led by SANBI in partnership with a range of organisations. The overall results are summarised in the report: *National Biodiversity Assessment 2011: A report on the state of South Africa's biodiversity* (Driver *et al.* in prep).

A technical reference group was convened by SANBI in April 2009 to guide the approach taken in the NBA 2011. This group was reconvened in January 2011 to review outputs and provide guidance on key messages that should be highlighted in the NBA summary report.

The marine and coastal component is one of four components of the NBA 2011. A technical report is available for each component, as listed at the front of this report. While the NBA 2011 summary report is intended for a wide audience, this technical report is intended for a more specialist audience. It explains the data used and the analysis undertaken in the 2011 assessment, highlighting advances made since 2004, and discusses the results.

Common features across the components of the NSBA 2004 and the NBA 2011 are the use of the systematic approach and the focus on the two headline indicators of ecosystem threat status and ecosystem protection level. Each of these is discussed briefly below.

Working in an integrated and aligned way across aquatic and terrestrial environments can be challenging, as disciplines in these environments have historically developed separately, with separate sets of terminology, methods and approaches. Insisting on compatible approaches can be seen as a constraint on conventional approaches. However, the benefits are numerous, including enabling comparisons, shared learning and innovations across environments.

1.2 Biodiversity assessment and planning[1] in South Africa

There are several possible approaches to biodiversity assessment and planning. The approach used most often in South Africa, including in the NBA, is a systematic approach. It is based on three key principles:

- The need to conserve a **representative sample** of biodiversity pattern (the principle of representation);
- The need to conserve the **ecological and evolutionary processes** that allow biodiversity to persist over time (the principle of persistence);
- The need to set quantitative **biodiversity targets** that tell us how much of each biodiversity feature should be kept in a natural condition in order to maintain functioning landscapes and seascapes.

---

[1] Biodiversity planning is sometimes referred to as conservation planning. We prefer to use biodiversity planning because many people associate the term conservation planning purely with planning for the establishment and expansion of formal protected areas, rather than with influencing the way resources are used and managed throughout the landscape or seascape.

South Africa is at the forefront of biodiversity planning internationally, and the methods and techniques used in the systematic spatial assessment are at the cutting edge of the discipline. The NBA rests on over 30 years of biodiversity planning research, development and practice by South African scientists, often in collaboration with colleagues from other countries.

1.3 Headline indicators: ecosystem threat status and ecosystem protection level

As explained above, the NSBA 2004 introduced two new headline indicators for assessing the state of South Africa's biodiversity: ecosystem threat status and ecosystem protection level. Ecosystem threat status tells us how threatened our ecosystems are, and ecosystem protection level tells how well- or under-protected our ecosystems are. These headline indicators provide not only a way of comparing results meaningfully across the different aquatic and marine environments, but also a standardised framework which links with policy and legislation in South Africa, facilitating the interface between science and policy. There is growing recognition within government and other institutions of this framework and the need to respond to these headline indicators in planning and decision-making.

These two headline indicators have been carried forward in the NBA 2011, and will be updated again in future revisions of the NBA in order to provide a temporal comparison of the state of ecosystems in South Africa. Between 2004 and 2011, methods for assessing ecosystem threat status have been refined, meaning that the results are not strictly comparable over this time period. The classification and mapping of terrestrial vegetation types in South Africa rests on decades of research whereas marine habitat clasiification and mapping is in its infancy in South Africa.

The assessment of ecosystem threat status is **completely independent** of the assessment of ecosystem protection level. As shown in Figure 1, ecosystem threat status is based on the condition of an ecosystem type, while ecosystem protection level is based on the extent to which an ecosystem type is formally protected. A well protected ecosystem type may thus be in poor condition, and equally an ecosystem in good condition may not be formally protected.[2]

[2] In practice, highly threatened ecosystems are often poorly protected. However, this correlation emerges not from the nature of the analysis itself but because ecosystems in which large amounts of natural habitat have been lost, or which have become

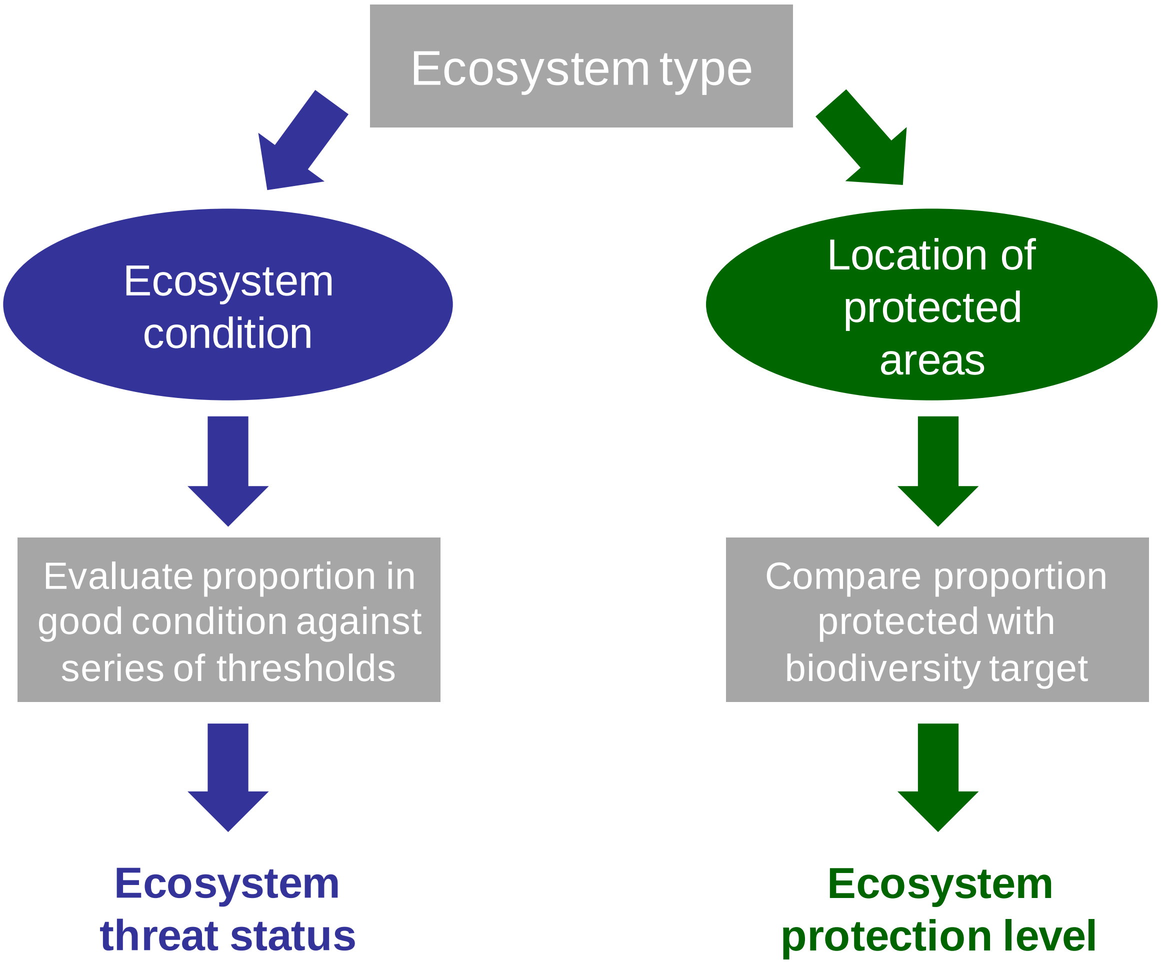


Figure 1: Overview of the approach to determine ecosystem threat status and ecosystem protection levels.These headline indicators are assessed independently of one another. Ecosystem threat status is based on the proportion of an ecosystem type in good condition, while ecosystem protection level is based on the proportion of an ecosystem type that is formally protected.

---

severely degraded, tend to be those under pressure from a range of socio-economic activities that are incompatible with maintaining a well functioning ecosystem and that raise the opportunity costs of establishing protected areas.

1.4 Marine biodiversity assessment in South Africa

South Africa's first status report on marine biodiversity was published in 2000 and focused on the state of knowledge, expertise and capacity relevant to marine biodiversity in the country (Durham and Pauw 2000). The report reviewed the knowledge base for several types of ecosystems, the conservation and use of resources, the implications of genetic and biochemical research and the scope and efficacy of national biodiversity policies. Threats to ecosystem functioning were reviewed for nine broad types of ecosystems and gaps in knowledge of ecosystem functioning were identified. This valuable assessment which has not been repeated since 2000 was a key base document that was drawn from during the 2011 assessment. In 2002, Van der Elst provided a succinct overview of the species biodiversity, endemism, threatened species and key pressures for South Africa's marine ecoregion. In 2010, Griffiths *et al.* reported on the current state of knowledge of marine biodiversity in South Africa.

The 2004 National Spatial Biodiversity Assessment (Driver *et al.* 2005) included a comprehensive marine component (Lombard *et al.* 2004) that significantly advanced the assessment of marine biodiversity in South Africa and represented the first spatial assessment. Considerable effort was expended in identifying agreed biogeographic and depth patterns for the South African marine environment, based on excellent research in these areas from South Africa's strong marine science research community. Expert-based assessment of pressures in different biogeographic and depth zones allowed the first spatial assessment of ecosystem status. Protection levels for 34 biozones were assessed using the first map and GIS layer for Marine Protected Areas (MPAs). Lombard *et al.* 2004 also collated and mapped species data for fish, seaweeds and selected intertidal invertebrates, assessing achievement of species targets at a national scale for the first time. Species data were not included in the spatial assessment for 2011. The 2004 National Spatial Biodiversity Assessment included a national conservation plan and identified several priority areas. This was not undertaken in 2011, although coastal and marine biodiversity priorities (as identified by other systematic plans) are discussed in the thematic component of this report.

The marine and coastal component of the National Biodiversity Assessment represents a current analysis of pressures and biodiversity state in South Africa's coastal and marine environment. The area assessed extends 500 m inshore of the coastline and extends 200 nautical miles offshore including the mainland Exclusive Economic Zone (EEZ). The Prince

Edward Islands and their surrounding EEZ were not considered in the assessment but are recommended for inclusion in future assessments.

1.5 Structure of this report

This technical report is structured as follows:

There are 17 sections nested within 3 broader divisions, beginning with the spatial assessment, followed by the thematic component and culminating in an overview of key findings, gaps and research priorities and recommended actions. The spatial assessment includes three main sets of input layers: habitats, pressures and protected areas.

- Section 1 is this introduction
- Section 2 presents the National marine and coastal habitat classification and map.
- Section 3 reviews and maps 27 pressures on coastal and marine biodiversity.
- Section 4 presents an updated Marine Protected Area map and an overview of South Africa's MPA network.
- Section 5 discusses the biodiversity targets for marine habitats.
- Section 6 presents the spatial analyses to determine ecosystem threat status for all habitat types based on the comparison of habitat condition inferred from pressure data (weighted according to a habitat-pressure matrix) to biodiversity thresholds.
- Section 7 covers the analyses and results from the protection level assessment that classifies each habitat type into a protection level category based on the extent of representation in South Africa's Protected Area network in relation to biodiversity targets.
- Section 8 draws from other initiatives to present some spatial priorities for protected area establishment (the 2011 assessment did not undertake such analyses)
- Sections 9 to 14 report on the thematic elements of the biodiversity assessment addressing ecosystem services, species of concern, alien and invasive species, climate variability and change and the status of taxonomic and genetic knowledge.
- Key findings, gaps and priorities are presented in sections 15, 16 and 17 respectively.

2 Classification of coastal and marine habitats

South Africa's previous National Spatial Biodiversity Assessment (Lombard *et. al.* 2004) used an expert-based approach to assess ecosystem status for 35 marine biozones. A hierarchical habitat classification was presented to clarify terminology used in the assessment although ecosystem status was not assessed at a habitat level. The 2004 assessment recognised and mapped 5 broad intertidal habitat types; sandy beaches, pebble beaches, boulder beaches, mixed shores and rocky shores in each of 5 inshore bioregions. Mixed and rocky shores were further classified by wave exposure. Offshore, GIS layers were developed for benthic sediments drawing from geological maps (Dingle *et al.* 1987) and maps of sediment texture (Texture of surficial sediments of the continental margin Marine Geoscience, Series 3, Department of Mineral and Energy Affairs, 1986 as digitised by Lombard *et al.* 2004). Three other offshore features were mapped; seamounts and banks, untrawlable grounds on the Agulhas Bank and submarine canyons. Canyons were the only offshore feature to be sub-classified and this was done according to bioregion.

In 2011, SANBI developed a National marine and coastal habitat classification to support the classification, mapping and assessment of coastal and marine habitat types at a national scale using a uniform approach (Figure 2 and Figure 3). Although the classification units are referred to as habitat types, they are considered to include interacting assemblages of species, their physical habitat and trophic structure as ecological communities that could also be referred to as ecosystems. South Africa's Biodiversity Act (2004) defines an ecosystem as "a dynamic complex of animal, plant and micro-organism communities and their non-living environment interacting as a functional unit", a definition that recognises that ecosystems can be defined at multiple scales. As such, the coastal and marine habitat types referred to in this report are considered appropriate units for the assessment of ecosystem threat status which addresses the international demand for a broader approach to biodiversity assessment and conservation of ecological communities in addition to individual species (Nicholson *et al.* 2009). Species and genetic levels of biodiversity and physical, ecological and evolutionary processes were not incorporated in the 2011 marine spatial assessment, although these aspects are considered in the thematic sections of this report.

Building on the habitat classification and mapping undertaken by Lombard *et al. (*2004), 136 marine habitat types including 58 coastal, 62 offshore benthic and 16 offshore pelagic habitat types, all grouped into 14 broad ecosystem groups, were classified and mapped.

The National coastal and marine habitat classification and maps (Figures 2 – Figure 6) are the result of a collaborative effort involving many experts and drawing from previous and emerging national and fine-scale planning projects (Lombard *et al.* 2004, SEAPlan, Sink *et al.* 2011) as well as other local (Lagabrielle 2009, Harris *et al.* 2010, Harris *et al.* 2011a) and international classification schemes (Gubbay 2002, Connor *et al.* 2004, Snelder *et al.* 2006, Spalding *et al.* 2007, Howell 2010). Although the classification can be presented as a hierarchy (Figure 3), it is difficult to determine which physical and ecological characteristics play a dominant role in structuring coastal and marine ecosystems and habitat types as this can depend on the scale and the habitat in question.

Key differences between the classification developed in 2011 and that presented in the 2004 assessment include: the introduction of a broader coastal and offshore division in 2011; the separation of offshore benthic and pelagic habitat types: the amalgamation of supra-tidal and a portion of the shallow subtidal zones into "coast types"; the inclusion of products from the National Beach Classification and Mapping project (Harris *et al.* 2010); and the consideration of biogeography at a much lower level in the classification hierarchy. Experts with experience in different habitat types (such as sandy beaches versus rocky shores) argued for different biogeographic regions for different habitat types, necessitating the inclusion of biogeography further down the classification tree. Recent new research and publications support this decision (Porter 2009, Harris *et al.* 2010). A broader unit of habitat classification that would be similar to the biomes used in the terrestrial ecosystem classification and therefore accommodate several broad ecosystem groups within the classification was sought. These broad ecosystem groups are similar to those used in the previous marine biodiversity status report (Durham and Pauw 2000). The broad ecosystem groups are functionally similar, although biogeographic differences account for significant differences in species composition and even ecology in many of these habitat types. For example, inshore reefs in the Delagoa region (northern KwaZulu-Natal) have very little if any overlap in species composition with the same habitat type in the south-western Cape. Nevertheless reefs are more functionally similar across bioregions than reefs and unconsolidated habitat types within the same bioregion.

2.1 Key elements in the habitat classification

The 2011 National coastal and marine habitat classification incorporate the following key drivers of marine biodiversity patterns:

- Terrestrial and benthic-pelagic connectivity
- Substrate (consolidated or unconsolidated)
- Depth and slope
- Geology, grain size and wave exposure (which interact in the case of beaches)
- Biogeography

In addition, a separate classification was undertaken for offshore pelagic habitat types incorporating sea surface temperature, productivity, chlorophyll, depth and the frequency of eddies, temperature changes and chlorophyll fronts (see Lagabrielle 2009 for details and summary below).

2.1.1 Terrestrial & benthic-pelagic connectivity

The first major division in the habitat classification is one based on links with the terrestrial environment and links between the benthic and pelagic environment (Figure 2 and Figure 3). The primary distinction is between the coastal and offshore zones and the secondary distinction is between benthic and pelagic habitat types within the offshore zone. Heuristic principles were used to demarcate ecosystems differing in terms of terrestrial connectivity and benthic-pelagic coupling. Marine habitat types were classified into two broad divisions; coastal and offshore, separated at the 30 m bathymetric contour, although subtidal island-associated habitat types extend beyond the 30 m contour in some places. This division is relatively arbitrary but aligns with other assessment and planning divisions such as the Offshore Marine Protected Area Project (Sink and Attwood 2008, Sink *et al.* 2011) and the Marine Conservation Plan for the Agulhas Bioregion (Clarke and Lombard 2007).

Further divisions relating to terrestrial connectivity include the subdivision of the coastal area into 4 divisions; coast types, inshore, island-associated and lagoon habitat types. Estuaries are dealt with as a separate National Biodiversity Assessment 2011component report (refer to the Estuarine Component of the National Biodiversity Assessment). All coastal habitat types were not separated into either terrestrial and marine or benthic and pelagic components. This was due to strong links between all these components in coastal ecosystems and because most threats also impact benthic and pelagic components of ecosystems in shallow water. Although new coastline mapping was undertaken as a component of a related project (Harris *et al.* 2011), it is emphasised that coast type habitat types have marine and terrestrial components, and consist of a three-dimensional habitat rather than a one-dimensional line. The area from 500 m inland of the high water mark (defining the coastal landward boundary) to the 5 m depth contour offshore (defining the coastal seaward boundary) was classified as a “coast type” zone. The 500 m inland boundary was based on pragmatic considerations, while the -5 m depth contour was used as an offshore boundary because this approximates the depth of effective wave action (see section on Depth below). These coast types reflect the connectivity of coastal habitats through complex linkages such as energy and nutrient flow, sediment dynamics and movement pathways for biota. Future work is required to determine and map these boundaries on ecological grounds.

Continental islands and their surrounds are perceived to be a priority habitat type (Williams *et al.* 2000) but have not been included in previous South African spatial assessments or planning (Lombard *et al.* 2004, Clark and Lombard 2007, Harris *et al.* 2010, Sink *et al.* 2011). Islands and their associated subtidal habitats are recognised as distinct habitat types because of dominance by land-breeding marine predators and associated unique features including those related to nutrient input (e.g. from guano) and predation pressure (e.g. trophic interactions between seabirds, seals and sharks (Williams *et al.* 2000)). Intertidal and subtidal biota around islands differs from shores of adjacent mainland areas (Bosman and Hockey 1986, Williams *et al.* 2000). The approach for classifying islands was developed in discussion with several experts from DEA culminating in the recognition of the need for further dedicated research to support island classification. For this assessment, two main types of islands were recognised. Islands that are typified by dense seal colonies and low numbers of seabirds and that are typically ≤ 0.025 km^2 in area were classified as “minor islands”. Islands that are characterised by permanent seabird colonies and potentially seal colonies and that are typically larger than 0.02 km^2 in size were classified as “major islands”.

South Africa’s only lagoon (Langebaan) was not classified as an estuary because it does not receive freshwater surface flow. Both the estuarine and marine science community recognise that Langebaan does receive freshwater input via groundwater (Whitfield 2010) and therefore shares certain ecological features with estuaries. This unique ecosystem was included as a marine habitat type with the recognition that it could also have been included in the estuarine assessment. Although Langebaan lagoon may be unique in South Africa, comparable systems exist elsewhere in southern Africa such as Sandwich harhour in Namibia and Baía dos Tigres in Angola.

Offshore, benthic (the seabed) and pelagic (the water column) habitat types were considered and assessed in separate components of this report as these types of habitats show different responses to different types of pressures and separate management of benthic and pelagic habitats is feasible in water deeper than 30 m. Experts advised that benthic-pelagic coupling is still very relevant in water deeper than 30 m and occurs throughout the shelf, shelf edge and even deepsea ecosystems. Many experts motivate for the benthic and pelagic ecosystems to be considered as a single unit in all areas shallower than the shelf edge or the 100 m depth contour.

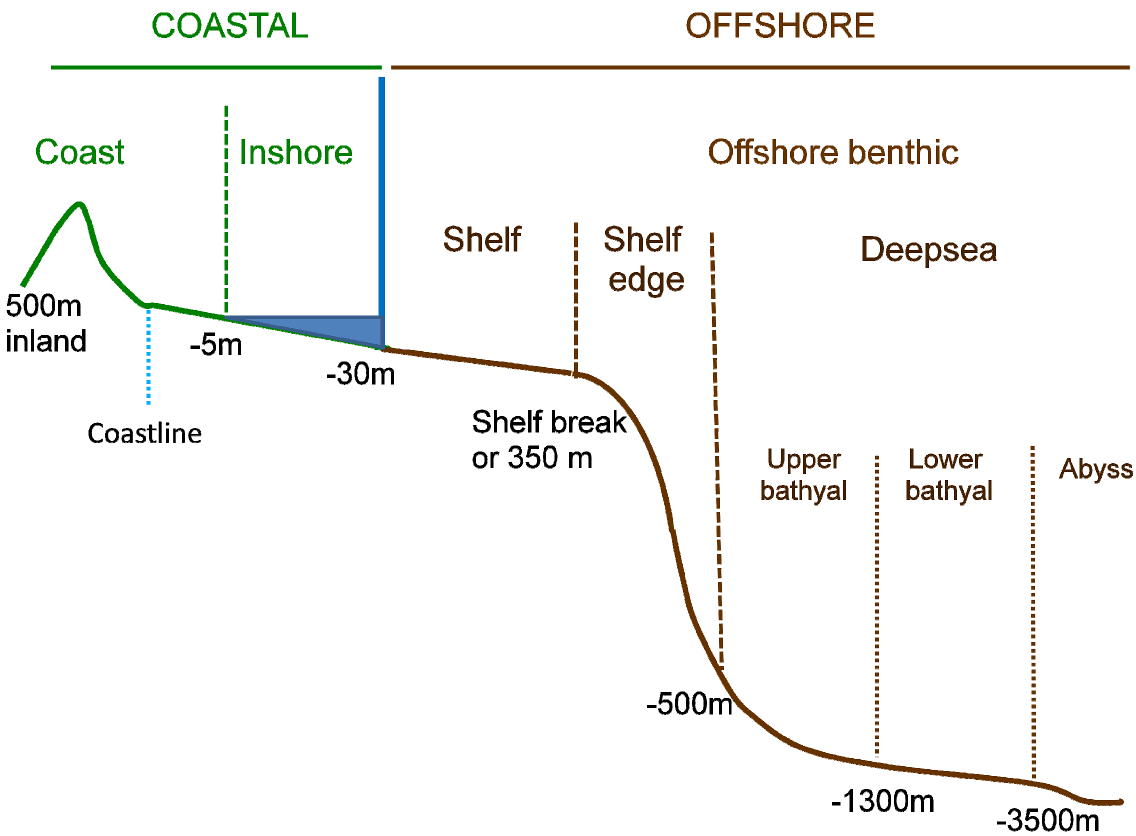


Figure 2: Schematic illustrating the key divisions in the National marine and coastal habitat classification. The coastal and offshore division and other zones related to terrestrial connectivity, benthic-pelagic coupling, large-scale topography and depth are sh

MARINE AND COASTAL HABITAT TYPES (136)

Drivers of biodiversity pattern	**COASTAL** (58) 500 m inland to -30 m including island-associated and lagoon habitat types Benthic & pelagic combined							**OFFSHORE** (78) 30 m to EEZ boundary Separate benthic & pelagic habitats						
Terrestrial & benthic-pelagic connectivity	**Coast type** (37) (500 m inland to -5 m) Benthic & pelagic combined			**Inshore** (17) (-5 m to -30 m)		**Island-associated** (3)	**Lagoon** (1)	**Offshore Benthic** (52)						Offshore Pelagic (16)
Substrate	Rocky coast	Mixed coast	Sandy Coast	Rocky	Unconsolidated	Na (3)	Na (1)	Rocky (23)			Unconsolidated (39)			
Depth and slope	Na	Na	Na	Na	Na	Na	Na	Shelf (Inner & outer shelf in some ecoregions)	Shelf edge	Deepsea (Upper bathyal, Lower bathyal, Abyss)	Shelf (Inner & outer shelf in some ecoregions)	Shelf edge	Deepsea (Upper bathyal, Lower bathyal, Abyss)	NA
BROAD ECOSYSTEM GROUPS	Rocky coast (16)	Mixed coast (5)	Sandy Coast (16)	Rocky inshore (8)	Unconsolidated inshore (9)	Island (3)	Lagoon (1)	Rocky shelf (12)	Rocky shelf edge (9)	Seamount (2)	Unconsolidated shelf (19)	Unconsolidated shelf edge (11)	Deepsea sediments (9)	Offshore pelagic (16)
Wave exposure, grain size, geology or beach state	Wave exposure Very exposed Exposed Sheltered Boulder	Na	Beach state Reflective Intermediate Intermediate-dissipative Dissipative Estuarine	Geology Reef Hard grounds	Grain size Sandy Muddy Gravels Mixed	Na	Na	Geology Reef Hard grounds Bank	Geology Reef Hard grounds Canyons	NA	Grain size Sandy Muddy Gravels Mixed	Grain size Sandy Muddy Gravels Mixed	Geology With or without Ferro-manganese deposits	
Biogeography (Ecozones or Ecoregions)	Ecozones Namaqua SW Cape Agulhas Natal Delagoa	Ecozones Namaqua SW Cape Agulhas Natal Delagoa	Ecoregions Southern Benguela Agulhas Natal-Delagoa	Ecozones Namaqua SW Cape Agulhas Natal Delagoa	Ecozones Namaqua SW Cape Agulhas Natal Delagoa	Ecozones Namaqua SW Cape Agulhas	Na	Ecozones Namaqua SW Cape Agulhas Natal Delagoa	Ecoregions Southern Benguela Agulhas Natal Delagoa	Ecoregions Southeast Atlantic Southwest Indian	Ecozones Namaqua SW Cape Agulhas Natal Delagoa	Ecoregions Southern Benguela Agulhas Natal Delagoa	Ecoregions Southeast Atlantic Southwest Indian	

Figure 3: Schematic illustrating the hierarchical classification of coastal and marine habitat types in South Africa. The classification considers terrestrial and/ or benthic-pelagic connectivity, substrate, depth and slope, geology, grain size, wave exposure and biogeography. Beach morphodynamic state (beach state) incorporates the interaction of wave exposure and grain size. Numbers of habitat types in each category are shown in parenthesis.

2.1.2 Substrate

In coastal and offshore benthic environments, substrate is considered an important primary determinant of community structure and biodiversity and the use of substrate in habitat classifications is universal (Connor *et al.* 2004, Connor *et al.* 2006, Howell *et al.* 2010). Habitat types were classified into three main groups based on the stability of the substrate; consolidated (rocky, reefs and hard grounds), unconsolidated (sandy, muddy, gravel and mixed sediments) and with an additional mixed category in the coast types. Within both unconsolidated and consolidated habitat types, additional substrate categories based on geology, grain size and beach morphodynamics were included.

For coast types, the first phase of the National Beach Classification and Mapping Project (Harris *et al.* 2010, Harris *et al.* 2011a) distinguished between rocky, sandy and mixed coast types. Rocky coasts were scored when the intertidal area comprised rock only; sandy coasts were scored where the intertidal area comprised sand; and mixed coasts were scored when rock and sand were both present in the intertidal area. To avoid scoring a sandy coast with a single rock on it as a mixed coast, a rule was instituted where the coast type had to change for a distance along-shore that was longer than the across-shore intertidal width. To qualify as a mixed coast, rocky sections had to replace one or more of the intertidal sandy beach zones across the shore (*sensu* Dahl 1952 and Salvat 1964). The National Beach Classification and Mapping project (Harris *et al.* 2010, Harris *et al.* 2011) captured details of which across-shore zones (such as high, mid and low shore) were sandy, mixed or solid rock in the mixed coast category. Once overlaid with subsequent habitat classification criteria (wave exposure and biogeography), it would have resulted in 60 types of mixed coast, which was considered to be too complex for the current assessment. Mixed coasts were thus considered as a single coast type category, subclassified only by biogeography for the 2011 National Biodiversity Assessment.

In both the inshore and offshore regions, maps of reefs, hard grounds and other consolidated features (such as submarine canyons, banks and seamounts) were used to demarcate consolidated habitat types. All remaining areas were considered to be unconsolidated sediment.

2.1.3 Depth and slope

Depth is an easily measurable, well-established surrogate of biodiversity pattern. Depth zones reflect patterns in distribution linked to many environmental parameters that influence benthic biological communities including temperature, light attenuation, large-scale topography or geomorphology, wave action, hydrostatic pressure, oxygen minimum zones, currents, food supply, larval dispersal and even many ecological processes (see Howell 2010 and references therein). Most classification systems incorporate various zones in the near-shore regions relating to complex faunal zonation patterns linked to gradients in immersion, thermal stability, light, wave action and salinity (Connor *et al.* 2004, Connor *et al.* 2006). Lombard *et al.* (2004) recognised supra-tidal, tidal and subtidal zones which are generally included in most marine habitat classifications. Finer depth zonation patterns were not developed in the coastal environment because of a lack of fine-scale national data for these inshore zones and because of a deliberate attempt to develop a relatively simple habitat classification for this first assessment of ecosystem threat status at a habitat type level.

In deeper water, depth breaks that are consistently used in classification schemes frequently include large-scale geomorphological divisions such as shelf, slope and abyss; as well as depth breaks based on patterns in faunal zonation (see detailed review by Howell 2010). Howell (2010) reports that four major faunal boundaries are consistently reported in the substantial body of literature dealing with depth patterns in the ocean:

(1) the shelf slope break (usually at 500–700 m)

(2) a less-pronounced boundary around 1000–1400 m that often aligns with the depth of the permanent thermocline

(3) 1600–2000 m with 1800 m reported as the deeper boundary (bottom) of the permanent thermocline (4 °C isotherm) and an area of change in bottom currents in the north east Atlantic

(4) A general boundary at 2500–3000 m for megafauna reflecting the transition from bathyal to abyssal fauna.

We drew from these patterns where applicable and aligned terminology, but boundaries for this assessment were based on local information. Faunal boundaries are related to factors that vary with depth (e.g. temperature, nutrients, oxygen), not depth itself, and there is a recognition that the depth of boundaries varies within and between regions (Howell 2010).

Similar depth zones were used in classifying biozones in the previous National Spatial Biodiversity Assessment (Lombard *et. al.* 2004) with two related changes inshore and further divisions offshore and some changes in terminology. An updated bathymetric GIS layer (Sink *et* *al.* 2011) based on updated bathymetric data was used for the contour lines in this assessment. These differ slightly from contours used in the previous assessment (Lombard *et. al.* 2004). Depth data were updated using the General Bathymetric Chart of the Oceans (GEBCO) global data set in 2009. GEBCO is a continuous ocean bathymetric model largely generated by combining quality-controlled ship depth soundings, with predicted depths between the sounding points guided by satellite-derived gravity data.

Within the inshore section of the marine environment (500 m inshore of the coastline to the 30 m depth contour), the supratidal, intertidal and half of the shallow photic zone as defined by Lombard *et al.* (2004) were amalgamated into a single broader "coast type" (see detailed explanations under "Terrestrial and benthic-pelagic connectivity" above). Since the seaward boundary of the coast types extended to the -5 m contour, it subdivided the previous "Shallow photic" zone (mean spring low mark to -10 m) described by Lombard *et al.* (2004). It was decided that the "surf zone" component of the shallow photic (or subtidal), with relatively constant light and water motion, rather belonged with the adjacent coast type. Having a small depth zone extending from the -5 to -10 m contour lines would add additional complexity and little added benefit, and thus this portion of the previous "Shallow photic" zone (Lombard *et al.* 2004) was included with the inshore zone (-5 m to -30 m depth contours). The seaward limit of the surf zone was debated, with a recognition that it varies around the coast and even over small distances. The 10 m bathymetric contour was not used because this led to an exaggerated coast type extending more than 15 km out to sea in places. Since the -5 m contour approximates the depth of effective wave action (as mentioned above), it was agreed that this was the preferred boundary.

Offshore, finer depth zonation divisions were introduced on the shelf in some areas based on work undertaken to plan for a network of offshore MPAs (Sink *et al.* 2011) and other depth zonation research (Sink *et al.* 2006, Samaai *et al.* 2010) and the shelf edge was recognised as a distinct depth zone and feature, aligning with international classification efforts (Howell *et al.* 2010). On the west coast and the Agulhas Bank, the continental shelf was classified into inner and outer shelf areas separating at 150 m on the west coast and 100 m on the south coast. This was based on expert workshop discussions as well as published literature (Roel 1987, Roeleveld *et al.* 1992, Smale *et al.* 1993, Yemane *et al.* 2009). The narrow shelf in the Natal and Delagoa bioregions and the lack of evidence for finer scale pattern within shelf communities there, led to single shelf ecozones in these ecoregions (Figure 4).

The shelf edge zone includes the shelf break, a distinct habitat type that warrants explicit consideration in biodiversity assessment and MPA planning because there are documented differences in the composition and abundance of key fish species between these zones e.g. hake and other demersal species (Roel 1987, Shine 2008, Atkinson 2010, Atkinson *et al.* 2011a). Drawing from work undertaken to plan for offshore MPAs in South Africa (Sink *et al.* 2011), the shelf edge was mapped using the shelf break line from Lombard *et al.* (2004) and expert-based assessments of fish biodiversity pattern (Larry Hutchings; Rob Leslie Dave Japp, pers. comm.). In the Southern Benguela, the shelf edge extends from the 350 m depth contour or the shelf break line (whichever is shallowest) to the 500 m depth contour or the shelf break line (whichever is deepest). In the Agulhas, Natal and Delagoa ecoregions, the shelf edge extends from the shelf break line to the 500 m depth contour. However, in a few places the shelf is extremely steep and the 500 m depth contour lies shallower than the shelf break line. In these cases, there is no shelf edge habitat (such as at the southern tip and eastern edge of the Agulhas bank and near Port St Johns). This complexity is the result of a combination of the shelf break being defined by angle rather than depth contour and the shelf break line being less accurate than the depth contours. The shelf break line consequently weaves over both the 350 and 500 m contour lines.

Anderson and Hulley (2000) report that deepsea communities have never been examined in South Africa and there are no data on deepsea zonation patterns. Beyond the shelf edge (also known as the upper slope in some classifications such as Howell 2010), the deepsea is subdivided into three zones, the upper and lower bathyal and the abyss. The upper bathyal extends from the deeper boundary of the shelf edge zone to the 1800 m depth contour, aligning with the third major faunal boundary reported by Howell (2010). Howell (2010) defines an upper (750-1100 m) and mid (1100-1800 m) bathyal zone within the shelf edge to 1800 m zone in the northeast Atlantic, but no evidence for such a further subdivision in South Africa was found. South Africa has very deep water limited expertise and has only isolated samples from bathyal habitats (Anderson and Hulley 2000). There is a reported transition zone between the 1600 and 1800 m depth contours where both upper and lower bathyal fish species are recorded (Eric Anderson, pers. comm.). The lower bathyal in South Africa extends from 1800 m to the 3500 m bathymetric contour. The abyss is defined as the area below 3500 m. These zones remain unchanged for this National Biodiversity Assessment 2011 except in name from the same deepsea units used by Lombard *et al.* (2004), i.e. the upper slope, lower slope and abyss. This terminology was revised to align with global classification efforts (Howell 2010).

2.1.4 Wave exposure, grain size, geology and beach state

Wave exposure, grain size and geology were incorporated at the fourth level of the South Africa's national coastal and marine habitat classification. For beaches, these interacting variables determine beach state. Wave exposure is a key driver of rocky shore biodiversity patterns and ecology (Dayton 1971; McQuaid & Branch 1985; Fuji and Nomura 1990, McQuaid and Lindsay 2007) and is applied in most habitat classifications accounting for rocky shore biodiversity (Connor *et al.* 2004, 2006). In South Africa, the effect of wave exposure on rocky shore biodiversity and ecology is well established (McQuaid and Branch 1984, McQuaid and Branch 1985, Field and Griffiths 1991, Bustamante and Branch 1996a, Bustamante and Branch 1996b, Emanuel *et al.* 1992, Bustamante *et al.* 1997, Sink 2001, Griffiths 2000, McQuaid and Lindsay 2007, Blamey and Branch 2009) and Lombard *et al.* (2004) mapped 33 types of rocky shores (boulder, pebble, mixed and rocky) incorporating four exposure categories; very exposed, exposed, sometimes exposed and sheltered. "Exposed" and "sometimes exposed" were grouped into a single category for the 2011 assessment using only three exposure categories: sheltered, exposed and very exposed. Wave exposure was not included in the classification of mixed coast types in this assessment. A further key determinant of rocky shore and inshore reef biodiversity pattern in South Africa is sand inundation (McQuaid and Dower 1990, Reigl and Branch 1995, Sink 2001, Porter 2009) but national data are not available to facilitate this factor into a national habitat map. Rocky coast types and mixed shores were not further subdivided on the basis of geology because other factors, such as wave action and productivity, have been shown to have a much greater influence on biological community structure.

For sandy shores, the interaction between tidal regime, wave climate (strongly driven by exposure) and grain size gives rise to a continuum of beach morphodynamic states, which in turn is the primary determinant of biodiversity pattern, ecosystem processes and ecosystem services (e.g. Wright and Short 1984; McLachlan *et al.* 1993, Brown *et al.* 2000, Defeo and McLachlan 2005; Short 2006). Since all South African sandy shores are microtidal, tidal regime was not included in the classification. Wave climate and grain size, represented by beach morphodynamic state, were thus the second level in the coastal classification hierarchy. Four beach morphodynamic types were recognised: dissipative; dissipative-intermediate; intermediate; and reflective, that can be determined by beach width (Harris *et al.* 2010, Harris *et al.* 2011a). The inclusion of 16 sandy coast types based on 4 beach morphodynamic states, biogeography and the presence of estuaries represents an advancement from 2004 where only

5 types of sandy intertidal habitats were classified because bioregion was considered the only distinguishing factor among sandy beach types.

In the inshore component of the coastal region and in all offshore components, geology and grain size were incorporated into the habitat classification where possible but wave exposure was not considered further because of a lack of data and evidence that other factors (biogeography, productivity, turbidity, etc) play a bigger role in determining biodiversity patterns in the inshore zone (Anderson 2000, Porter 2009). Note that finer-scale depth patterns may correlate with wave exposure so that some of this variance would be captured in the depth component of the classification. Within consolidated habitat types, reefs, hard grounds, submarine canyons and banks were considered separately but finer geological patterns such as rock type were not incorporated. Howell (2010) reviewed the biological relevance of many surrogates of marine biodiversity pattern and noted that although seabed features and geomorphology are frequently used in habitat classifications, the extent to which these surrogates represent distinct biodiversity is not well understood. They argue that “while we can be certain that some features, e.g. ‘seamounts’ and ‘canyons’ support quite different biological communities as a result of the very different physical environmental conditions existing at these features, we can be less certain about faunal differences between large scale topographic highs”. Submarine canyons and seamounts, and submarine banks were therefore included as distinct features, recognizing that these habitat types are locally very poorly studied. Images of canyon habitats (SANBI marine image database) suggest that these environments support distinct habitat types in South Africa but seamounts have never been sampled within the EEZ. South Africa has only one offshore feature that is classified as a submarine bank, this being Childs Bank off Hondeklipbaai on the west coast. As there is uncertainty regarding the formation of this feature (i.e. either as a sedimentary or an erosional feature) it cannot be classified as a “ “mound” and is therefore best classified as a bank. Childs Bank is described as a rugged limestone feature, bounded at outer edges by precipitous cliffs at least 150 m high (Birch and Rogers (1973).

The effect of geological rock types in defining reef types is poorly understood in South Africa and national data is not available for classifying rock type in the marine environment. Reefs were distinguished from hard grounds as these features were mapped using different data sets (see below). Although hard grounds could include reefs, those ecosystems classified as reefs are known to be consolidated rock habitat of a minimum size of 100 m^2 (i.e. 10 x 10 m) and elevated above the surrounding unconsolidated seabed. Hard grounds include other types of hard substrate which may have no or very little vertical profile such as phosphate cemented sediments or consolidated sands such as beachrock.

In unconsolidated subtidal habitat types, the effect of grain size is an internationally recognised determinant of biodiversity pattern that is often used in classifying habitats (Connor *et al.* 2006, Howell *et al.* 2010). Connor *et al.* (2006) reclassified the Folk sediment classification (Folk 1954) into a more biologically meaningful classification with greater application in terms of seabed mapping. The four unconsolidated sediment classes were; mud and sandy mud, sand and muddy sand, mixed sediments and coarse sediments. This revised classification for the inshore and offshore benthic habitats in South Africa was adopted based on the assertion that not all geological distinctions are appropriate in terms of surrogacy for biodiversity (Leslie *et al.* 2000, Connor *et al.* 2006, Howell 2010) but recognising the need for local research to refine biodiversity surrogates for unconsolidated habitat types in South Africa.

Leslie *et al.* (2000) reported that South Africa has very poor knowledge about soft-sediment, subtidal communities although there have been some studies of fish communities by trawling. Research on benthic infauna (composition, community structure, productivity and recruitment) and the study of ecosystem functioning are priorities of relevance to the management of South Africa’s important demersal fisheries. There has been an increase in research in subtidal unconsolidated sediment communities in South Africa but existing publications are focused on impacts (Atkinson 2010, Atkinson *et al.* 2011b) with results of further biodiversity pattern and ecosystem function studies still to be released. Studies by Louise Lange (University of Cape Town), Natasha Karenyi (Nelson Mandela Metropolitan University) and the African Coelacanth Ecosystem Program will advance our understanding of these habitat types.

Only two types of unconsolidated deepsea sediments were recognised, those with and without Ferro-managanese deposits, but these were considered different in different bioregions. Images from the lower slope and abyss were examined and the Ferro-manganese nodules were considered to represent a distinct feature that provides hard substrate where sessile emergent epifauna attach. Such fauna were not observed in areas without Ferro-manganese deposits. No other data are available to support further biologically meaningful classification in the deep sea.

2.1.5 Biogeography

Most habitat and ecosystem classification schemes recognise the importance of including variation due to biogeographic differences (Connor *et al.* 2004, Connor *et al.* 2006, Spalding *et* *al.* 2007, UNESCO 2009, Howell 2010). Coastal and inshore biogeographic patterns in South Africa have been well studied for some habitat types and groups of taxa (Griffiths 1974, McQuaid and Branch 1984, Hommersand 1986, Thander 1989, Emanuel *et al.* 1992, Engledow *et al.* 1992, Williams 1992, Gibbons *et al.* 1995, Bolton *et al.* 1997, Turpie *et al.* 2000, Awad *et al.* 2002, Bolton *et al.* 2004, Sink *et al.* 2004, Porter 2009) and reflect major differences linked to temperature, nutrients and productivity within South Africa's marine environment. The broad biogeographic classification (Sink *et al.* 2004) developed during South Africa's first National Spatial Biodiversity Assessment was used with some revision that emerged through investigation of offshore biodiversity patterns during work undertaken to support the identification of offshore MPAs (Sink *et al.* 2011). Different biogeographic patterns for different broad ecosystem groups were also accommodated.

The previous NBA recognised 34 biozones that nested within 9 bioregions (5 inshore and 4 offshore) on the basis of published literature and expert opinion (see Sink *et al.* 2004 for details). The terms 'ecoregions' and 'ecozones' replace the similar, but revised 'bioregions' and 'biozones' used in the national marine and coastal habitat classification. Ecozones incorporate finer patterns in depth as in Lombard *et al.* (2004) but also include a less distinct biogeographic break between the previous Namaqua and Southwestern Cape bioregions which has now been deemed to apply only inshore of the 150 m contour line. The change in terminology also helps avoid confusion between the different layers from 2004 and the new ecoregions and ecozones used in 2011.

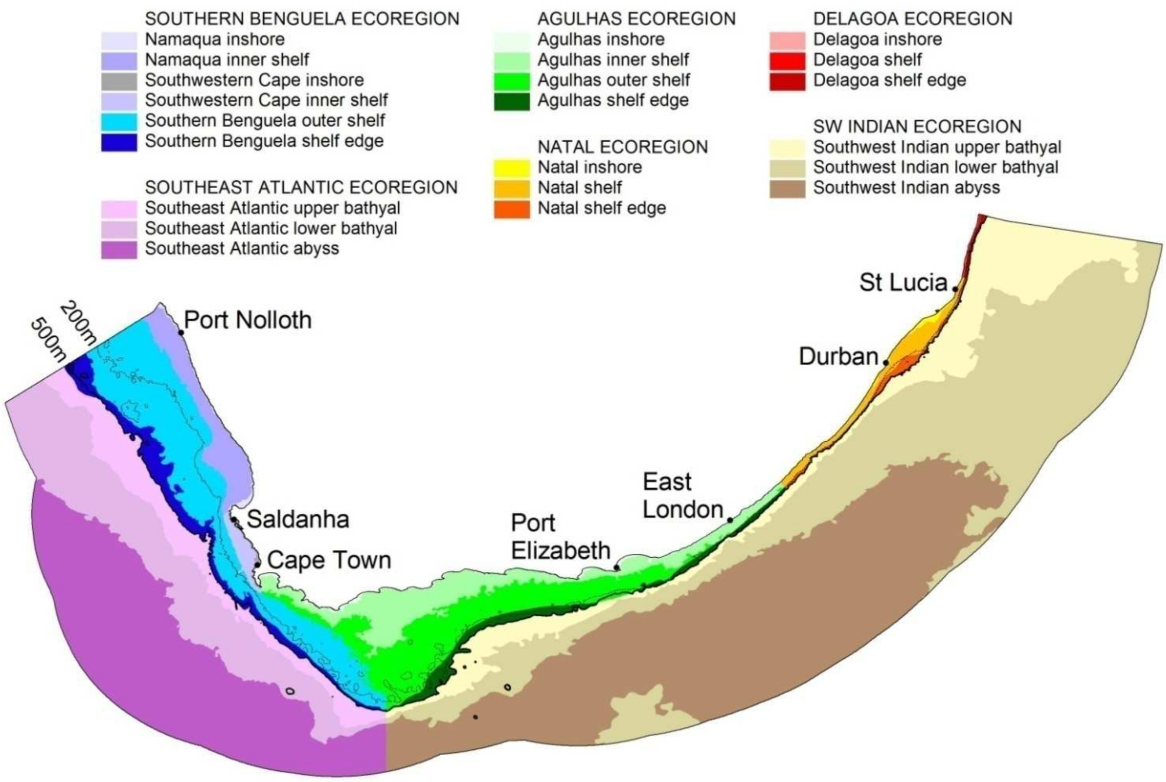


Figure 4: Six marine ecoregions with 22 ecozones incorporating biogeographic and depth divisions in the South African marine environment.

The national classification includes six ecoregions (Figure 4), Benguela, Agulhas, Natal, Delagoa, Southeast Atlantic and Southwest Indian. The Benguela, Agulhas, Natal and Delagoa ecoregions include the coast, continental shelves and shelf edge, whereas the deepsea Atlantic and Southwest Indian ecoregions include the upper and lower bathyal zones and the abyss. In the 2004 National Spatial Biodiversity Assessment (Lombard *et al.* 2004) there were 5 inshore bioregions equivalent to the 4 shelf ecoregions (with the Namaqua and southwestern Cape joined at the broadest level of biogeography). There were 4 offshore bioregions equivalent to the two deepsea ecoregions used in the revised classification. There was no evidence that the biogeographic distinction at Cape Vidal between the Natal and Delagoa shelf ecoregions (former inshore bioregions) extended offshore and therefore the former South-west Indian Offshore bioregion was merged with the former “West Indian Offshore bioregion”. The former “West Indian Offshore bioregion” is only distinguished from the former Indo-Pacific Offshore bioregion” on the basis of depth and therefore only two deepsea ecoregions (former offshore bioregions) were recognised in the habitat classification and the 2011 assessment: the

Southeast Atlantic and the southwest Indian, based on biogeographic affinities reported by Anderson and Hulley (2000). There are 22 finer-scale ecozones incorporating biogeographic and depth patterns (Figure 4) that nest within these ecoregions and each ecozone is considered to have distinct species assemblages that need to be considered in biodiversity assessments and in planning for a representative MPA network.

Experts with experience in different habitat types (such as sandy beaches versus rocky shores) argued for different biogeographic regions for different habitat types necessitating the inclusion of biogeography further down the classification tree (Figure 3). A key difference was the use of only three biogeographic units for sandy coasts based on assertions and recent research by beach ecologists (McLachlan *et al.* 1981, Hockey *et al.* 1983, Harris *et al.* 2010, Harris *et al.* 2011a). For beaches, these authors consider the southwestern Cape and Namaqua bioregions as a single joint unit, called the Southern Benguela. Similarly they did not find any differences in beach fauna between the Natal and Delagoa bioregions (as identified by Lombard *et al.* 2004) and therefore define one Natal-Delagoa biogeographic unit for sandy beaches and sandy coast types north of the Mbashe River. The Agulhas bioregion remains unchanged and was considered an appropriate biogeographic unit for sandy beaches and sandy coast types. For most other broad ecosystem groups in the coastal, offshore shelf and shelf edge environments, the same biogeographic units as Lombard *et al.* (2004) were used although the former biozones had some revision as described under the heading “Depth and slope” above.

Table 1: Biogeographic units used in the finer classification of 14 broad ecosystem groups

Broad Ecosystem Group	**Biogeographic classification**	**References**
Sandy coast	3 Sandy beach biogeographic units • Southern Benguela (includes inshore component of Namaqua & southwestern Cape) • Agulhas • Natal-Delagoa	Day 1969 in Harris *et al.* 2010 McLachlan *et al.* 1981 *(macrofauna);* Hockey *et al.* 1983 *(shore birds);* Turpie *et al.* 2000 *(coastal fish)*; Harris *et al.* 2010 *(macrofauna and phytoplankton)*
Rocky coast	5 inshore ecozones • Namaqua • Southwestern Cape • Agulhas • Natal • Delagoa	Stephenson 1948, McQuaid and Branch 1985, Emanuel *et al.* 1992, Bustamante et al. 1997, Anderson 2000, Griffiths *et al.* 2000, Turpie *et al.* 2000, Lombard *et al.* 2004, Sink *et al.* 2005, Porter 2009.
Mixed shore	5 Shelf ecozones (as for rocky coast)	Sink *et al.* 2004
Island-associated	3 Shelf ecozones • Namaqua • Southwestern Cape • Agulhas	Williams *et al.* 2000, Expertise from DEA
Lagoon	1 type - Southwestern Cape	
Rocky inshore	5 inshore ecozones (as for rocky coast)	Field and Griffiths 1991, Anderson 2000, Lombard *et al.* 2004, McClanahan *et al.* 2007, Porter 2009
Sandy inshore	5 inshore ecozones (as for rocky coast)	Field and Griffiths 1991, Sink *et al.* 2004
Unconsolidated shelf	Shelf ecozones • Namaqua inner shelf • Southwestern Cape inner shelf • Southern Benguela outer shelf • Agulhas inner & outer shelf • Natal shelf • Delagoa shelf	Roel 1987, Sink *et al.* 2011, Atkinson *et al.* 2011a, Louise Lange unpublished data Natasha Karenyi unpublished data
Rocky shelf	Shelf ecozones (as for unconsolidated coast)	Sink *et al.* 2011, Porter 2009, Lawrence 2005
Unconsolidated shelf edge	Shelf edge ecozones • Southern Benguela shelf edge • Agulhas shelf edge • Natal shelf edge • Delagoa shelf edge	Roel 1987, Sink *et al.* 2011, Atkinson *et al.* 2011a, Louise Lange unpublished data Natasha Karenyi unpublished data
Rocky shelf edge	4 Shelf ecozones (as for unconsolidated shelf edge)	Sink *et al.* 2011
Deepsea sediment	2 Deepsea ecoregions • Southeast Atlantic • Southwestern Indian	Anderson and Hulley 2000 and references therein, Sink *et al.* 2004, Sink *et al.* 2011
Seamount	2 Deepsea ecoregions (as for deepsea sediment)	*Sink et al. 2011*
Offshore pelagic	7 "biozones", nested within 3 broad "bioregions"	Gibbons *et al.* 2009, Lagabrielle 2009, Sink et al. 2011

2.1.6 Offshore pelagic classification

Patterns in offshore pelagic biodiversity in South Africa are poorly understood although there is a substantial body of knowledge focused on oceanography, ecosystem structure and science to support the management of pelagic fisheries resources (reviewed by Hutchings *et al.* 2000), the classification of the more dynamic pelagic environment into meaningful units for biodiversity has only recently been considered for the first time. A pelagic bioregionalisation exercise was undertaken in 2009 to support potential MPA planning and assessment of pelagic biodiversity and resources (Lagabrielle 2009). The bioregionalisation exercise covered the South African offshore environment, from the 30 m bathymetric contour to beyond the 200 nautical mile limit of the Exclusive Economic Zone (EEZ). Classification was based on sea surface temperature, net primary productivity, chlorophyll-a, depth, turbidity, the frequency of eddies and the distribution of temperature and chlorophyll fronts. Three pelagic bioregions, 7 pelagic biozones and 16 pelagic “habitat types” were mapped hierarchically by cluster analysis for inclusion in the offshore MPA network (Figure 6). The bioregions separate primarily on the basis of productivity and sea surface temperature whereas pelagic biozones separate on the basis of the mean, maximum and standard deviation (variability) in productivity, sea surface temperature and chlorophyll. Pelagic habitat types were defined on the basis of these same variables as well as the distribution of cyclonic and anti-cyclonic eddies, sea surface temperature fronts and chlorophyll fronts. It has been advised that this classification should only be considered relevant to the upper mixed layer.

2.1.7 Limitations of the habitat classification

Key areas for improvement of the classification of marine and coastal habitat types in South Africa relate to the need for systematic biodiversity surveys, research to improve our understanding of the drivers of biodiversity patterns and the delimitation of ecologically-determined boundaries for habitat mapping. In addition, the acquisition of national data sets for key variables will need to be prioritised for new variables that are incorporated into habitat classification to support further habitat mapping. In pelagic habitats, patterns in pelagic biodiversity are poorly known and it is a challenge to classify the three dimensional pelagic environment. The classification of islands and associated habitats associated needs to be revisited.

2.2 Coastal and benthic offshore habitat mapping

2.2.1 Coast type mapping

Classification of the coast, based on substrate stability, wave exposure, grain size, geology and biogeography resulted in 37 coast types. These were initially mapped as a polyline shapefile off detailed satellite imagery (Google Earth and SPOT5) (Harris *et al.* 2010). The Harris *et al.* (2010) coastline was used in this assessment and was considered a more appropriate coastline to estimate the coastline length than that used by Lombard *et al*. (2004) because the latter overestimates the coastline length by including typology for rocky sections of coast within the line. The polyline was expanded into broader segments of “coast types” incorporating the area between the -5 m depth contour offshore (defining the coastal seaward boundary) and 500 m inland of the high water mark (defining the coastal landward boundary). Coast type was assigned to each segment according to the closest coastline type using a distance-based least-cost allocation method, similar to using Thiessens Polygons. This polygon of the coast was bisected by the coastline layer, giving a landward and a seaward unit for each of the coastal segments. Some pressure data layers were only applied to one segment although the ecosystem threat and protection assessment results were reported for entire coastal segments. For rocky coast types, exposure data from Lombard *et al.* (2004) were manually coded to the appropriate coastal segments by expert judgement. Sandy beaches were mapped according to beach morphodynamic types using a classification and mapping tool that was statistically trained, verified and applied in the second phase of the National Beach Classification and Mapping project (Harris *et al.* 2010, see Harris *et al.* 2011a for detailed methodology). The model selected intertidal beach width as the single significant predictor of beach morphodynamic type, distinguishing between four states: dissipative, dissipative-intermediate, intermediate and reflective. Once applied with additional considerations of surf zone type, the predictive accuracy of the classification tool was 93% (Harris *et al.* 2011a). Numerous other similar habitat types were combined within these four because the Harris *et al.* (2010) classification scheme had too many categories for the purposes of this assessment.

2.2.2 Island-associated habitat and Lagoon mapping

Information on island size and types, and number of land-breeding predators (provided by the Department of Environmental Affairs) was used to classify “minor” versus “major” islands. Islands were mapped using Google Earth imagery and topographic sheets. Major islands were buffered by 20 km to define a zone of "island influence", while the minor islands were buffered by 10 km. The islands together with the zone of “island influence” are termed the island-associated habitat. Lagoon habitat was identified using data from Lombard *et al.* (2004). Islands within Langebaan lagoon were not buffered and did not include any zone of “island influence” (see 2.2.5 Integrated habitat map).

2.2.3 Inshore and offshore benthic habitat mapping

Inshore and offshore benthic habitat types were mapped using existing data sets for wave exposure, geological features and grain size. For unconsolidated sediments in the inshore and offshore, the texture map (Marine Geoscience 1986) that was digitised during the 2004 assessment was used and some of the sediment types merged to result in a less complex result. The following texture types were grouped in accordance with the classification by Connor *et al.* 2006;

- Sand and muddy sand were classed as sand
- Mud and sandy mud were classed as mud
- Gravelly mud and mud sand gravel were classed as mixed
- Gravel and sandy gravel were classed as gravel

The texture map does not extend beyond the shelf edge for most of South Africa and the digitised geological map (Dingle *et al.* 1987, Lombard *et al.* 2004) was used to support the mapping of deepsea sediments.

Reef data were acquired from SANBI’s Reef Atlas Project (Majiedt and Sink 2011), a dedicated project that aims to address a research priority that emerged from the 2004 assessment (Lombard *et al.* 2004, Driver *et al.* 2005) i.e. the classification and mapping of reefs. The GIS layers for hard grounds, seamounts, submarine banks (Child’s Bank) and submarine canyons as developed by SANBI’s Offshore MPA project team (Sink *et al.* 2011) were used for these distinct habitat types. Hard grounds were developed from DAFF’s untrawlable grounds database that shows which 5 minute survey grids are considered untrawlable due to the presence of reef, other types of hard substrate or areas of strong current. These areas are demarcated as places where research trawling should not take place due to the high risk of gear damage and loss, and unsuccessful sampling during demersal research trawl surveys. Areas of strong currents were removed from this GIS layer with only the known areas of hard ground included (Rob Leslie, pers. comm.).

2.2.4 Offshore pelagic habitat mapping

The “habitats” defined in the pelagic bioregionalisation exercise (Lagabrielle 2009) were used to map 16 pelagic “habitat types” in South Africa. Some minor adjustments were made to this GIS layer to align it with the -30 m edge used in the current assessment and to transfer the island surrounds to the coastal category outlined above. Although island-associated habitat types were included in the coastal component of the national classification, their relevance to the pelagic components led us to include the results for the island-associated assessment results on the pelagic map, in addition to the coastal and offshore benthic maps.

2.2.5 Integrated habitat map

A primary requirement for a spatial assessment of ecosystem threat status and protection levels is an integrated habitat map. Although the National Beach Classification and Mapping project was recently completed (Harris *et al.* 2010), and the Offshore Marine Protected Area project (Sink et al. 2011) collected new data and significantly refined other data collated during the 2004 National Spatial Biodiversity Assessment (Lombard *et al.* 2004), no integrated reasonably fine-scale habitat map existed for the entire South African marine and coastal territory. GIS map integration for the coastal, inshore, island-associated and lagoon areas was undertaken by applying a set of rules: Coastal and lagoon habitat types overrode all types except island-associated habitat types. Where islands were located close to mainland areas, the intervening habitat was assigned to the closer type, with the division between types occurring half way between the island and the mainland. Where islands were located in lagoons, only the terrestrial portions of the island was classified as island, with the areas below the high tide mark being classified as lagoon. In the inshore areas, reef polygons took precedence over buffered reef points which took precedence over hard grounds, which in turn took precedence over all unconsolidated sediments. Map integration for the benthic offshore areas was undertaken by applying similar rules to the inshore areas: features such as seamounts, submarine banks and canyons overrode reefs, which in turn took precedence over hard grounds, which in turn took precedence over all unconsolidated sediments. The pelagic habitat map produced by Lagabrielle (2009) did not require integration.

2.2.6 Limitations of the habitat maps

Recognised limitations of the coastal and offshore benthic habitat maps include: the deliberate amalgamation of several finer classifications (such as intertidal and subtidal zones); the inclusion of distinct habitats within broader coast types (such as the inclusion of kelp forests within rocky coast types, and dune fields in sandy coast types); the deliberate grouping of many mixed shore habitat types; the inability to map some recognised fine-scale habitat types due to a lack of data (such as fluvial fans, other deepsea sediment types); and the poor quality of habitat mapping for several habitat types. Comprehensive finer-scale systematic mapping of offshore unconsolidated sediments (particularly muds and gravels), reefs and hard grounds, submarine canyons and banks, seamounts and other features would result in a significant improvement in the resolution of this dataset. The current habitat map should be considered as a work in progress. SANBI's Reef Atlas Project (Majiedt and Sink 2011) has already advanced the reef habitat map and new work in the Natal Bight (African Coelacanth Ecosystem Program) will contribute to improved habitat maps for that area in the future.

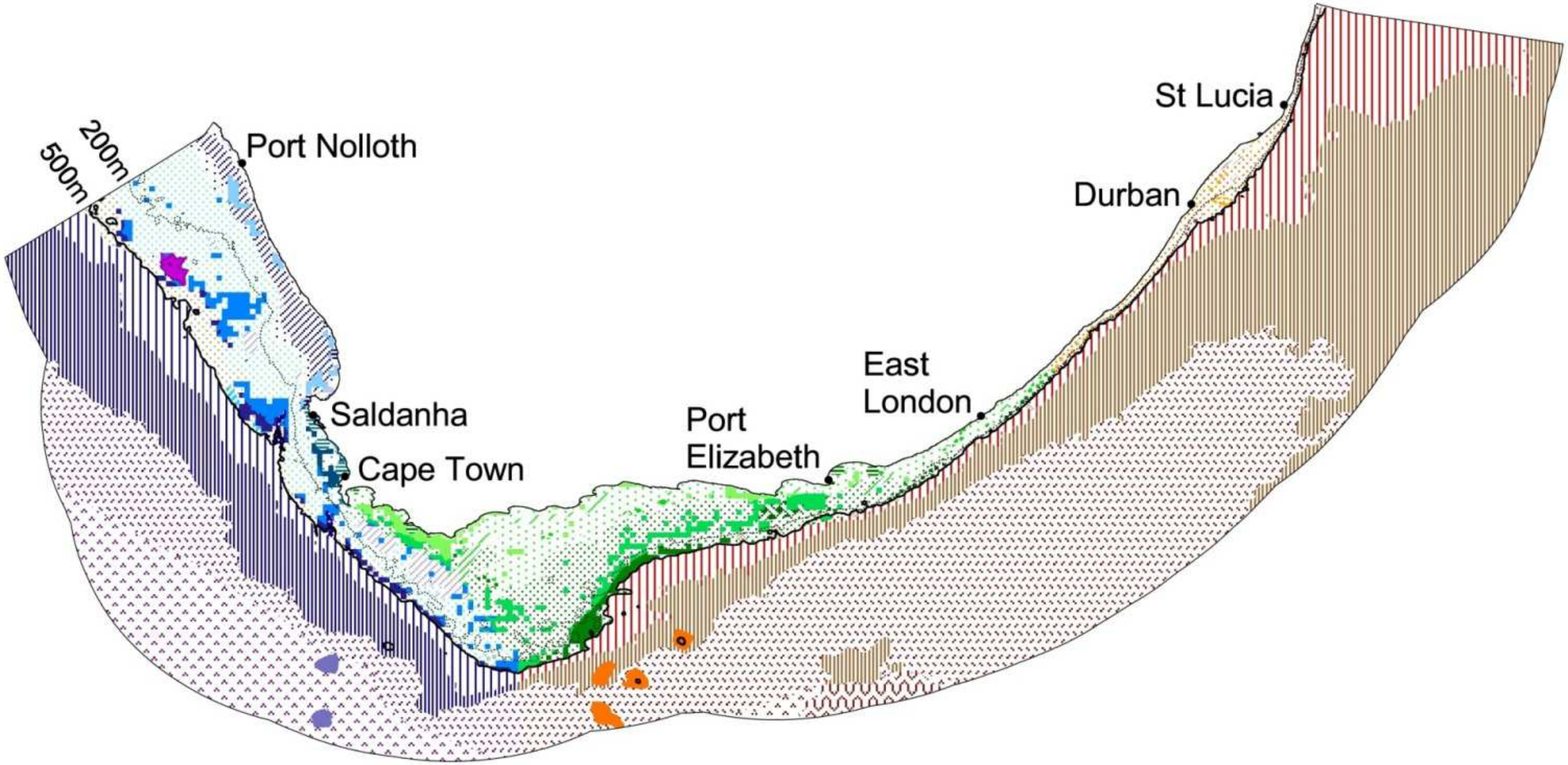


Figure 5: Coastal and offshore benthic habitat types in the South Africa (see legend on opposite page). Consolidated (rocky) habitat types are indicated by solid colour whereas unconsolidated habitat types are patterned with consistent patterns for sand, mud, gravel and mixed sediments. Colours indicate biogeographic affinities.

- Agulhas Boulder Shore
- Agulhas Canyon
- Agulhas Dissipative Sandy Coast
- Agulhas Dissipative-Intermediate Sandy Coast
- Agulhas Estuarine Shore
- Agulhas Exposed Rocky Coast
- Agulhas Gravel Inner Shelf
- Agulhas Gravel Outer Shelf
- Agulhas Gravel Shelf Edge
- Agulhas Hard Inner Shelf
- Agulhas Hard Outer Shelf
- Agulhas Hard Shelf Edge
- Agulhas Inner Shelf Reef
- Agulhas Inshore Gravel
- Agulhas Inshore Hard Grounds
- Agulhas Inshore Reef
- Agulhas Intermediate Sandy Coast
- Agulhas Island
- Agulhas Mixed Sediment Inner Shelf
- Agulhas Mixed Sediment Outer Shelf
- Agulhas Mixed Shore
- Agulhas Muddy Inner Shelf
- Agulhas Muddy Outer Shelf
- Agulhas Muddy Shelf Edge
- Agulhas Outer Shelf Reef
- Agulhas Reflective Sandy Coast
- Agulhas Sandy Inner Shelf
- Agulhas Sandy Inshore
- Agulhas Sandy Outer Shelf
- Agulhas Sandy Shelf Edge
- Agulhas Shelf Edge Reef
- Agulhas Sheltered Rocky Coast
- Agulhas Very Exposed Rocky Coast

- Delagoa Sandy Shelf Edge
- Delagoa Canyon
- Delagoa Inshore Reef
- Delagoa Mixed Shore
- Delagoa Sandy Inshore
- Delagoa Sandy Shelf
- Delagoa Shelf Edge Reef
- Delagoa Shelf Reef
- Delagoa Very Exposed Rocky Coast

- Harbour

- Namaqua Boulder Shore
- Namaqua Exposed Rocky Coast
- Namaqua Hard Inner Shelf
- Namaqua Inner Shelf Reef
- Namaqua Inshore Hard Grounds
- Namaqua Inshore Reef
- Namaqua Island
- Namaqua Mixed Shore
- Namaqua Muddy Inner Shelf
- Namaqua Muddy Inshore
- Namaqua Sandy Inner Shelf
- Namaqua Sandy Inshore
- Namaqua Sheltered Rocky Coast
- Namaqua Very Exposed Rocky Coast

- Natal Boulder Shore
- Natal Canyon
- Natal Estuarine Shore
- Natal Exposed Rocky Coast
- Natal Gravel Shelf
- Natal Gravel Shelf Edge
- Natal Inshore Gravel
- Natal Inshore Reef
- Natal Mixed Sediment Shelf
- Natal Mixed Sediment Shelf Edge
- Natal Mixed Shore
- Natal Muddy Inshore
- Natal Muddy Shelf
- Natal Muddy Shelf Edge
- Natal Sandy Inshore
- Natal Sandy Shelf
- Natal Sandy Shelf Edge
- Natal Shelf Edge Reef
- Natal Shelf Reef
- Natal Very Exposed Rocky Coast

- Natal-Delagoa Dissipative Sandy Coast
- Natal-Delagoa Dissipative-Intermediate Sandy Coast
- Natal-Delagoa Estuarine Shore
- Natal-Delagoa Intermediate Sandy Coast
- Natal-Delagoa Reflective Sandy Coast

- South Atlantic Abyss
- South Atlantic Abyss With Ferro-Manganese Deposits
- South Atlantic Lower Bathyal
- South Atlantic Upper Bathyal
- Southeast Atlantic Seamounts

- Southern Benguela Canyon
- Southern Benguela Carbonate Mound
- Southern Benguela Dissipative Sandy Coast
- Southern Benguela Dissipative-Intermediate Sandy Coast
- Southern Benguela Estuarine Shore
- Southern Benguela Gravel Outer Shelf
- Southern Benguela Gravel Shelf Edge
- Southern Benguela Hard Outer Shelf
- Southern Benguela Hard Shelf Edge
- Southern Benguela Intermediate Sandy Coast
- Southern Benguela Muddy Outer Shelf
- Southern Benguela Muddy Shelf Edge
- Southern Benguela Outer Shelf Reef
- Southern Benguela Reflective Sandy Coast
- Southern Benguela Sandy Outer Shelf
- Southern Benguela Sandy Shelf Edge

- Southwest Indian Abyss
- Southwest Indian Abyss With Ferro-Manganese Deposits
- Southwest Indian Lower Bathyal
- Southwest Indian Lower Bathyal With Ferro-Manganese Deposits
- Southwest Indian Seamounts
- Southwest Indian Upper Bathyal

- Southwestern Cape Boulder Shore
- Southwestern Cape Exposed Rocky Coast
- Southwestern Cape Hard Inner Shelf
- Southwestern Cape Inshore Hard Grounds
- Southwestern Cape Inshore Reef
- Southwestern Cape Island
- Southwestern Cape Lagoon
- Southwestern Cape Mixed Shore
- Southwestern Cape Sandy Inner Shelf
- Southwestern Cape Sandy Inshore
- Southwestern Cape Sheltered Rocky Coast
- Southwestern Cape Very Exposed Rocky Coast

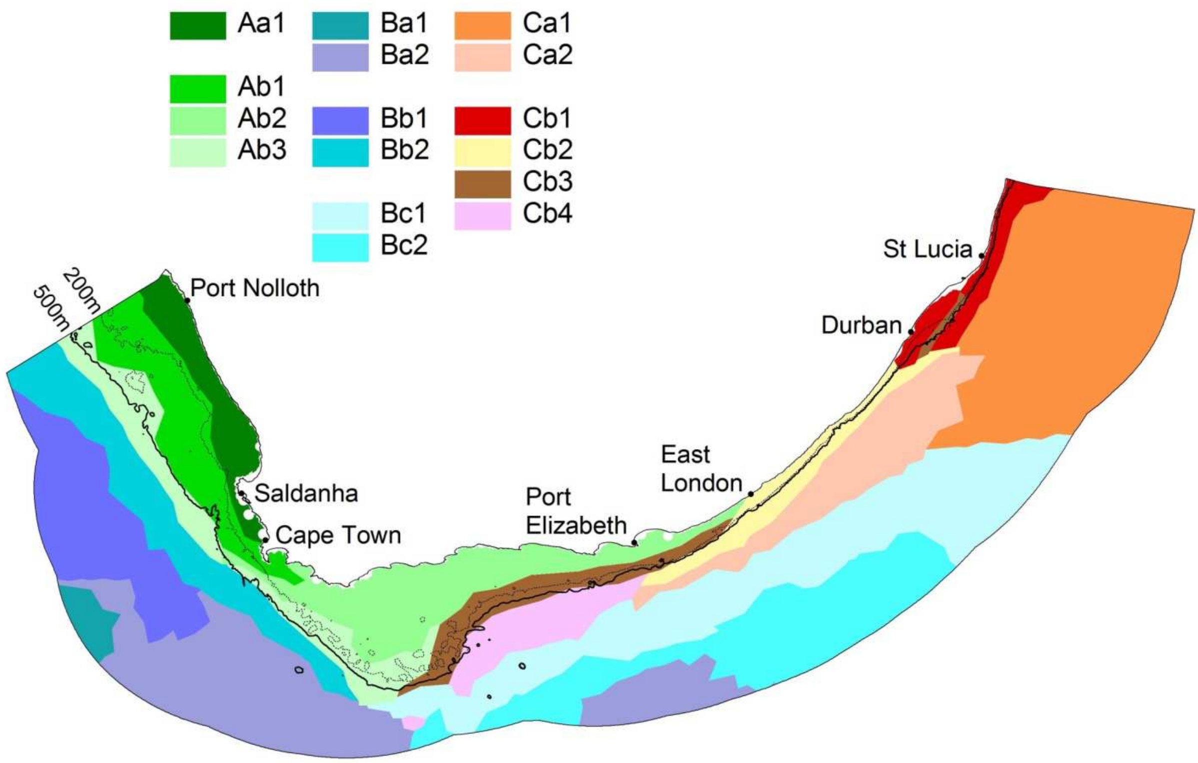


Figure 6: Pelagic habitat types nested within pelagic bioregions and biozones.

2.3 Overview of habitat types

2.3.1 Coast types

Classification of coast types, based on substrate; geology, grain size and wave exposure, and biogeography resulted in 37 coast types: 16 sandy types; 16 rocky types; and 5 types of mixed shores. The extent of different coast types reflects the dominance of sandy beaches and mixed shores. Of South Africa's approximately 3100 km coastline, 38% is sandy, 32% comprises mixed shores and 29% is rocky (see Harris *et al.* 2011a for details). The remaining fraction is made up of estuary and river mouths, and harbours. The distribution of coast types along the South African shoreline can be partly explained by geography, likely reflecting large-scale patterns in coastal geology (as seen in Northern Ireland by Jackson & Cooper 2005). The west coast is very heterogeneous with stark contrasts between rocky cliffs, long sandy beaches, extremely sheltered deep bays and highly exposed open coasts (Harris *et al.* 2010). While the west coast has representatives of the full spectrum of beach morphodynamic types, the majority of the country's long dissipative beaches are found in this region. The South African south coast is largely a series of log spiral bays (such as Mossel Bay, Plettenberg Bay and Algoa Bay) interspersed with cliffs or long stretches of rocky coastline (like the Tsitsikamma). Dissipative-intermediate beaches dominate the sandy coast type in Agulhas bioregion almost exclusively. The Alexandria dune field is a unique feature of the south coast and represents one of the largest active coastal dune fields in the world (McLachlan *et al.* 1982). Cliffs, rocky shores and intermediate estuarine pocket beaches dominate the transition zone through the Transkei. In KwaZulu-Natal, rocky shores and reflective or intermediate sandy beaches dominate the south whereas beaches become more intermediate and dissipative-intermediate in the north.

Overall, most South African beaches are intermediate (approximately 51% dissipative intermediate and 30% intermediate) with only about 12% and 7% classified as dissipative and reflective respectively (Harris *et al.* 2011a). Many components of sandy beach and surf zone biodiversity and ecology are well-researched in South Africa (see reviews by Brown *et al.* 2000 and Harris *et al.* 2010), but microbes, zooplankton and meiofauna require greater attention. Additional research is required to investigate and quantify ecosystem services, and develop our understanding of key ecological processes, such as connectivity among coastal ecosystems, and sandy beach population connectivity (Harris *et al.* 2010). New research on population connectivity is currently underway (Karien Bezuidenhout and Ronel Nel, Nelson Mandela Metropolitan University).

Table 2: Key references for different broad ecosystem groups in South Africa. These references were used to update information used in this assessment in classifying habitat types and weighting the impact of different pressures in different habitat groups in the spatial assessment. The table includes references used in the 2000 Status of Marine Biodiversity report (Durham and Pauw 2000) but is updated to include additional references from the last 11 years.

Broad Ecosystem Group	Key Literature
Sandy coast (including sandy beaches and dunes)	Day 1969, Wright and Short 1984, Tinley 1985, McLachlan *et al.* 1981, Hockey *et al.* 1983, Brown and McLachlan 1990, Fairweather 1990, Brown and Harris 1991, McLachlan 1991 , McLachlan *et al.* 1994, McLachlan 1996, Moffett *et al.* 1996, Parkins and Branch 1997, Clark *et al.* 1998, Brown *et al.* 2000, Schoeman 2000, Daniel 2001, Mills *et al.* 2001, Thomas *et al.* 2001, Brown and McLachlan 2002, Nel and Pulfrich 2002, Nel *et al.* 2003, Pulfrich *et al.* 2003a, Celliers *et al.* 2004, Nel *et al.* 2004, Pulfrich 2004, Jackson and Cooper 2005, McLachlan 2005, Peterson *et al.* 2006, Pulfrich *et al.* 2007, Rosenzweig *et al.* 2007, Schlacher *et al.* 2007, Dugan *et al.* 2008, Fish *et al.* 2008, Harris 2008, Richardson and Poloczanska 2008, Schleupner 2008, Brierley and Kingsford 2009, Defeo *et al.* 2009, Karenyi 2009, Dugan and Hubbard 2010, Harris *et al.* 2010, Lucrezi *et al.* 2010, Harris *et al.* 2010
Rocky coast and mixed shore	Stephenson 1948, Dayton 1971, Stephenson and Stephenson 1972, Bally *et al.* 1984, McQuaid and Branch 1984, McQuaid and Branch 1985, McQuaid and Dower 1990, Field and Griffiths 1991, Emanuel *et al.* 1992, Bustamante *et al.* 1995, Bustamante and Branch 1996a, Bustamante and Branch 1996b, Bustamante *et al.* 1997, Griffiths and Branch 1997, Anderson 2000, Griffiths *et al.* 2000, McQuaid and Phillips 2000, McQuaid *et al.* 2000, Lawrie and McQuaid 2001, Sink 2001, Branch and Odendaal 2003, Erlandsson *et al.* 2005, Erlandsson and McQuaid 2004, McQuaid and Lawrie 2005, McQuaid and Lindsay 2005, Robinson *et al.* 2005, Sink *et al.* 2005, Steffani and Branch 2005, Hill *et al.* 2006, McQuaid and Lindsay 2007, Porri *et al.* 2007, Reaugh *et al.* 2007, Robinson *et al.* 2007, Branch *et al.* 2010, Hill *et al.* 2008, Laird and Griffiths 2008, Blamey and Branch 2009, Branch *et al.* 2009, Pelc *et al.* 2009, Porter 2009, Branch *et al.* 2010, Cole and McQuaid 2010, McQuaid and Millar 2010, Plass-Johnsson *et al.* 2010, Reaugh-Flower *et al.* 2010, 2011, Jackson and McIlvenny 2011, Pfaff *et al.* 2011
Island-associated	Hutchinson 1950, Brooke and Crowe 1982, Bosman and Hockey 1986, Brooke and Prins 1986, Cooper and Brooke 1986, Barkai and Branch 1988, Berruti *et al.* 1989, Payne *et al.* 1995, Hanel and Chown 1999, Williams *et al.* 2000, Kemper *et al.* 2007
Lagoon	Day 1959, Henry and Mostert 1977, Grindley 1977, Puttick 1977, Shannon & Stander 1977, Christie 1981, Day 1981, Branch and. Pringle 1987, Allanson and Baird 1999, de Villiers *et al.* 1999, Siebert and Branch 2005 a, Siebert and Branch 2005b, Angel *et al.* 2006, Siebert and Branch 2006, Siebert and Branch 2007, Pillay *et al.* 2009a,b, 2010, Whitfield 2010.
unconsolidated inshore	Field and Griffiths 1991, Leslie *et al*. 2000, Turpie *et al.* 2000, Connor *et al*. 2006, Penney and Pulfrich 2004, Steffani and Pulfrich 2007
Rocky inshore	Berry *et al.* 1979, Field *et al.* 1980, Newell *et al.* 1982, Field and Griffiths 1991, Riegl *et al.* 1995, Bolton and Anderson 1997, Schleyer *et al.* 2003a, Schleyer *et al.* 2003b, Glassom *et al.* 2006, Mann *et al.* 2006, Schleyer *et*

Broad Ecosystem Group	Key Literature
	al. 2006, Celliers *et al.* 2007, McClanahan *et al.* 2007, Celliers and Schleyer 2008, Schleyer *et al.* 2008, Götz *et al.* 2009a, Götz *et al.* 2009b, Porter 2009, Ruiz Sebastián et al. 2009.
Unconsolidated shelf, unconsolidated shelf edge and deepsea sediment	Dayton and Hessler 1972, Tyler 1980, Silver and Alldredge 1981, Kensley 1983, Kensley 1984, Dingle *et al.* 1987, Macpherson and Roel 1987, Payne *et al.* 1987, Roel 1987, Alongi 1990, Haedrich and Merrett 1990, Williams 1990, Badenhorst and Smale 1991, Gage and Tyler 1991, Meyer and Smale 1991a, Meyer and Smale 1991b, Rogers and Bremner 1991, Smale and Badenhorst 1991, Watling 1991, Wilson and Brown 1991, Grassle and Maciolek 1992, Haedrich and Merrett 1992, Smale 1993, Smale *et al.* 1993, Hall 1994, Iwamoto and Anderson 1994, Le Clus *et al.* 1994, Le Clus and Roberts 1995, Le Clus *et al.* 1996, Bailey and Rogers 1997, Anderson & Hulley 2000, Leslie *et al*. 2000, Wilkinson & Japp 2005c, Connor *et al*. 2006, Penney *et al.* 2008, Atkinson 2010, Howell *et al.* 2010, Sink *et al*. 2010, Atkinson *et al.* 2011a, Atkinson *et al.* 2011b.
Rocky shelf, rocky shelf edge and seamount	Rowe 1971, Millard 1978, Hayward and Cook 1979, Birch & Rogers 1973, Dingle *et al.* 1987, Rogers 1994, Rowden *et al.* 2005, Sink *et al*. 2005, Heemstra *et al.* 2006, Sink *et al.* 2006, Sink and Samaai 2009, Atkinson 2010, Samaai *et al.* 2010, Sink et al. 2011.
Offshore pelagic	Bogdanov 1965, Grindley and Penrith 1965, Ryther *et al.* 1966, De Decker 1973, Garrison 1976, Krefft 1978, Wishner 1980, Hulley 1981, Robison and Bailey 1981, McGinnis 1982, Stockton and De Laca 1982, De Decker 1984, Rubies 1985, Cohen 1986, Hulley 1986, Smith and Heemstra 1986, Hulley and Prosch 1987, Payne *et al.* 1987, Arnaud and Child 1988, Hulley 1989, Hulley and Lutjeharms 1989, Wakefield and Smith 1990, Hallegraeff and Bolch 1992, Hulley 1992, Rowe and Pariente 1992, Jarre-Teichmann *et al.* 1998, Ruiz Sebastián and O'Ryan 2001, Botes and Awad 2004, Doblin *et al.* 2004, Drake *et al.* 2005, Gibbons *et al.* 2009, Lagabrielle 2009.

Sandy coast managers generally have a poor understanding of the processes that maintain sandy shores and therefore the management issues that affect sandy coasts (La Cock and Burkinshaw 1985, Brown *et al.* 2000). Consequently, there is scope for further work to communicate the value of sandy shores, their vulnerability, the pressures on and risks to these important ecosystems, and the solutions for effective management of the coastal zone.

South Africa has a relatively exposed coastline and most rocky sections of coast are exposed. The rocky coast type of greatest extent is Agulhas Exposed Rocky Coast, followed by Namaqua, Natal and Southwestern Cape Exposed Rocky Coast. Rocky coast types of very limited extent include Delagoa Very Exposed Rocky Coast, Natal and Namaqua Boulder Shores, Southwestern Cape Sheltered Rocky Coast and Southwestern Cape Very Exposed Rocky Coast.

Rocky shores in South Africa are relatively well studied (Stephenson and Stephenson 1972, McQuaid and Branch 1984, McQuaid and Branch 1985, Field and Griffiths 1991, Emanuel *et al.* 1992, Bustamante *et al.* 1995, Bustamante *et al.* 1997, Griffiths *et al.* 2000, Griffiths and Branch 1997, Branch *et al.* 2008). Many of the information gaps identified by Griffiths *et al.* (2000) have received research attention and there are improvements in our understanding of larval supply and recruitment dynamics (McQuaid and Phillips 2000, Lawrie and McQuaid 2001, Erlandsson and McQuaid 2004, McQuaid and Lawrie 2005, McQuaid and Lindsay 2007, Porri *et al.* 2007, Reaugh *et al.* 2007, McQuaid and Millar 2010, Reaugh-Flower *et al.* 2010, 2011, Pfaff *et al.* 2011), abiotic and biotic determinants (Sink 2001, McQuaid *et al.* 2000, McQuaid and Lindsay 2000, McQuaid and Lindsay 2005, Erlandsson *et al.* 2005, Blamey and Branch 2009, Cole and McQuaid 2010, Plass-Johnsson *et al.* 2010), energy flow (Hill *et al.* 2006, Hill *et al.* 2008, Porter 2009) and the effects of exploitation (Sink 2001, Branch and Odendaal 2003, Pelc *et al.* 2009). The effect of alien and invasive alien species on rocky shores is also better understood (Branch and Steffani 2004, Robinson *et al.* 2005, Steffani and Branch 2005, Robinson *et al.* 2007, Laird and Griffiths 2008, Branch *et al.* 2009, Branch *et al.* 2010). Long term experiments and co-ordinated monitoring over large spatial scales remain a challenge although several studies have been conducted at multiple sites and improved the understanding of rocky shore ecology over large spatial scales (Pfaff *et al.* 2011, Reaugh-Flower *et al.* 2011).

2.3.2 Inshore habitat types

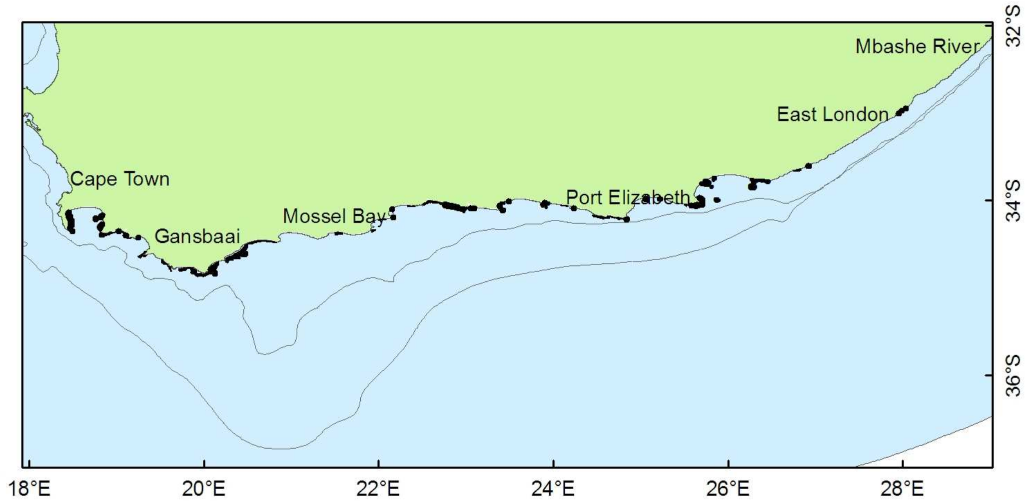
Inshore ecosystems include those ranging from the subtidal coast type boundary (i.e. the -5 m bathymetric contour) to the offshore boundary (i.e. the -30 m bathymetric contour) and were considered as a single coupled benthic and pelagic unit. Inshore habitat types were subdivided according to substrate and geology as well as 5 shelf ecoregions. Unconsolidated inshore ecosystems include sandy, gravel and muddy habitat types whereas inshore reefs and hard grounds constitute the two main types of inshore rocky habitat types. Natal Inshore Gravel is the unconsolidated sediment habitat of smallest extent and Agulhas Inshore Gravel and Natal Muddy Inshore are also rare habitat types (Table 14). Namaqua Muddy Inshore is of the muddy habitat type of greatest extent but inshore sandy habitat types are more prevalent with greatest extent in the Agulhas and Natal ecoregions. Shallow unconsolidated sediment habitat types are poorly studied in South Africa (Leslie *et al.* 2000).

Rocky or consolidated inshore ecosystems were distinguished from unconsolidated ecosystems with 8 rocky and 9 unconsolidated habitat types. Namaqua Inshore Reef is the rocky inshore habitat of smallest extent although this may be due to a lack of reef data in this region. Agulhas Inshore Hard Grounds have the greatest extent. Anderson (2000) reviewed the status of knowledge of subtidal hard substratum in South Africa and concluded that “we know so little about rocky reefs on the south east coasts that it is not possible to identify gaps in our knowledge”. Delagoa Shelf Reef is the habitat type with the most biodiversity information (Riegl *et al.* 1995, Schleyer *et al.* 2003a, Schleyer *et al.* 2003b, Glassom *et al.* 2006, Celliers and Schleyer 2008) but information about reefs and hard grounds from other areas is more limited. Mann *et al.* (2006) and Celliers *et al.* (2007) advanced knowledge of reef ecosystems in the Pondoland area and Götz *et al.* (2009a, b) published information about reef communities on the south coast. Porter (2009) studied the biodiversity and ecology of shallow subtidal reefs in KwaZulu-Natal.

SANBI’s Reef Atlas Project recently compiled descriptions of South Africa’s reef types (Box 1).

Box 1: Description of Agulhas Inshore Reef and Hard Grounds from SANBI's Reef Atlas Project (Majiedt and Sink 2011). Such habitat descriptions need to be developed for all marine and coastal habitat types.

Reef type	**Agulhas Inshore Reef (Critically endangered, Moderately protected) and Agulhas Inshore Hard Grounds (Vulnerable, Moderately protected)**
Distribution:	These reefs and hard grounds extend from the Mbashe River to Cape Point. Examples include the East London Reefs (such Wagon Wheels, Nahoon Bay, Three Sisters), Bell Buoy, Riy Banks and Thunderbolt reefs in Port Elizabeth, the beautiful Tsitsikamma reefs, reefs such as Die Oog (near Gericke's Point) and Roman Rock, A Frame and Pyramid Rock in False Bay.
Depth:	5 m – 30 m
Environmental Parameters:	The Agulhas ecoregion is oceanographically complex, being subjected to warm water intrusions from the Agulhas current and wind-induced upwelling of cold South Atlantic central water (Harris 1978). This region has medium productivity, moderate chlorophyll, and frequent chlorophyll fronts.
Description:	Reefs of this region are considered to be warm temperate reefs. Many rocky sub-tidal reefs in this region are reported to be of aeolianite or sandstone origin (Flemming *et al.* 1983), but granite, quartzite and siltstone all feature in the subtidal geology of this region (see map in Clark and Lombard 2007). Reefs in this extensive ecozone seem to have a more heterogeneous community structure when compared with the Southwestern Cape and Natal inshore ecozones.
Important taxa	Agulhas reefs are dominated by sponges, ascidians, bryozoans and octocorals. Sponges include the golf ball sponge *Tethya aurantium*, the black stink sponge *Ircinia arbuscula*, the orange teat sponge *Polymastia mamillaris* and *Clathria spp*. Ascidian species include the characteristic red *Gynandrocarpa placenta*, *Sycozoa arborescens*, *Didemnum* sp., *Pycnoclavella narcissus*, and the endemic *Clavellina lepadiformis*. Characteristic bryozoans include *Schizoretepora tessellata*, *Laminopora jellyae* and *Gigantopora polymorpha*. Other key species include noble coral *Stylaster nobilis,* the sunburst soft coral *Malacacanthus capensis*, cauliflower soft coral *Drifa thyrsoidea*, purple soft coral *Alcyonium fauri,* Valdivian soft coral *A. valdiviae*, and the Variable soft coral *A. variabile*. Big seafans or gorgonians are conspicuous on these reefs with key species including *Leptogorgia palma*, *Eunicella tricoronata, E. papillosa, E. albicans,* and *Acabaria rubra.* Other important invertebrates include the red-chested sea cucumber *Pseudocnella insolens,* basketstars *Astroclades euryale*, featherstars *Comanthus wahlbergi* and *Tropiometra carinata*. Algal species include *Plocamium* spp., articulated corallines *Corallina* spp. and *Arthrocardia* spp.. In shallow waters, abalone were dominant space occupiers although poaching and overexploitation have reduced abalone in their core habitat. The articulated coralline algae *Amphiroa ephedrae* is a dominant species in the shallow subtidal.
Remarks	Reefs within False Bay are considered to be relatively distinct from the rest of the reefs from this ecoregion, possibly due to the influence of both the Agulhas Current, the seasonal intermediate upwelling experienced in this bay and the significant shelter within the bay. The Mossel Bay and Port Elizabeth areas also show relatively distinct changes in community structure. In the Gericke's Point area near George photographs were submitted for newly documented sites showing unique reef assemblages dominated by extensive cover of cauliflower soft coral (sites included Sodwana se gat, Die Oog, and Pizza Oven). Quantitative fine scale reef surveys are needed to further sub-classify reefs within this ecozone.
Conservation	Table Mountain National Park*, Helderberg, Betty's Bay, De Hoop*, Still Bay*, Goukamma, Robberg, Tsitsikamma*, Sardinia Bay*, Bird Island* and Dwesa Cwebe* MPAs all include this reef type. As mentioned above, reefs in this region are very heterogeneous and may include several sub-types. Existing photographs suggest this is the case with different sub-types within False Bay, between Cape Agulhas and Still Bay, adjacent to Goukamma, in Tsitsikamma, off Port Elizabeth, in East London and possibly south of the Kei River. Quantitative data and more reef images are needed especially south of Port Elizabeth. Although many MPAs include some or complete protection from fishing (indicated by an asterisk), results from protection level assessments in the National Biodiversity assessment 2011 showed that fishing pressure on this reef type must be reduced with more protection needed within no-take zones. Reefs in this ecozone are sensitive to overfishing, pollution impacts, anchor damage and impacts associated with mariculture, mining and petroleum activities. Further opportunities for reefs to provide for non-consumptive activities, potentially within MPAs, should be explored in this ecozone. Key areas to increase reef protection are within the Betty's Bay area, Robberg MPA, Goukamma MPA and south of Goukamma.
References	Harris 1978, Flemming *et al.* 1983, De Clerk *et al.* 2005, Sink *et al.* 2011.



Map depicting the extent of the Agulhas Inshore Reef and Hard Grounds habitat type.

Images of this reef type from Port Elizabeth (top) and False Bay.

2.3.3 Island-associated habitats

A total of 34 continental islands were included in this assessment, one more than the number previously reported by Williams (2000). These islands were classified as 'major' or 'minor' islands, based on their conservation importance in terms of the land-breeding predator colonies that they support, although the classification is also broadly applicable to the size of the islands. Twenty "islands" that are dominated by dense colonies of Cape fur seals were classified as minor islands, because the Cape fur seal is not a conservation priority and is categorised as least concern in terms of IUCN red listing criteria (Hofmeyr and Gales 2008). Such islands, are generally less than about 0.025 km^2 in area (Rand 1972). Major islands are generally much larger in size and support important colonies of threatened seabird species (Kemper *et al.* 2007) including the Endangered African Penguin (IUCN 2010a), Endangered Bank Cormorant (IUCN 2010b), Vulnerable Cape Gannet (Birdlife International 2008). It should be noted that some of the major islands also contain seal colonies (Bird Island in Lambert's Bay and Vondeling Island), while some of the minor islands support small numbers of breeding seabirds.

While the dominant seal and seabird populations have been relatively well studied, there is less knowledge of near-shore island biota and a limited understanding of ecosystem functioning (Williams *et al.* 2000). Therefore, little is known about key determinants of island and associated subtidal habitat types. Nevertheless, three broad ecoregional groupings of the above two island classes were recognised in this assessment, based on expert knowledge of the differences in island associated habitats (such as rocky shores) in different ecoregions. In the Namaqua region, there is one major island (Bird Island in Lamberts Bay) and three minor islands. In the southwestern Cape there are eight major islands (including Jutten, Vondeling, Dassen and Robben Islands) and three minor islands, and in the Agulhas ecregion there are five major islands (including the Bird Island and St Croix Island groups in Algoa Bay and Dyer Island) and four minor islands. Four other major islands (including Jutten, Malgas and Marcus Islands) in the southwestern Cape occur at the mouth of the Langebaan Lagoon. The islands and an associated "zone of island influence" (except in the case of islands within lagoons) were combined into a series of island-associated habitat types based on breeding predators, size and ecoregion.

2.3.4 Lagoon

Langebaan Lagoon is the only lagoon habitat type considered in the marine component although it can be argued that this habitat could also have been classified as an estuary

(Whitfield 2010). The ecology of this coastal embayment was outlined by Day (1959) and there are many subsequent publications that have furthered our understanding of this important ecosystem (see Grindley 1977, Henry and Mostert 1977, Puttick 1977, Shannon and Stander 1977, Christie 1981, Day 1981, Branch and Pringle 1987, Allanson and Baird 1999, de Villiers *et al.* 1999, Wooldridge 1999 and Hockey and Turpie 1999 in Whitfield 2010, Siebert and Branch 2005a, Siebert and Branch 2005b, Angel *et al.* 2006, Siebert and Branch 2006, Siebert and Branch 2007, Pillay et al. 2009a,b, 2010). Note that the aquatic area surrounding Schaapen and Meeu Islands within Langebaan Lagoon is considered a component of the lagoon ecosystem.

2.3.5 Offshore Benthic Habitat Types

A total of 62 offshore benthic habitat types comprising 23 consolidated or rocky habitat types and 39 unconsolidated habitat types were mapped on the shelf, shelf edge and deepsea zones of the South African EEZ. A total of 16 pelagic “habitat types” were identified and mapped in a separate analysis (see *Offshore Pelagic Habitat Types*). Offshore benthic habitat types included 6 broad ecosystem groups: rocky shelf, rocky shelf edge, seamounts and unconsolidated shelf, unconsolidated shelf edge and deepsea sediments.

Unconsolidated shelf is the most heterogeneous broad ecosystem group with 16 different habitat types recognised in the South African EEZ. This is the result of the many different sediment types (determined by grain size) and finer-scale depth and biogeographic patterns. The most widespread habitat types are unconsolidated with the southwest Indian Abyss constituting the benthic habitat type of greatest extent (249 366.14 km^2). Rare benthic habitat types include Natal Mixed Sediment Shelf (1.57 km^2), Natal Mixed Sediment Shelf Edge (29.17 km^2) and Southern Benguela Gravel Shelf Edge (29.88 km^2). Sandy shelf habitat types have the greatest extent with muddy, gravel and mixed sediment habitat types constituting smaller areas. Our knowledge of offshore unconsolidated habitat types is relatively poor (Leslie *et al.* 2000, Anderson and Hulley 2000) with further work needed to support habitat classification, ecological understanding and the impact of human activities on different habitat types. Recent new research is building the knowledge base for these habitat types (Shine 2008, Atkinson 2010, Sink *et al.* 2011b, Atkinson *et al.* 2011a, 2011b, Louise Lange, University of Cape Town unpublished data) but limited expertise, a scarcity of suitable equipment and the considerable expense of offshore research limit the study of deep water ecosystems in South Africa.

Many reef types have very limited extent with the Namaqua Inner Shelf Reef (0.56 km^2) constituting the smallest estimated reef area. This small extent may be due to poor state of knowledge rather than limited extent of this habitat type. Canyons and the submarine feature known as Childs Bank also have limited extent and hard shelf and shelf edge habitat types occupied less area than unconsolidated shelf and shelf edge habitat types. Living and dead cold water coral fragments have been collected in grab samples adjacent to Childs Bank (Atkinson 2010) leading to speculation that this habitat may support reef-building corals. Reef-building cold water corals have also been documented within the Southwest Indian Upper Bathyal, Natal Sandy and Gravel shelf Edge, Agulhas Sandy Shelf Edge and in association with deep reefs and submarine canyons on the Agulhas Inner Shelf and Shelf Edge respectively (Sink and Samaai 2009, Sink et al. 2011). These fragile habitat types are completely unstudied in South Africa and almost nothing is known of their extent, biodiversity, key ecological determinants and role in offshore ecosystems.

2.3.6 Offshore Pelagic Habitat Types

Three pelagic bioregions (A, B and C), 7 pelagic biozones (Aa, Ab, Ba, Bb, Bc, Ca and Cb) and 16 pelagic “habitats” (Lagabrielle 2009) were mapped hierarchically by cluster analysis for inclusion in the offshore MPA network (Figure 6). The pelagic bioregions separate primarily on the basis of productivity and temperature. The Benguela pelagic bioregion (A) is the only one to occur in the high productivity cluster while two bioregions, the temperate Atlantic and Indian Ocean (B) and the warm Indian and Agulhas pelagic bioregions (C), occur within a low productivity cluster. Pelagic biozones separate on the basis of the mean, maximum and standard deviation (variability) in productivity, sea surface temperature and chlorophyll. Pelagic habitat types were defined on the basis of these same variables as well as the distribution of cyclonic and anti-cyclonic eddies, sea surface temperature fronts and chlorophyll fronts.

The pelagic bioregionalisation represents a first attempt at defining potential “habitat types” within South Africa’s pelagic environment. It is not known whether these “habitat types” host distinct pelagic biodiversity patterns but there is some confidence in the assumption that these areas of the open ocean constitute areas of distinct physical environments in terms of sea surface temperature, productivity and nutrients and the frequency of eddies and fronts. It is also recognised that these factors are important determinants of pelagic biodiversity patterns elsewhere (see Lagabrielle 2009 for details and references). Many of the key ecosystem components of the pelagic environment are microscopic and there is insufficient information to validate habitats in terms of these ecological assemblages with current research effort and fishing focused on the moving component of biodiversity at higher trophic levels.

The surrogates used in this classification require further ground-truthing and assessment in terms of their role in structuring pelagic communities. The distribution of potential habitat types needs to be considered in the context of the movement pathways for important components of pelagic biodiversity such as resource species (including sardines, tuna, billfish and sharks), whales and other components of pelagic ecosystems in order to improve our understanding of pelagic biodiversity. An important first step in validating these potential habitat types would be to compare their distribution with the known distribution data for pelagic species using GIS.

There is scope for improvement of this classification and key recommendations for future efforts include further work to capture vertical stratification within the water column and to improve the inclusion of data reflecting the variability associated with the pelagic environment. The current classification is applicable within the upper mixed layer (which varies in depth across the shelf). This limitation was recognised after the development of the ecosystem-pressure matrix used to weight pressure impact scoring in different habitat types was developed. Scientists thus considered the entire water column in the threat assessment rather than only the upper mixed layer. Bathymetry drives some of the difference in the pelagic habitat types and this should be more fully explored. One suggestion was to remove bathymetry from the classification but it was agreed that depth should be excluded only if other surrogates that capture vertical stratification can be incorporated. Other variables that can be included in future classification efforts could include thermocline depth (sea surface height could be used as a proxy), depth integrated chlorophyll data and the deep chlorophyll maxima. The inclusion of other model outputs representing retention and other key oceanographic processes could also refine the classification when such products become available at a national scale.

Table 3: Key characteristics of the 16 pelagic "habitat types" recognised within the South African EEZ (Lagabrielle 2009). Note that descriptions of key characteristics are within a South African and not a global context.

Pelagic "habitat"	Key characteristics
Aa1	Very high productivity, high chlorophyll and very cold water (SST mean = 15.2℃) over the shallow gradually sloping shelf of the upwelling centre of the Benguela current in the south Atlantic ocean.
Ab1	High productivity and high but highly variable chlorophyll and cold water (SST mean 16.6℃) due to upwelling over the deeper gradually sloping Benguela shelf area of the south Atlantic ocean. Very high occurrence of chlorophyll fronts.
Ab2	Medium - high productivity and very high variability in productivity, medium-high chlorophyll and very high variability in chlorophyll over the shallow gently sloping Agulhas bank. Moderate Indian Ocean temperatures that are highly variable (SST mean = 19.1 ℃).
Ab3	Medium productivity, cold to moderate Atlantic temperatures (SST mean=18.3℃) moderate chlorophyll related to the eastern limit of the Benguela upwelling on the outer shelf. Relatively frequent chlorophyll fronts occur in this bioregion.
Bc1	Moderate temperature (SST mean = 21.8℃), low productivity, frequent sea surface temperature fronts in the Open Indian Ocean.
Bc2	Moderate temperature (SST mean = 20.5℃) with moderate variability in the Indian Ocean Abyss. Medium frequency of eddies. Agulhas retroflection and transition toward the Southern Ocean.
Bb1	Atlantic Ocean abyss, consistently low productivity and temperature (SST mean 18.7C°), low frequency of SSF fronts
Bb2	Consistently low productivity, chlorophyll and temperature (SST mean = 18.5℃) Atlantic open ocean transition toward the Benguela upwelling region.
Ba2	Cool (SST = 19.4℃) Indian and Atlantic ocean steep slope or abyss with high frequency of eddies, medium frequency of SST fronts, associated with the Subtropical convergence and Agulhas Return Current. This cluster exhibits occasional short –lived events of high productivity associated with the subtropical convergence (Llido *et al.* 2005).
Ba1	Cold (SST mean 17.8℃) Atlantic Ocean abyss with consistently low chlorophyll and medium frequency of eddies.
Ca1	Warm (SST mean = 24.1℃) Indian ocean abyss with very low chlorophyll, productivity and frequency of chlorophyll fronts.
Ca2	Consistently warm (SST mean 23.5℃) Indian ocean water with low variability in temperature and very low frequency of chlorophyll fronts.
Cb1	Very warm (SST mean = 24.9℃) stable subtropical Indian Ocean shelf ecosystem with low frequencies of eddies and SST fronts.
Cb2	Warm (SST mean = 23.5℃) core of the Agulhas current along the steep slope of the eastern continental shelf. High variability in primary productivity and chlorophyll with moderate to high chlorophyll values.
Cb3	Cool (SST mean = 21.2℃) Indian Ocean water with high productivity and high but variable chlorophyll, associated with very frequent SST and chlorophyll fronts. This habitat represents cool productive water that has been advected onto the shelf in this shear zone through Agulhas-current driven upwelling cells (Lutjeharms *et al.* 1989, 2000).
Cb4	Moderate (SST mean = 22.2℃) Indian Ocean water with frequent SST and chlorophyll fronts associated with the steep outer shelf.

Hutchings *et al.* (2000) reviewed the state of knowledge of the pelagic open ocean and highlighted research gaps that are still valid today. There has been some progress on plankton research (e.g. Ruiz Sebastián and O'Ryan 2001, Gibbons *et al.* 2009) but quantitative zooplankton research remains an important research gap and an improved understanding of ecosystem changes involving gelatinous species is still needed. Spatially explicit seasonal production models for the south coast are a key outstanding research priority and subsurface chlorophyll patterns need to be researched. Deep pelagic habitats are poorly understood with most publications constituting taxonomic work (Grindley and Penrith 1965, Hulley 1986, Hulley 1989, Hulley and Prosch 1987).

3 Current pressures on marine and coastal biodiversity

The 2004 National Spatial Biodiversity Assessment employed expert assessment to map the relative impact of 9 major categories of resource use and other influences on the marine environment. The 2011 assessment drew from recent efforts in mapping human use in coastal and offshore environments (Sink et al. 2011, Harris 2011) and produced 27 GIS layers reflecting the relative intensity of 27 drivers of ecosystem change. These 27 pressures include 18 types of extractive marine living resource use (13 commercial fisheries, commercial kelp harvesting, 2 types of recreational fishing, subsistence harvesting and shark control program), petroleum activities, diamond and titanium mining, shipping, coastal development and disturbance associated with coastal access, waste-water discharge, mariculture, invasive alien species and the reduction of freshwater flow into marine ecosystems. Most of the fisheries layers were derived from spatially referenced data collected through the Offshore Marine Protected Area project (Sink *et al.* 2010) and new coastal pressure layers were developed, with additional layers acquired through collaboration with Linda Harris at the Nelson Mandela Metropolitan Municipality (Harris 2011). An overview of each pressure was complied drawing from key literature that reports on the known and potential impact of each pressure (Table 4).

Table 4: References used to compile an overview of all pressures on biodiversity. These references were used to calculate impact weights for different broad ecosystem groups later in the assessment.

Pressures	Key Literature
Inshore demersal trawl	Japp 1997, Attwood et. al. 2000, Leslie *et al.* 2000, Sauer *et al.* 2003, Nel 2005, Wilkinson and Japp 2005a, Fishing Industry Handbook 2006, Shannon *et al.* 2006, Walmsley *et al.* 2007a, Walmsley *et al.* 2007b, Atkinson and Sink 2008, Hutchings *et al.* 2009, Sink and Samaai 2009, Atkinson 2010, DAFF 2010, Attwood *et al.* 2011.
Offshore demersal trawl	Japp 1989, Punt and Japp 1994, Kaiser and Spencer 1996, Barnes *et al.* 1997, Collie *et al.* 1997, Churchill 1998, Jennings and Kaiser 1998, Watling and Norse 1998, Jennings *et al.* 1999, Attwood *et al.* 2000, Ball *et al.* 2000, Bianchi *et al.* 2000, Sparks-McConkey and Watling 2001, Kaiser *et al.* 2002, Japp 2004, Butterworth and Rademeyer 2005, Nel 2005, Wilkinson and Japp 2005a, Wilkinson and Japp 2005b, Wilkinson and Japp 2005c, Queiros *et al.* 2006, Shannon *et al.* 2006, Walmsley *et al.* 2007a, Walmsley *et al.* 2007b, Atkinson and Sink 2008, Brandão and Butterworth 2008, Edwards *et al.* 2008, Watkins *et al.* 2008, Hutchings *et al.* 2009, Sink and Samaai 2009, Atkinson 2010, DAFF 2010, Atkinson *et al.* 2011b, Attwood *et al.* 2011.
Demersal longline	Japp 1989, Punt and Japp 1994, Barnes *et al.* 1997, Griffiths *et al.* 2000, Berkeley *et al.* 2004, Shannon *et al.* 2006, Petersen *et al.* 2007, Atkinson and Sink 2008, Brandão and Butterworth 2008, Field *et al.* 2008, Yemane *et al.* 2008, Hutchings *et al.* 2009, Petersen *et al.* 2009c, DAFF 2010.
Small pelagics	Crawford *et al.* 1987, Crawford 1999, Cury *et al.* 2000, Hutchings *et al.* 2000, Sauer *et al.* 2003, Griffiths *et al.* 2004 , Pecquerie *et al.* 2004, Freon *et al.* 2005, Twatwa *et al.* 2005, Bakun and Weeks 2006, Fairweather *et al.* 2006a, Fairweather *et al.* 2006b, Underhill *et al.* 2006, Van der Lingen *et al.* 2006, Pichegru *et al.* 2007, Roy *et al.* 2007, Atkinson and Sink 2008, Coetzee *et al.* 2008, Hutchings *et al.* 2009, Pichegru *et al.* 2009, Pichegru *et al.* 2010.
Midwater trawl	Kerstan and Leslie 1994, Sauer *et al.* 2003, Nel 2004, Atkinson and Sink 2008, DAFF 2010.
Crustacean trawl	Berry 1969, Wallace 1975, De Freitas 1989, Pollock 1989, Alverson *et al.* 1994, Fennessy 1994a, Fennessy 1994b, Fennessy 1995, Groeneveld and Melville-Smith 1995, Fennessy and Groeneveld 1997, Groeneveld and Cockcroft 1997, Whitfield 1998, Fennessy 1999, Hansson *et al.* 2000, Lindegarth *et al.* 2000, Pollock *et al.* 2000, Stevens *et al.* 2000, Hutchings *et al.* 2002, Dudley 2003, Sauer *et al.* 2003, Tanner 2003, Lombard *et al.* 2004, Forbes and Demetriades 2005, Fennessy and Isaksen 2007, Atkinson and Sink 2008, Hinz *et al.* 2009, DAFF 2010.
South coast rock lobster trap fishery	Pollock 1989, Pollock and Augustyn 1982, Cockcroft and Goosen 1995, Groeneveld 1997, Cockcroft and Payne 1999, Pollock *et al.* 2000, Groeneveld and Branch 2002, Groeneveld 2003, Sauer *et al.* 2003, Japp 2004, Atkinson and Sink 2008, DAFF 2010.
West coast rock lobster fishery	Elner and Vadas Sr 1990, Tarr *et al.* 1996, Cockcroft 1997, Cockcroft and Mackenzie 1997, Mayfield and Branch 2000, Pollock 2000, Pollock *et al.* 2000, Tegner and Dayton 2000, Griffiths *et al.* 2004, Pederson and Johnson 2006, Atkinson and Sink 2008, Cockcroft *et al.* 2008, Hutchings *et al.* 2009, DAFF 2010.

Pressures	Key Literature
Squid fishery	Augustyn and Smale 1989, Lemm and Attwood 2003, Glazer and Butterworth 2006, Lapinski and Soule 2007, Olyott *et al.* 2007, Petersen and Nel 2007, Atkinson and Sink 2008, Oosthuizen and Roberts 2009, Roberts and Mullon 2010, DAFF 2010.
Linefishing	Van Der Elst and Garratt 1984, Garratt 1985, Buxton 1993, Fennessy 1994, Griffiths 1997a, Griffiths 1997b, Attwood and Farquhar 1999, Götz *et al.* 2009a, Götz *et al.* 2009b, Penney *et al.* 1999, Toral-Granda *et al.* 1999, Attwood *et al.* 2000, Booth & Hecht 2000, Pinnegar *et al.* 2000, Griffiths 2000, Griffiths & Lamberth 2002, Griffiths and Wilke 2002, Mann 2000, Brouwer *et al.* 2005a, Brouwer *et al.* 2005b, Da Silva 2007, Da Silva and Burgener 2007, Kerwath *et al.* 2007a, Kerwath *et al.* 2007b, , Atkinson and Sink 2008, Palmer *et al.* 2008, Götz *et al.* 2009a, Götz *et al.* 2009b, DAFF 2010, Attwood *et al.* 2011.
Tuna pole fishery	Shannon *et al.* 1989, Hampton *et al.* 1999, Atkinson and Sink 2008, DAFF 2010, Sink et al. 2011.
Shark fisheries	Stevens *et al.* 2000, DEAT 2005, McCord 2005, Da Silva 2007, DAFF 2010.
Large pelagic fishery	Shannon *et al.* 1989, Kroese 1999, Hutchings 2000, Govender *et al.* 2002, Ryan *et al.* 2002, Myers and Worm 2003, Sauer *et al.* 2003, McQueen and Griffiths 2004, Nel 2004, Pauly *et al.* 2005, Bakun and Weeks 2006, Petersen *et al.* 2007, Petersen *et al.* 2009a, Petersen *et al.* 2009b, Petersen *et al.* 2009d, DAFF 2010.
Kelp harvesting	Koop & Griffiths 1982 (see Kirkman and Kendrick 1997), Hockey *et al.* 1983, McLachlan *et al.* 1985, Bustamante and Branch 1996a, Bustamante and Branch 1996b, Parkins & Branch 1996, Tegner and Dayton 2000, Brown & McLachlan 2002, Levitt *et al.* 2002, Dugan *et al*. 2003, Anderson *et al.* 2006, Pisces Environmental Services 2007, Lastra *et al.* 2008, Defeo *et al.* 2009, DAFF 2010, Dugan and Hubbard 2010.
Shark control program	Davies 1964, Paterson 1979, Van der Elst 1979, Cliff *et al.* 1989, Cockcroft 1990, Paterson 1990, Dudley and Cliff 1993, Krogh and Reid 1996, Dudley 1997, Allen and Cliff 2000, Stephens *et al.* 2000, Dudley and Simpfendorfer 2006, Dudley and Cliff 2010 , Cliff and Dudley 2011.
Mariculture	Carriker 1992, *Copeley et al. 1992*, Pemberton and Shaughnessy 1993, Kerry *et al.* 1995, Wu 1995, Agius and Tanti 1997, Black *et al.* 1997, Clifford *et al.* 1998, Davies *et al.* 1998, Davies 2000, Crawford *et al.* 2001, Haya *et al.* 2001, McLure 2001, Milewski 2001, Naylor *et al.* 2001, Bjørn and Finstadt 2002, Wuersig and Gailey 2002, Carroll *et al.* 2003, McGinnity *et al.* 2003, Morton *et al.* 2003, Black *et al.* 2004, Boyra *et al.* 2004, Carr and Whoriskey 2004, Feng *et al.* 2004, La Rosa *et al.* 2004, Sara *et al.* 2004, Vita *et al.* 2004, Bjørn *et al.* 2005, Bongiorni *et al.* 2005, Chambers and Ernst 2005, Heggoey *et al.* 2005, Heuch *et al.* 2005, ICES 2005, Kloskowski 2005, Pitta *et al.* 2005, Porrello *et al.* 2005, Ruesink *et al.* 2005, Tymchuk *et al.* 2005, Krkošek *et al.* 2007, Senanan *et al.* 2007, Ford and Myers 2008, Haupt 2009, Haupt *et al.* 2010a, Haupt *et al.* 2010b, Mead *et al.* 2011a, Mead *et al.* 2011b.
Abalone	Blamey 2010, DAFF 2010, Zeeman 2010.

Pressures	Key Literature
Alien Invasive Species	Le Roux *et al.* 1990, Griffiths *et al.* 1992, Hockey and Van Erkom Schurink 1992, Parkins and Branch 1997, Cohen & Carlton 1998, Wilcove *et al.* 1998, Ruiz *et al.* 1999, Van Erkom Schurink & Griffiths 1999, Winckler 1999, Attwood 2000, Culver & Kuris 2000, Lowe *et al.* 2000, Mack *et al.* 2000, Myers *et al.* 2000, Monniot *et al.* 2001, Hanekom and Nel 2002, Robinson and Griffiths 2002, Ruiz Sebastián *et al.* 2002, Occhipinti-Ambrogi & Savini 2003, Steffani and Branch 2003a, Steffani and Branch 2003b, Branch and Steffani 2004, Casas *et al.* 2004, Hewitt *et al.* 2004, Lombard *et al.* 2004, Miller *et al.* 2004, Anderson 2005, Hewitt *et al.* 2005, ICES 2005, Robinson *et al.* 2005, Steffani & Branch 2005, Ashton *et al.* 2006, Bownes and McQuaid 2006, Coutts and Forrest 2007, Hampton & Griffiths 2007, Olenin *et al.* 2007, Pulfrich *et al.* 2007, Robinson *et al.* 2007a, Robinson *et al.* 2007b, Branch *et al.* 2008, GISP 2008, Laird and Griffiths 2008, Molnar *et al.* 2008, Penney *et al.* 2008, Simon-Blecher *et al.* 2008, Forrest *et al.* 2009, Griffiths *et al.* 2009a, Griffiths *et al.* 2009b, Haupt 2009, Rodrigues-Labajos *et al.* 2009, Wanless *et al.* 2009, Branch *et al.* 2010, Haupt *et al.* 2010a, Sink *et al.* 2010, Tamelander *et al.* 2010, Crooks *et al.* 2011, Mead *et al.* 2011a, Mead *et al.* 2011b.
Petroleum activities	Neff *et al.* 1989, Gray *et al.* 1990, Kingston 1992, Hyland *et al.* 1994, Steinhauer *et al.* 1994, Olsgard and Gray. 1995, Newell *et al.* 1998, Cranford *et al.*1999, Gray *et al.* 1999, Love *et al.* 1999, Atwood *et al.* 2000, CCA and CMS 2001, Hall 2001, Grant and Briggs 2002, Holdway 2002, Peterson *et al.* 2003, Sammarco *et al.* 2004, Currie and Isaacs 2005, Findlay 2005, Love *et al.* 2005, MENZ 2005, Blood & Corbett 2006, Grundling *et al.* 2006, Page *et al.* 2006, Coutts *et al.* 2007, Atkinson and Sink 2008, Schaanning *et al.* 2008, Wanless *et al.* 2009, Kerr *et al.* 2010, Sheehy and Vik 2010, Sink *et al.* 2010.
Shipping	Clarke 1984, Carlton 1985, Hutchings 1992, State of Environment Report 1999, Underhill *et al.* 1999, Attwood *et al.* 2000, Crawford *et al.* 2000, Holdway 2002, Kingston 2002, IMO 2005, O'Donaghue & Marshall 2003, Claudi and Ravishankar 2006, Garcia de la Parra *et al.* 2006, Gründlingh *et al.* 2006, Serrano *et al.* 2006, Atkinson and Sink 2008, Barry *et al.* 2008, SAHO 2009, GloBallast Partnerships 2011, www.mcm-deat.gov.za
Coastal development	Daniel 2001, Mills *et al.* 2001, Fish *et al.* 2008, Dugan *et al.* 2008, Harris 2008, Harris *et al.* 2010, Smith *et al.* 2010, Jackson and McIlvenny 2011.
Waste water discharge	Moldan 1989, DWAF 1995, RSA 1998 – National Water Act, Lane and Carter 1999, Brown & McLachlan 2002, O'Donoghue and Marshall 2003, Lombard *et al.* 2004, RSA-DWAF 2004, Sink 2004, Gründlingh *et al.* 2006, Schleyer *et al.* 2006, Dubula *et al.* 2007, RSA-DEAT 2008, Naidoo 2008, DEAT 2009, Karenyi 2009, Weerts et al, 2009, Harris *et al.* 2010 Crooks *et al.* 2011.
Freshwater flow reduction	Berry *et al.* 1979, Schleyer 1981, Berry and Schleyer 1983, Campbell and Bates 1991, Bennett 1993, Whitfield 1998, Demetriades *et al.* 2000, QuiÑores and Montes 2001, Gillanders and Kingford 2002, Lamberth and Turpie 2003, Louw 2003 in Van Ballegooyen *et al.* 2007, Van Ballegooyen *et al.* 2007, Lamberth *et al.* 2009, Porter 2009, Harris *et al.* 2010.

Pressures	Key Literature
Recreational fishing	Van der Elst 1979, Coetzee *et al.* 1989, Hughes 1989, Bennet 1991, Weinburg and Branch 1991, Bennett *et al.* 1994, Attwood *et al.* 1997, Brouwer *et al.* 1997, Griffiths and Branch 1997, McGrath *et al.* 1997, Mann *et al.* 1997, Sauer *et al.* 1997, Tomalin and Tomalin 1997, Tomalin and Kyle 1998, Mann 2000, Brouwer 2002, Brouwer and Buxton 2002, Cowley *et al.* 2002, Griffiths and Lamberth 2002, Fennessy *et al.* 2003, Mann *et al.* 2003, Griffiths *et al.* 2004, Cooke and Suski 2005, Bartholomew and Bohnsack 2005, Lewin *et al.* 2006, Pradevand and Hiseman 2006, Cockcroft and Mackenzie 2007, Tunley 2009, DAFF 2010, Governement of South Africa 2010.
Subsistence harvesting	Siegried *et al.* 1985, Hockey and Bosman 1986, Siegfried 1988, Lasiak and Dye 1989, Lasiak 1991, Wynberg 1991, Wynberg and Branch 1991, Dye *et al.* 1994a, Dye *et al.* 1994b, Wynberg and Branch 1994, Lasiak and Field 1995, Dye *et al.* 1997, Griffiths and Branch 1997, Kyle *et al.* 1997a, Kyle *et al.* 1997b, Wynberg and Branch 1997, Harris *et al.* 1998, Tomalin and Kyle 1998, Sink 2001, Clark *et al.* 2002, Branch and Odendaal 2003, Harris *et al.* 2003, Napier *et al.* 2005, Lasiak 2006, Harris *et al.* 2007, Pelc *et al.* 2009.
Mining (see also petroleum activities)	Barkai & Berge 1992, McLachlan *et al.* 1994, Parkins & Branch 1995, McLachlan *et al.* 1996, Savage 1996, Parkins & Branch 1996, Van der Merwe 1996, Clark *et al.* 1998, Clark *et al.* 1999, Pulfrich 1998, Pulfrich and Penney 1999, Attwood *et al.* 2000, Savage *et al.* 2001, Clarke & Nel 2002, Nel & Pulfrich 2002, Nel *et al.* 2003, Pulfrich *et al.* 2003a, Pulfrich *et al.* 2003b, Griffiths *et al.* 2004, Penney and Pulfrich 2004, Pulfrich 2004, Steffani and Pulfrich 2004, Penny 2005, Roos 2005, DEAT 2006, Pulfrich 2007a, Pulfrich 2007b, Pulfrich *et al.* 2007, Steffani and Pulfrich 2007, Penney *et al.* 2008, Karenyi 2009, Harris *et al.* 2010
Coastal Disturbance	Bally and Griffiths 1989, Keough and Quinn. 1998, Moffett *et al.* 1996, Leseberg *et al.* 2000, Thomas *et al.* 2000, Thomas *et al.* 2001, Verhulsta *et al.* 2001, Brown & McLachlan 2002, Milazzo *et al.* 2004, Schlacher *et al.* 2007.
Climate change	Crawford 1998, Goreau *et al.* 2000, Helmouth *et al.* 2002, Kaiser *et al.* 2002, Schleyer & Celliers 2003, Bakun and Weeks 2004, Hays *et al.* 2005, Harley *et al.* 2006, Mieszkowska *et al.* 2006, McClanahan *et al.* 2007a, McClanahan *et al.* 2007b, Roy *et al.* 2007, Smith *et al.* 2007, Cockcroft *et al.* 2008, Coetzee *et al.* 2008, Harris 2008, Schleyer *et al.* 2008, Theron & Roussou 2008, Cheung *et al.* 2009, Chust *et al.* 2009, Hutchings *et al.* 2009, Mather 2009, Rouault *et al.* 2009, Ruiz Sebastian *et al.* 2009, Griffiths *et al.* 2010, Rouault *et al.* 2010, Smith *et al.* 2010, DEA 2011, Mead 2011

3.1 Processing of pressure data

Data on the each of the pressures were summarised to 5' grids (approximately 8 x 8 km) to facilitate the spatial assessment. This scale represented a compromise between the finer-scale data available for some coastal pressures and the coarser-scale offshore fishing data, and corresponded with the data collation scale of the major base data source for this assessment (Sink et al. 2011). For most pressures, pressure values were converted to a 0-1 range using the formula $p=d^1/d^{80}$, where d^1 is the raw pressure data in a 5' grid, d^{80} is the 80th percentile of the pressure values for that data set, with resultant values over 1 being assigned a value of one. This method was required as some of the datasets contained some very high values which would have masked the potential impact of moderate levels of pressure. The compilation of the individual pressure layers into this consistent format and range was necessary to allow spatial patterns of intensity of different pressures to be compared and cumulative pressures to be calculated.

3.1.1 Commercial fishing

Industry fishing data covered all major fisheries and included inshore, offshore, crustacean, and midwater trawling, hake demersal longlining, squid jigging, linefishing, tuna pole fishing, fisheries for small pelagics, large pelagics, sharks and west coast and south coast rock lobster. The abalone fishery was closed when this work was initiated and was omitted from the spatial assessment. Fishing effort data were used where possible, as these are considered a better reflection of potential impacts on marine biodiversity than catch data, which may not reflect other impacts such as bycatch and habitat degradation. Effort data were scaled using the d/d80 method described above (processing of pressure data). No effort data were available for the tuna pole sector but the important areas for albacore and yellowfin tuna as mapped by Sink *et al.* 2010 were integrated to produce a single scaled layer reflecting important fishing areas for both species. A kelp harvesting layer was developed based on the total annual kelp harvest data collected from 2000-2009 for each concession. Harvesting intensity was calculated by dividing harvest by the coast length in kilometres. These values were then scaled using the d/d80 method.

3.1.2 Shark control program

South Africa has a shark control program on the east coast and maps reflecting the area of influence of shark nets and drum lines were included in the analysis. Spatial data reflecting the potential impact of shark nets were acquired from Ezemvelo KZN Wildlife who mapped net and drum line positions acquired from the Natal Sharks Board and buffered these to cover the estimated area of influence, as determined by scientific experts (Sheldon Dudley, pers. comm.). Catch data were not used and values were binary with a value of zero in grids outside of the area of influence of the shark control program and a value of one within all grid cells within the area of influence.

3.1.3 Mariculture and invasive alien species

A GIS layer was produced to show the current impact of invasive alien species by mapping the known distribution of the European mussel *Mytilus galloprovincialis* and the European shore crab *Carcinus maenas* (Robinson *et al.* 2005). Point and linear data on the distribution of invasive alien species were analysed for the presence of these invasive alien species within a 5 minute block. Blocks with both *M. galloprovincialis* and *C. maenas* were assigned a value of one, while areas with *M. galloprovincialis* were assigned a value of 0.9. Data for other invasives was not available at the time of mapping. See Section 3.2.16 - *Mariculture* and Section 3.2.17 - *Invasive alien species*.

3.1.4 Mining and Petroleum

In addition to the fishing and mariculture industry, pressure layers were prepared for the petroleum industry and mining. Diamond and petroleum leases were mapped (Sink *et al.* 2010), but actual mined or prospected areas (including beach, inshore and offshore vessel-based diamond mining) and petroleum wellheads were used to provide a more accurate representation of mining pressure on marine habitat types. For mining in water deeper than 30 m, data were acquired from the Offshore MPA project (Sink *et al.* 2010). Inshore, areas mined and prospected for diamonds were mapped from data acquired through the Benguela Current Large Marine Ecosystem Program (Penney *et al.* 2008). For petroleum, published positions of wellheads were buffered to include the whole 5 minute grid used in this assessment. Coastal land-based mining (up to 500 m inland, as per the landward extent of the coast type layer) was mapped by extracting the mined land features out of the National Land Cover (NLC) 2000 map, acquired from SAN Parks. These features include, for example, the mined dunes in Richards Bay.

3.1.5 Shipping

Shipping was the only pressure for which no national level data were available, and a layer was derived from the international dataset from Halpern *et al.* (2008). This dataset represents the density of vessel tracks as a map of heavily used shipping lanes relative to normal South

African vessel traffic. The international data were subsampled to the South African EEZ, the values were normalised to a 0 to 1 range and the lowest 20% of values were reassigned a zero value.

3.1.6 Coastal development

A shapefile of property parcels for the coast was constructed from Erf layers for the four coastal provinces, obtained from the Surveyor General. This was transformed into a fine-scale layer of all coastal buildings, by verifying and modifying (as necessary) each property parcel against Google Earth satellite imagery, and digitizing development that was not captured in the Erf layers (Harris 2011). This coastal buildings layer was overlaid with the development-related features extracted from the National Land Cover 2000 map (obtained from SAN Parks). This base data layer was used to calculate the percentage of the terrestrial area within 1 km of the coastline area that was under urban landcover types. The percentage of the area for each 5' block within 1 km of the coast that contained urban development (residential, commercial or industrial) was used as a proxy for coastal development pressure. The percentage values were linearly converted to a 0-1 range with 0 being completely undeveloped and 1 being completely developed.

3.1.7 Waste water discharge

The GPS location of municipal and industrial waste water discharge sites were acquired from the Department of Water Affairs. Waste water discharge sites were mapped into a single GIS layer and discharge sites were coded to the entire coastal segment in the coast type layer. These areas were allocated a value of 1, with remaining segments without any discharge points being allocated a value of 0. This application generally resulted in the reflection of entire bays as impacted by discharge points, but discharges at rocky points were coded to a smaller area. The percentage of coastal area with waste water discharge per 5' block was then calculated, and the resultant values normalised using the d/d80 method. It was not possible to map the effect of discharge into the wider marine environment due to the lack of flow volume data for several discharge points.

3.1.8 Freshwater flow reduction

A map of the expected greatest impact from changes in Mean Annual Runoff (MAR) from river systems was derived using data on MAR and MAR-reduction for major river systems from the Estuary Component of the National Biodiversity Assessment 2011, and with expert input from the estuarine component of this assessment. A value defined as the percentage change in MAR multiplied by the MAR (Million m^3/a) was assigned to the river or estuary mouth for river and associated estuarine systems that contribute more than 1% of the total MAR for South Africa. This includes 20 estuaries and represents 83.3% of total MAR. An iterative diffusion model was developed in IDRISI based on quarter degree squares (QDS) to show the diminishing effect of flow reduction with increasing distance from the river or estuary mouth. For each iteration, a mean filter was applied to a 5x5 QDS roving window. This was repeated 10 times to gradually diffuse the values assigned to the estuary mouth. This reflects the expected reduced impacts further away from the mouth, while accommodating both single large systems (e.g. in the west coast of SA) and the cumulative impacts of many smaller systems in close proximity (e.g. the KZN coast). An area weighted mean of these base values was calculated for each 5 minute block, and these values were then normalised to a 0-1 range. High values were not truncated.

Table 5: Estimated change in freshwater flow for the major river systems in South Africa

Catchment	MAR (million m^3/year)	% of South African runoff	% Change
Orange/Gariep	10833	29.0	56
Tugela/Thukela	3754	10.1	27
Mzimvubu	2894	7.8	10
Breë	1785	4.8	42
Mzimkulu*	1478	4.0	25
Olifants	1070	2.9	34
Mkomazi*	1070	2.9	15
Great Kei*	1064	2.9	15
Groot Berg	916	2.5	46
Mfolozi	885	2.4	19
Mbashe*	836	2.2	10
Mgeni*	683	1.8	50
Mhlathuze	645	1.7	20
Gourits*	539	1.4	40
Great Fish*	525	1.4	30
Gamtoos*	501	1.3	35
Mvoti*	482	1.3	25
St Lucia	418	1.1	30
Mtata	378	1.0	54
Mtamvuna*	304	0.8	15

3.1.9 Recreational and subsistence fishing

Data and maps reflecting relative fishing effort for both shore- and boat-based recreational fishing were included in this assessment. Coastal access data (Harris 2011) were used as the basis to identify accessible areas for shore-based fishing, from which no-take MPA areas were excluded. Base intensity of fishing along the coast was calculated by dividing angler days per kilometer (using data from Brouwer *et al.* 1997 and Mann *et al.* 2003) of accessible coast where fishing is allowed. An area weighted mean of the angling intensity was then calculated per 5' grid. For boat-based effort, a modelled fishing intensity base layer was developed based on the inverse Euclidean distance to boat launch sites. A maximum distance of 30 km was used to align with the approach used in the fine-scale conservation plan for KZN, and no-take MPA areas were excluded. An average intensity per 5' grid was calculated using an area weighted mean.

Intensity of subsistence harvesting was based on the number of subsistence fishers per kilometre of coastline (Clark *et al.* 2002) outside of no-take MPAs. An area weighted mean was calculated per 5' grid cell of fishing intensity and these values were scaled using the d/d80 method.

3.1.10 Coastal disturbance

Potential coastal disturbance impacts associated with human use of the coast (e.g. to shorebirds, surf zone elasmobranchs and fish, and trampling of intertidal fauna) was assessed. Coastal access was mapped by creating a 1 km buffer around all vehicle-based access points to the coast (see Harris 2011). This was coupled with the national recreational beaches layer to represent the coastal area that has the greatest associated human disturbance. The two base layers (vehicle access points and recreational beaches) were obtained from the Department of Environmental Affairs project “National Re-evaluation of the Beach Driving Decision Support Tool” (Anchor Environmental and International Ocean Institute, with input from Ronel Nel and Linda Harris). Within each 5' grid cell, the percentage of accessible beaches (recreational beaches and beaches within 1 km of an access point) was calculated as a proportion of the total coastline length. These percentages were linearly scaled to the standard 0-1 range.

3.1.11 Climate change

Climate change maps reflecting increasing sea surface temperature and ocean acidification were developed from global data sets (Halpern *et al.* 2008) but these were excluded from spatial analyses because South African experts had little confidence in these maps during review workshops and meetings. Although changing climate is a more recent field of research, and the understanding of spatial patterns of change is still evolving, a thematic review of the known and potential impacts of climate variability and change is provided in Section 12 (*Climate variability and change*).

3.2 Overview and Maps of Pressures

3.2.1 Inshore demersal trawl fishery

The inshore demersal trawl sector targets Agulhas sole (*Austroglossus pectoralis*) and shallow-water hake *Merluccius capensis* (Sauer *et al.* 2003). However, considering the substantial high-diversity bycatch, much of which is considered to be commercially important for this sector, this fishery may be more accurately described as a multi-species fishery (Attwood *et al.* 2011). The inshore trawl fishery operates between Cape Agulhas in the west, to the mouth of the Kei River in the east, and is restricted to water shallower than 110 m or within 20 nautical miles of the coast, whichever is the greatest distance (Figure 7). Highest fishing effort occurs in the sole grounds between Cape Agulhas and Mossel Bay with further areas of high effort east of Algoa Bay.

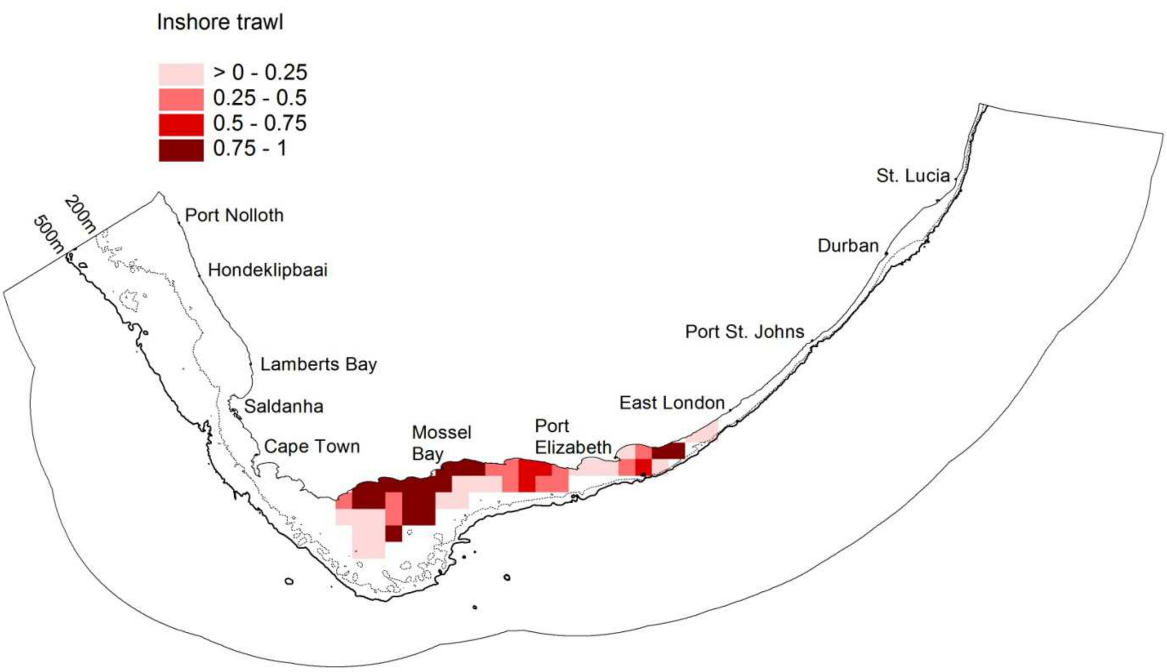


Figure 7: Scaled pressure values reflecting relative fishing effort for the inshore demersal trawl sector in South Africa.

Biodiversity concerns and potential ecosystem impacts of the inshore trawl sector include:

- Damage to seabed habitats and vulnerable marine ecosystems (Attwood *et. al.* 2000, Leslie *et al.* 2000, Nel 2005, Atkinson and Sink 2008, Sink and Samaai 2009, Atkinson 2010).
- The diverse and substantial bycatch which includes overexploited linefish species (Wilkinson and Japp 2005a, Walmsley *et al.* 2007a, Walmsley *et al.* 2007b, Attwood and Petersen 2010). A total of 137 nominal species has been documented by observers monitoring this fishery between 2003 and 2006 (Attwood and Petersen 2010).
- High catches of juvenile silver kob and geelbek (Walmsley *et al.* 2006, Attwood and Petersen 2010, Attwood *et al*. 2011).
- Chondrichthyan bycatch (Walmsley *et al.* 2006, Walmsley *et al.* 2007).
- Discarding of low value and small fish (Japp 1997 in Attwood 2000, Walmsley *et al.* 2007a, Walmsley *et al.* 2007b, Attwood 2000, Attwood et al. 2011).
- The uncertain stock status of Agulhas sole (DAFF 2010).

Of these issues, the first three are primary concerns.

3.2.2 Offshore demersal trawl fishery

The offshore trawl grounds extend in an unbroken band along the shelf edge from approximately 300 m depth off Hondeklipbaai on the west coast southwards to the southern tip of the Agulhas Bank (Figure 8). Effort diminishes closer to the Namibian border reflecting increasing fuel costs associated with increasing distance from port. Little offshore trawling occurs between the southern tip of the Agulhas Bank and offshore of Plettenberg Bay due to rocky terrain (Wilkinson and Japp 2005c). On the south coast, offshore trawlers concentrate fishing effort on the offshore edge of the Agulhas Bank with highest effort offshore of Port Elizabeth (Figure 8). This area, known as the chalk line grounds, yields high catches of kingklip. The offshore trawl fishery primarily targets deep-water hake *M. paradoxus* which occur in waters between 200 m and 800 m off the South African west coast continental shelf. Valuable bycatch species of the offshore demersal trawl fishery include monk (*Lophius vomerinus*), kingklip (*Genypterus capensis*), angelfish (*Brama brama*), snoek (*Thyrsites atun*) and horse mackerel (*Trachurus trachurus capensis*) (Atkinson and Sink 2008). In waters deeper than 500 m on the west coast, the bycatch includes other species such as oreos and slimeheads (*Hoplostethus* spp.) some of which are commercially valuable (Atkinson and Sink 2008). The market value of kingklip and monk are sometimes higher than the target hake species and fishing activities are sometimes known to be directed towards these bycatch species.

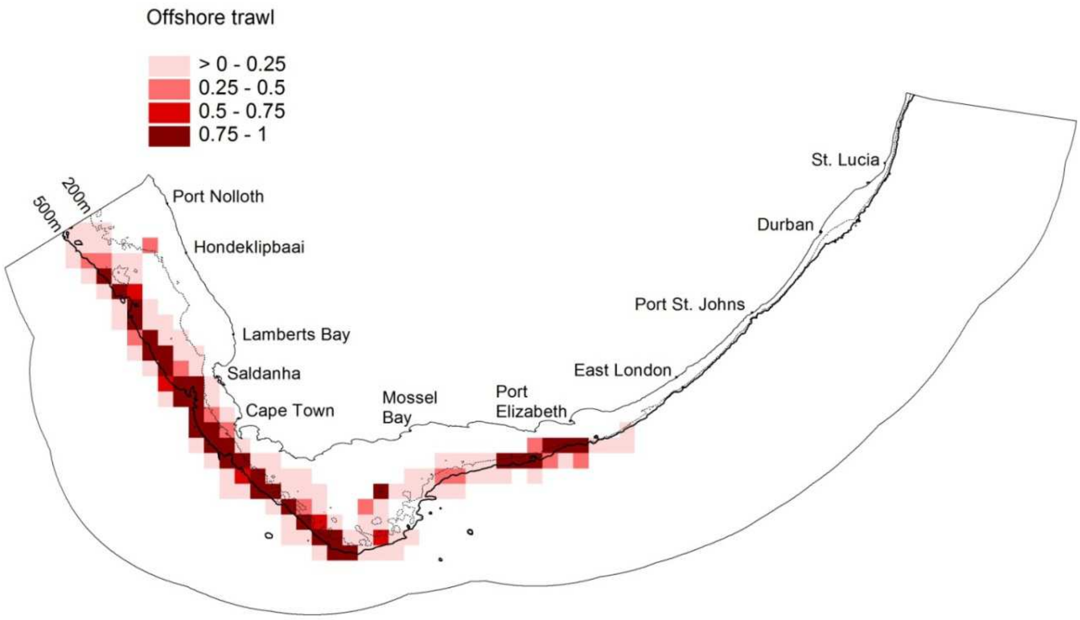


Figure 8: Scaled pressure values reflecting relative fishing effort for the offshore demersal trawl sector in South Africa.

Biodiversity and fishery sustainability concerns associated with the offshore trawl sector include:

- The impact of trawling on benthic communities (Shannon *et al.* 2006, Atkinson 2010, Atkinson *et al.* 2011b) and vulnerable marine ecosystems such as cold water corals (Sink and Samaai 2009)
- The incidental mortality of seabirds (Watkins *et al.* 2008)
- the vulnerability of some bycatch species (Japp 2004, Walmsely *et al.* 2007, Atkinson and Sink 2008) and targeting of bycatch species (Walmsley *et al.* 2006, Walmsley *et al.* 2007)
- Discarding of juvenile hake, jacopever and bycatch of low commercial value (Walmsley *et al.* 2006, Walmsley *et al.* 2007)
- Impacts on the size structure of target species by targeting large hake because of their high export value (Shannon *et al.* 2006)
- The uncertain stock status of kingklip (Japp 1989, Punt and Japp 1994, Brandão and Butterworth 2008)
- Concerns about the stock status of deepwater hake (DAFF 2010)

Impacts on benthic habitats are also poorly understood with particular concern for hard ground habitats including deep reefs, submarine mounds and canyons and hard areas of shelf edge. Such features often support species that comprise complex three-dimensional habitats that can be destroyed or severely damaged by demersal trawling. The incidental mortality of threatened and other seabirds is a concern, with estimates of 18 000 annual seabird mortalities associated with trawling in 2006 (Watkins *et al.* 2008). More information is urgently needed to provide more robust assessments of the incidental mortality of seabirds in this fishery. This includes

Endangered black-browed *Thalassarche melanophrys*, Indian yellow-nosed *T. carteri* and Atlantic yellow-nosed *T. chlororhynchos* albatrosses (Watkins *et al.* 2008).

3.2.3 Demersal longline fishery

South Africa's demersal longline fishery started as an experimental fishery in 1983, targeting both species of cape hake. This method was found to be very effective in targeting the more valuable kingklip and led to overfishing and closure of the fishery in 1991. A hake directed experimental longline fishery was introduced in 1994 with commercial rights issued in 2001 (Fairweather *et al.* 2006c). This fishery currently operates along the west and south coast with effort concentrated along the shelf edge (Figure 9). Highest effort has been recorded in the vicinity of the Cape Valley off Cape Point, near Cape Canyon off Cape Columbine, offshore of Tsitsikamma and near Port Elizabeth.

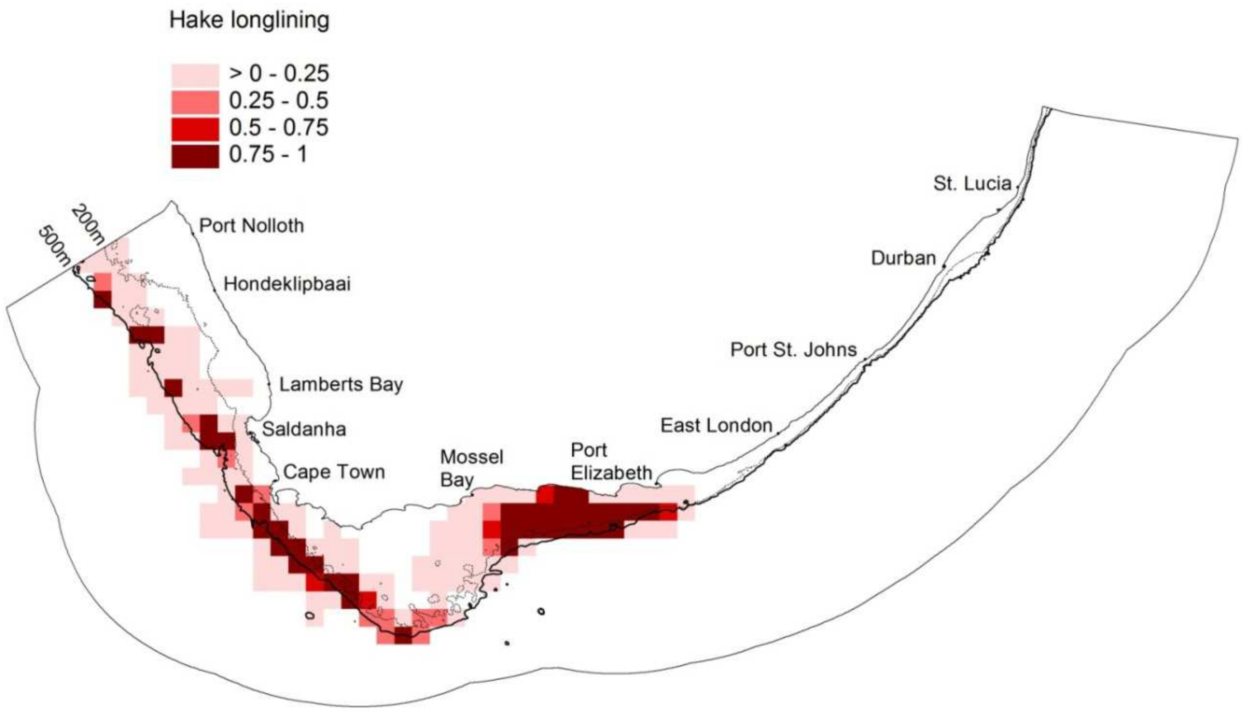


Figure 9: Scaled pressure values reflecting relative fishing effort for the offshore demersal longline fisher in South Africa.

Biodiversity concerns of this fishery include:

- Incidental mortalities of seabirds, sharks and turtles (Barnes *et al.* 1997, Petersen *et al.* 2007, Petersen *et al.* 2009c)
- Concern that this highly size-selective fishery may have indirectly reduced the reproductive output of the target species by targeting large hake (Berkeley *et al.* 2004, Shannon *et al.* 2006, Field *et al.* 2008, Yemane *et al.* 2008).
- Concerns about the stock status of kingklip (Japp 1989, Punt and Japp 1994, Brandão and Butterworth 2008) and deepwater hake (DAFF 2010)
- Localised seabed damage and ghost fishing due to gear loss (Atkinson and Sink 2008)

Demersal longlining was reported to kill an estimated 8000 white chinned-petrel *Procellaria aequinoctialis* in 1995 (Barnes *et al.* 1997). However, more recent estimates, based on larger sample sizes over a longer period, indicate an estimated total of 225 seabirds killed per year by this fishery (Petersen *et al.* 2009c). The white-chinned petrel, a vulnerable species on the IUCN Redlist, is the bird species most commonly caught by this sector, at an estimated rate of 0.0027 per 1 000 hooks. Yellow nosed albatross, Cape gannets and shearwaters are also caught. South Africa has good regulations to mitigate seabird mortality and the overall impact of this fishery on pelagic seabirds is considered relatively small (Petersen *et al.* 2009c). There is, however, a need for improved compliance and measures to further reduce mortalities during hauling. South Africa's observer program only covers 6.8% of the demersal longline fishing effort (Petersen *et al.* 2009c).

3.2.4 Small pelagic fishery

South Africa's small pelagic fishery targets adult sardine *Sardinops sagax*, juvenile anchovy *Engraulis encrasicolus* and adult redeye *Etrumeus whiteheadi* using purse-seine nets. This fishery has a long history characterised by resource fluctuations, changes in fishing patterns and dynamic ecosystem effects (Crawford *et al.* 1987, Hampton *et al.* 1999, Sauer *et al.* 2003, Griffiths *et al.* 2004, Pecquerie *et al.* 2004, Van der Lingen *et al.* 2006, Coetzee *et al.* 2008, Hutchings *et al.* 2009). The anchovy fishery targets recruits (of approximately 6 months old) in the inshore waters off the west coast, and processes them into fish meal and fish oil. The sardine fishery targets adult fish off the west and south coasts, the catch being canned or frozen for human consumption, bait, and pet food. Fishers off Mossel Bay and Port Elizabeth catch mainly sardine with little bycatch of the other target species. Purse-seine fishing operations are highly selective and target shoals of fish near the surface of the water column. Juvenile horse mackerel *Trachurus trachurus capensis*, sardine and redeye are caught as bycatch during anchovy directed fishing operations (Hutchings *et al.* 2009) and are turned into fishmeal and oil along with the anchovy.

Biodiversity concerns in this fishery include:

- By-catch of juvenile sardine during anchovy directed fishing
- The potential role of fishing in observed distribution shifts of sardines (Coetzee *et al.* 2008)
- Possible genetic impacts linked to fishing (Cury *et al.* 2000)
- The potential impact of fishing on the food availability for predators such as seabirds (Crawford 1999, Underhill *et al.* 2006, Pichegru *et al.* 2007, Pichegru *et al.* 2009, Pichegru *et al.* 2010)
- Dumping and poor observer coverage (Hutchings *et al.* 2009)

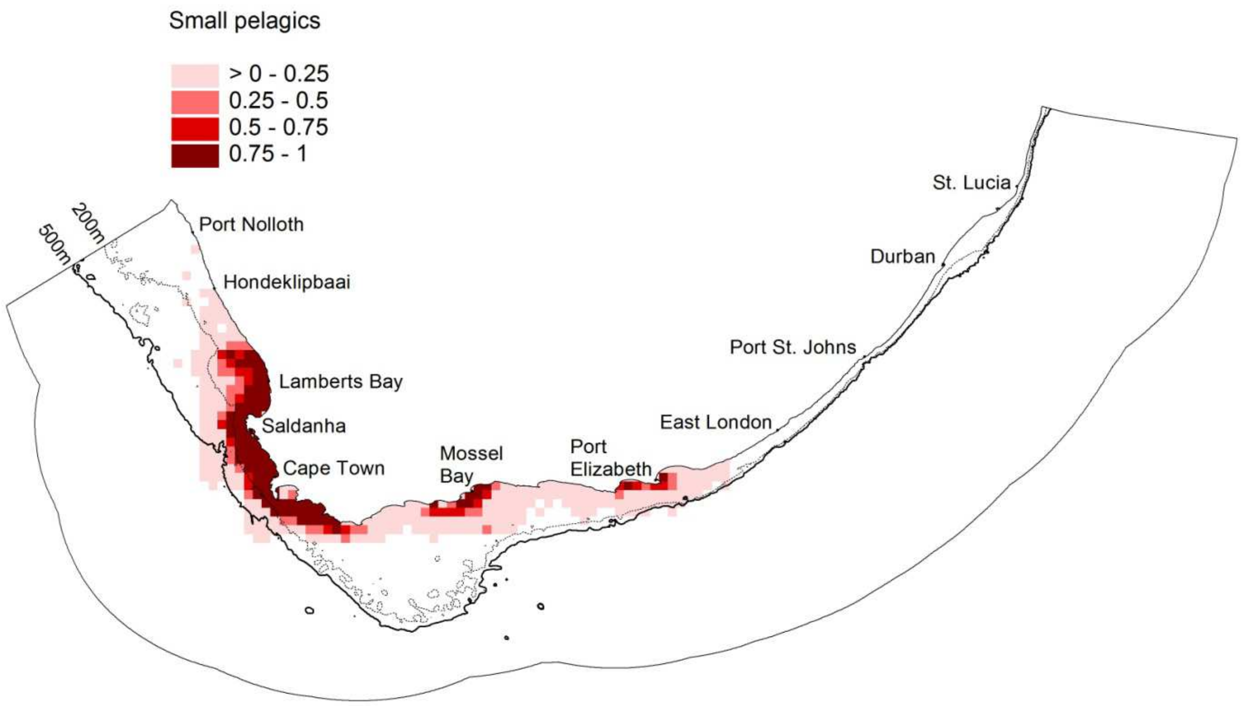


Figure 10: Scaled pressure values reflecting the catch of small pelagic fish in South Africa.

This fishery has made progress in terms of research to support the Ecosystem Approach to Fisheries (EAF) management with the development of biological and spatial ecosystem indicators (Pecquerie *et al.* 2004, Freon *et al.* 2005, Fairweather *et al.* 2006a, Fairweather *et al.* 2006b) and research to improve the understanding of spawning and recruitment dynamics (Twatwa *et al.* 2005, Roy *et al.* 2007). There is some concern about dumping in this fishery as observers have documented higher catch rates than those reported from vessels without observers, and low observer coverage (8%) is also of concern (Hutchings *et al.* 2009). Biodiversity concerns related to this fishery are centred on the important role that these fish play in marine foodwebs and in supporting threatened seabirds (Crawford 1999). These species play a crucial role in the transfer of energy between upper and lower trophic levels and changes in their abundance can have substantial impacts on the ecosystem (Cury *et al.* 2000, Griffiths *et al.* 2004). Small pelagic fishes are ranked at an intermediate trophic level, but, having large population sizes, exert top-down control on zooplankton and bottom-up control of predatory fish and marine birds. Cury *et al.* (2000) suggest that intense fishing of small pelagic populations can lead to reduced intra-specific genetic diversity. This threat is of concern as it could lead to a long-term reduction in resource productivity. Intensive fishing on the west coast (Figure 10) may also have contributed to the observed eastward shift of sardines (Coetzee *et al.* 2008). In South Africa, the potential impact of fishing for small pelagic species around breeding colonies of the endangered African penguin is currently under investigation.

3.2.5 Midwater trawl fishery

The midwater trawl fishery targets the semi-pelagic shoaling Cape horse mackerel or maasbanker *Trachurus trachurus capensis*, on the south coast in the 50-1000 m depth range (Figure 11). The midwater trawl fishery is focused on the Agulhas Bank (Kerstan and Leslie 1994), particularly on the shelf-edge along the south coast and it is reported that viable catches of horse mackerel are made only in this area (Sauer *et al.* 2003). It is interesting to note that this area occurs within a single "pelagic habitat" type (habitat Cb3 in Figure 6 and Table 3) as classified on the basis of physical oceanographic variables defined by Lagabrielle (2009).

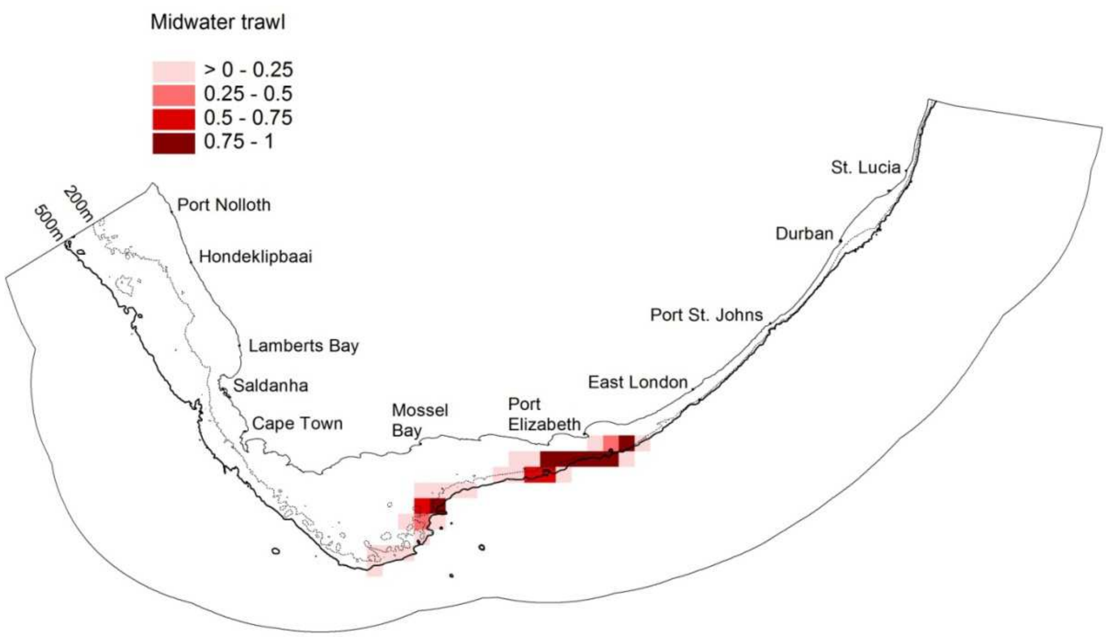


Figure 11: Scaled pressure values reflecting fishing effort for the midwater trawl sector in South Africa.

Current biodiversity concerns include:

- The current uncertain status of this resource (DAFF 2010)
- Uncertain bycatch
- Incidental entanglement and potential mortalities of seabirds, sharks, dolphins and seals and bycatch of sunfish *Mola mola* (Nel 2004, Atkinson and Sink 2008).

The bycatch species can include several demersal fish (e.g. shallow water hake) and meso-pelagic species such as chub mackerel *Scomber japonicus* and ribbon fish *Lepidopus caudatus* (Sauer *et al.* 2003). Midwater trawling is not considered to have significant impact on benthic biodiversity provided the fishery adheres to the definition of midwater trawling by not making contact with the seafloor (Atkinson and Sink 2008).

3.2.6 Crustacean trawl fishery

South Africa's crustacean trawl fishery is confined to the province of KwaZulu-Natal (KZN) and includes an offshore and inshore sector (Groeneveld & Melville-Smith 1995). The inshore crustacean trawl fishery operates primarily in water 20-45 m deep and is confined to the area within 0.5 to 7 nautical miles of the shore (Fennessy 1999, see Figure 12). The Tugela Bank is the primary inshore trawl area, but trawling also takes place off Richards Bay and St Lucia. The deepwater crustacean trawl fishery operates offshore, on the edge of the continental shelf in water 100-600 m deep from Port Edward to Cape Vidal, with highest effort offshore of Durban (Figure 12) (De Freitas 1989, Fennessy 1994a, Fennessy 1994b, Fennessy and Groeneveld 1997, Fennessy 1999, Forbes and Demetriades 2005, Atkinson and Sink 2008). The inshore fishery targets white prawns (*Fennereopenaeus indicus*), brown prawns (*Metapenaeus monoceros*), tiger prawns (*Penaeus monodon*) and bamboo prawns (*Marsupenaeus japonicas*), on the shallow water mud banks (Forbes and Demetriades 2005). The offshore crustacean trawl fishery targets langoustines (*Metanephrops mozambicus* and *Nephropsis stewarti*), pink prawns (*Haliporoides triarthus*), Natal deepwater rock lobster (*Palinurus delagoae*) and the east coast red crab (*Chaceon macphersonii*) (DAFF 2010). Slipper lobsters (*Ibacus novemdentatus* and *Scyllarides elizabethae*) also constitute a component of the retained bycatch (Sauer *et al.* 2003).

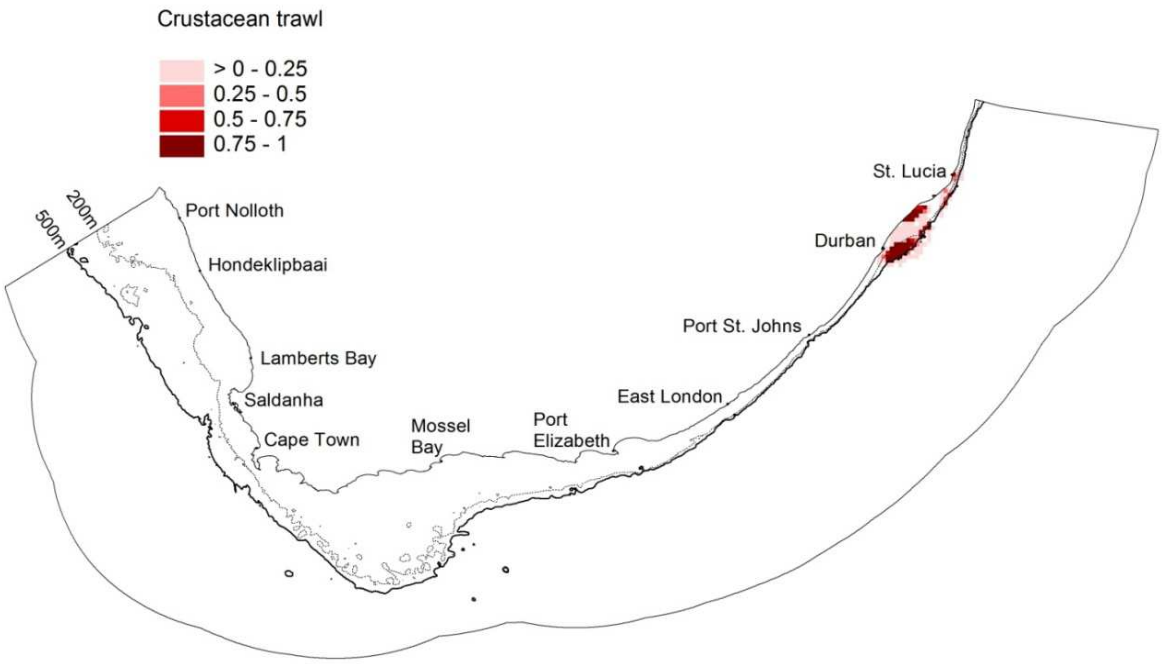


Figure 12: Scaled pressure values reflecting relative fishing effort for the crustacean trawl sector in KwaZulu-Natal.

Biodiversity concerns linked to the crustacean trawl fishery are reviewed by Atkinson and Sink 2008 and include:

- Impacts on unconsolidated sandy and muddy shelf habitats
- Impacts on rocky and unconsolidated shelf edge habitats by the offshore sector
- The diverse and substantial bycatch
- High rates of discarding
- Impacts on nursery habitats and juvenile fish
- Concerns about impacts on sharks, rays and overexploited linefish
- Incidental mortality of turtles (Fennessy and Isaksen 2007)
- Concerns about the sustainability of some deep water resources due to inadequate stock status information and the recognised vulnerability of slow-growing, deep-water species
- Incidences and risk of trawlers running aground leading to potential pollution impacts

The benthic impacts of crustacean trawling have not been examined in South Africa to date. Elsewhere investigations of the effects of prawn trawl fisheries on benthic communities have shown that epifaunal abundance and biomass values decrease substantially as a result of trawl disturbance (Hansson *et al.* 2000, Lindegarth *et al.* 2000, Tanner 2003). Impacts of a lobster trawl fishery in the Irish Sea, United Kingdom were shown to have significant negative effects on benthic infauna and epifauna (Hinz *et al.* 2009). Variations in gear type, fishing intensity and habitat type are reported to greatly influence the extent of trawl impacts on benthic biota.

Subtropical demersal communities are rich in species and endemics, and elasmobranchs, teleosts and invertebrates feature in trawler bycatch on the Tugela Bank (Fennessy 1994a, 1994b, Fennessy 1995, Fennessy 1999) and in the offshore sector (Sauer *et al.* 2003). Prawn trawling is one of the global fishing sectors with the highest discarded catch, accounting for one third of the global discarded catch (Alverson *et al.* 1994). DAFF (2010) reports that this fishery has up to 75% bycatch and discard rates. The average amount of bycatch discarded has been reported as 400 metric tons per year for the inshore trawl sector (Fennessy 1994a). The discards of the offshore fishery have not been formally investigated, but are thought to comprise about 70% of the total catch (Fennessy and Groeneveld 1997). Fishes that are currently not marketable, such as grenadiers (rat-tails), dominate the discards, followed by crustaceans, asteroids and molluscs that have no commercial value (Sauer *et al.* 2003). Estimates of approximately 10 000 sharks and rays caught per year as bycatch in the prawn trawl fishery (Fennessy 1994a, Fennessy 1994b) have been reported.

Aside from the considerable bycatch, the impact of inshore prawn trawling on nursery habitats is also of concern (Atkinson and Sink 2008). The area offshore of St Lucia is a spawning area for several species and serves as a nursery area for many species of teleosts, elasmobranchs and invertebrates (Wallace 1975, Whitfield 1998, Hutchings *et al.* 2002). These species frequently feature in prawn trawl catches. Fennessy (1994a, b) reported 26 elasmobranch species in trawl bycatch with large discards of newborn scalloped hammerhead sharks, *Sphyrna lewini,* by prawn trawlers on the Tugela Bank. Bycatch estimates for this species in this fishery range from an estimated 3288 sharks in 1989 to 1742 in 1992 (Dudley 2003). It is unknown whether the Tugela Bank is the only nursery ground for *S. lewini* off the South African east coast. If this is the case, the impact of the prawn trawlers on this species may be substantial (Dudley 2003). Offshore, elasmobranchs and unique faunal assemblages on the slopes are potentially very vulnerable to slope fisheries (Stephens *et al.* 2000).

Stock assessments of targeted prawns are challenging (DAFF 2010). Despite high variability in annual inshore prawn catches (linked to droughts and estuarine mouth closures), prawns are considered optimally exploited in South Africa (DAFF 2010) although the need for improved data collection and research is recognised for these fisheries. Shallow-water prawn catches have declined by about 90% between 2000 and 2008 due to the closure of the St Lucia mouth and associated recruitment failure (DAFF 2010). Landings of deep water prawns have increased in recent years and have been mostly stable over the past 15 years, whereas langoustine catches declined by about 40% between 2007 and 2008. Red crab catches declined by 45% between 2005 and 2008, with 30% decline between 2007 and 2008 (DAFF 2010). Catches of deepwater rock lobster declined by approximately 30% between 1992/3 and 2000 and declined by a further 50% between this period and 2003 (DAFF 2010), and have remained relatively stable at these low catch levels since 2003. Little is known about the biology of the deep-water prawns and langoustines but the deep water crustaceans are slow-growing and lobsters are likely to be vulnerable to overfishing, particularly in trawl fisheries (Berry 1969, Pollock 1989, Sauer *et al.* 2003, Groeneveld and Cockcroft 1997, Pollock *et al.* 2000).

3.2.7 South coast rock lobster trap fishery

This longline trap fishery targets the endemic south coast rock lobster *Palinurus gilchristi* in predominantly rocky areas in the 90- 200 m depth range between Cape Point and East London, as shown in Figure 13 (Pollock 1989, Groeneveld and Branch 2002). This resource has fluctuated since the inception of this fishery in 1974 with effort reductions and resource recovery measures implemented in the period between 1980 and 2001 (Pollock 1989, Pollock and Augustyn 1982, Sauer *et al.* 2003, Atkinson and Sink 2008, DAFF 2010). DAFF (2010) reports that the previous decline of the south coast rock lobster resource has been arrested through these management interventions and the resource is currently considered optimally exploited.

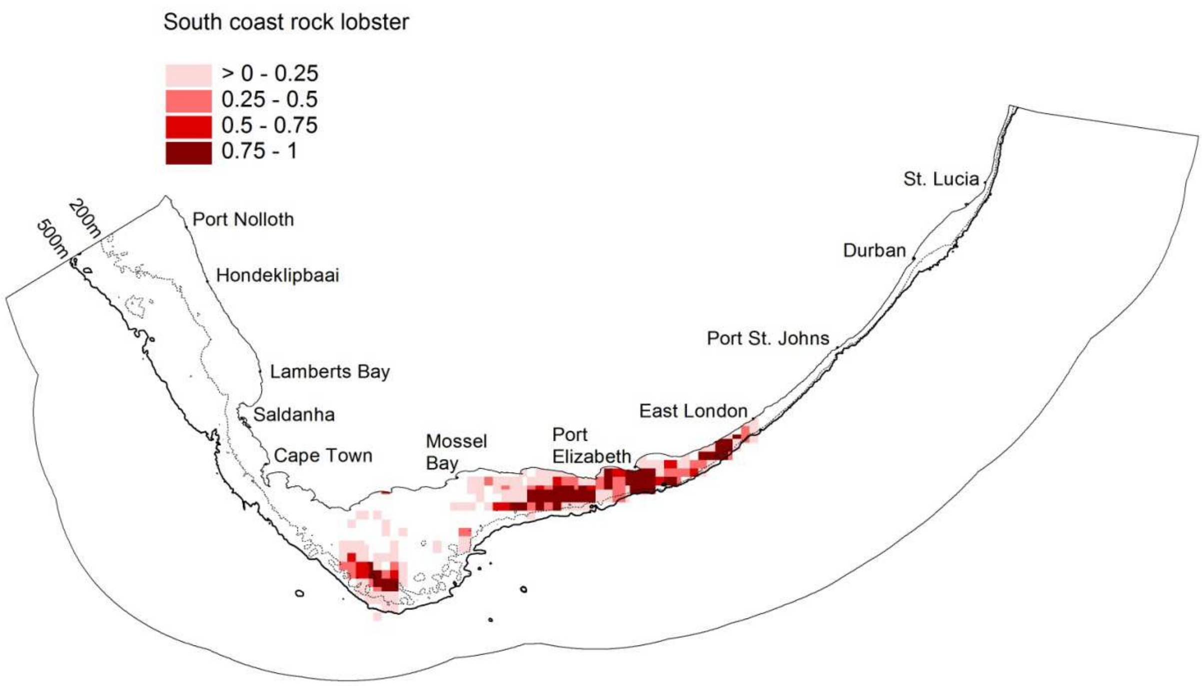


Figure 13: Scaled pressure values reflecting fishing effort for the south coast rock lobster fishery in South Africa.

Biodiversity considerations for this fishery include:

- The vulnerability and associated stock status concerns of the slow-growing target species (Groeneveld 1997, Groeneveld 2003, Pollock *et al.* 2000)
- Incidental bycatch of octopus, kingklip and slipper lobsters (Japp 2004)
- Occasional trap loss and potential associated ghost fishing (Japp 2004)
- Localised damage to the seabed through damage to benthic invertebrates (Japp 2004)
- Occasional incidences of whale entanglement (Atkinson and Sink 2008).

3.2.8 West coast rock lobster commercial fishery

The West Coast rock lobster fishery dates back to at least 1875 when the first commercial processing plant was established (Griffiths *et al.* 2004). This fishery targets the temperate, cold water, spiny lobster species *Jasus lalandii* and is South Africa's most valuable crustacean fishery on account of the high market value of this resource (DAFF 2010). The natural distribution range of this species stretches from Walvis Bay in Namibia to East London in South Africa. The South African commercial fishery operates between the Orange River mouth in the north to Danger Point in the south, extending to depths of more than 100 m (Figure 14). Two major fishing sectors harvest this resource; the offshore trap vessels operating in waters greater than 100 m depth, and the inshore sector that utilises hoop nets to harvest rock lobsters up to 1 nautical mile from the shore. The near-shore resource is also harvested by recreational fishers and the informal small-scale subsistence fishers operating only during summer months (Cockcroft & McKenzie 1997, DAFF 2010). The majority of the catch is apportioned to the offshore sector (80%) with a smaller portion (20%) being landed by the inshore sector.

Current biodiversity concerns associated with this sector include:

- Stock status concerns and declining growth rates (Cockcroft and Payne 1999, Pollock *et al.* 2000, DAFF 2010)
- Compliance concerns associated with this high value resource
- Occasional trap loss and potential associated ghost fishing (Atkinson and Sink 2008)
- Localised damage to the benthic invertebrates as traps are set on reefs (Atkinson and Sink 2008)

The commercial catch of west coast rock lobsters peaked in the early 1950s when an annual catch of 18 000 tons was recorded (DAFF 2010). Since the 1950s however, catches declined sharply even though several management measures were implemented e.g. minimum legal size limits and an annual total allowable catch (TAC) amount. During the 1990s a decrease in growth rate and poor recruitment further reduced total rock-lobster landings (Cockcroft and Goosen

1995, Cockcroft 1997, Cockcroft and Payne 1999), with the TAC being reduced to around half of what it was in the 1980s (Griffiths *et al.* 2004). The continued decline in catches is believed to be due to a combination of changes in fishing methods and gear efficiency, changes in management measures, overexploitation, poaching, environmental changes and reduced growth rates (DAFF 2010). As part of the TAC management system, annual catch limits are apportioned among the 10 traditional west coast fishing areas (from the Orange River mouth to Cape Hangklip). A general decrease in stocks along the west coast since the 1980s has been mirrored by an increase in the southern region (Cockcroft *et al.* 2008). An additional fishing ground was opened in False Bay in 1987 and following the sustained increase in rock lobster abundance east of Cape Hangklip (Tarr *et al.* 1996, Mayfield and Branch 2000), a further fishing ground was opened in this region in 1999. The traditional fishing areas along the west coast historically yielded up to 60% of the catch, however, they now yield only up to 40% of the annual total catch (Cockcroft *et al.* 2008, DAFF 2010). Under the current management framework, only hoop net fishers operating in the near-shore region are permitted to harvest rock lobster in the area from the Orange River mouth to the Brak River mouth (Zone A), in False Bay (Zone E) and in the most recently opened area east of Cape Hangklip (Zone F). Other management measures for this fishery include a prohibition of landing berried (with eggs) females and soft-shelled lobsters, a closed winter season, and a daily bag limit for recreational fishers (DAFF 2010).

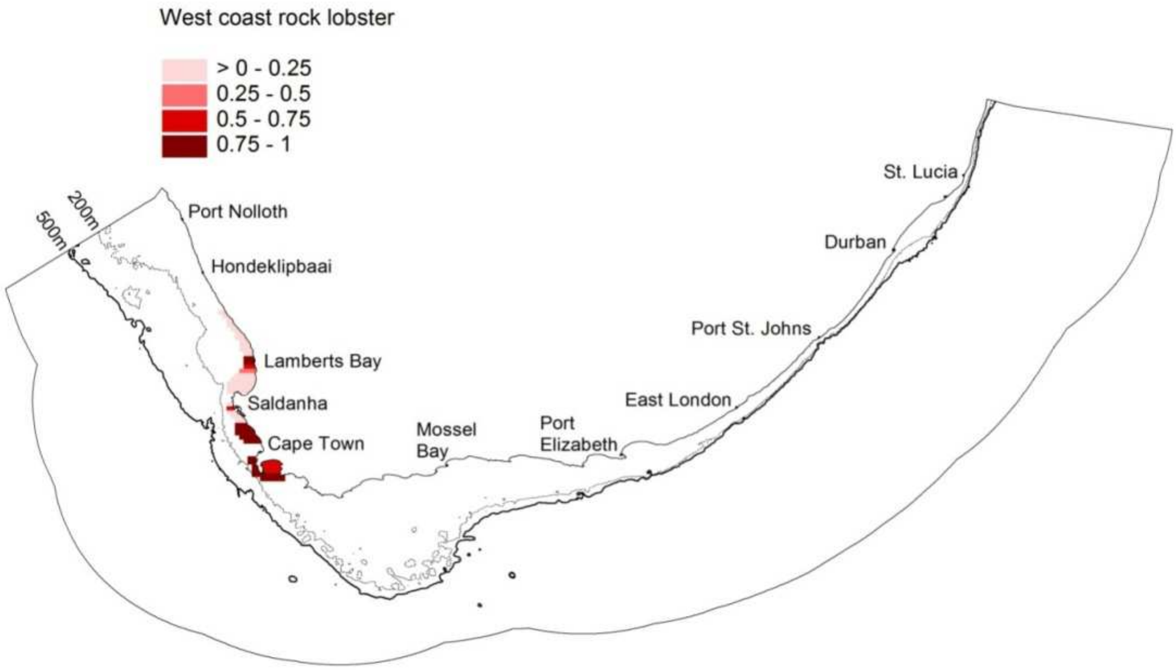


Figure 14: Scaled pressure values reflecting fishing effort for the west coast rock lobster fishery in South Africa.

In 2000, the South African rock lobster resource was estimated to be at 5% of pre-exploitation levels (the biomass > 75 mm CL) and the spawning biomass at 20% of pristine levels (Pollock *et al.* 2000). A stock assessment conducted in 2006 indicated that this resource had declined to 2.6% of pristine biomass levels but a further 3 years of stringent management has led to increases in biomass with current (2009) estimates at 3.4% of pristine biomass (DAFF 2010). Stock concerns, distribution shifts and associated ecosystem changes and declining growth rates remain the key biodiversity considerations for this important sector. This resource is set to recover if resource allocations remain within safe and sustainable limits and poaching is effectively reduced and managed.

3.2.9 Squid fishery

The chokka squid *Loligo reynaudii* have been targeted in South Africa for many years and the squid jig fishery makes a significant contribution to the economy of the South Eastern Cape coastal region. The South African line-fishery for squid developed along the south coast in the early 1980s where spawning aggregations between Plettenberg Bay and Port Elizabeth were targeted (Augustyn and Smale 1989). This fishery is somewhat seasonal (main season October-March) targeting adult squid in spawning aggregations. In winter, squid fishing takes place in deeper water where the use of lights is employed. *L. reynaudii* occur from Namibian waters in the west to the Wild Coast region in the east, and spawn and lay their eggs on the seabed. Most fishing takes place between Plettenberg Bay and Port Alfred (Roberts and Mullon 2010), between 20 m and 120 m depth range but effort is highest in water shallower than 40 m (DAFF 2010) (Figure 15). The squid resource is currently considered to be optimally exploited but uncertainties in the reliability of catch and effort data (due to changes in reporting systems) result in a lack of confidence or certainty in current assessments (DAFF 2010).

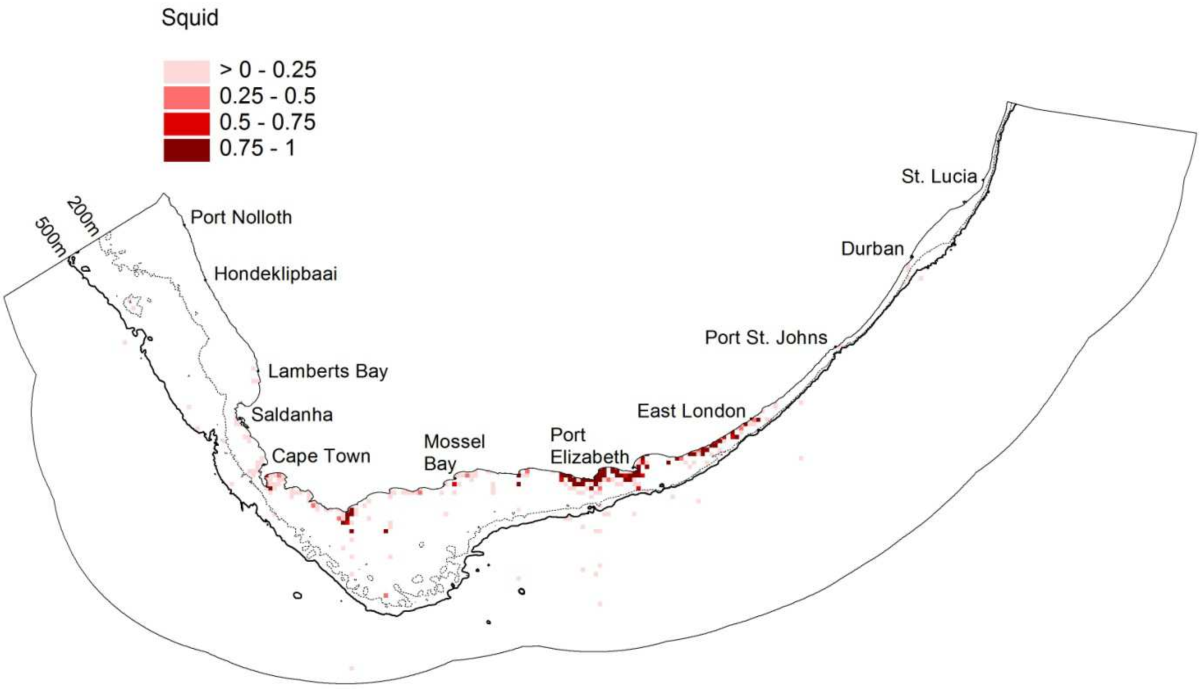


Figure 15: Scaled pressure values reflecting relative fishing effort for the squid fishery in South Africa.

The squid jig fishery has relatively little impact on other species and this fishery is considered to have very low impacts on biodiversity overall (Petersen and Nel 2007, Atkinson and Sink 2008). Benthic habitats are not damaged and bycatch is considered negligible. Key biodiversity concerns include:

- The potential trophic impacts on squid predator populations (seals, linefish, cetaceans, sharks and seabirds, Atkinson and Sink 2008)
- Plastic pollution from squid boats (Petersen and Nel 2007)
- Potential effects from the use of bright lights at night.

3.2.10 Commercial Linefishing

Linefishing has a long history in South Africa dating as far back as the 1500s (DAFF 2010). The South African commercial linefishery is a multispecies fishery which stretches from Port Nolloth on the west coast to Cape Vidal on the east coast (Figure 16). Biodiversity concerns for this sector are centred on the poor stock status of many linefish species, the lack of, or outdated stock assessments for several species and the potential impact of reduced linefish populations on marine ecosystems (Attwood and Farquhar 1999, Penney *et al.* 1999, Toral-Grande *et al.* 1999, Griffiths 2000, Mann 2000, Götz *et al.* 2009a, Götz *et al.* 2009b, Blamey 2010, DAFF

2010). South Africa's commercial linefishery has been characterised by rapid expansion and substantial effort increases through increased access and advances in fishing technologies leading to serial overfishing and a rising number of over-exploited and collapsed species (Penney *et al.* 1999, Griffiths 2000, Mann 2000). Serial overfishing is when fishers serially exploit different areas, shifting their focus of effort onto previously un-fished reefs as highly resident species are depleted from heavily fished sites (Penney *et al.* 1999, Booth and Hecht 2000).

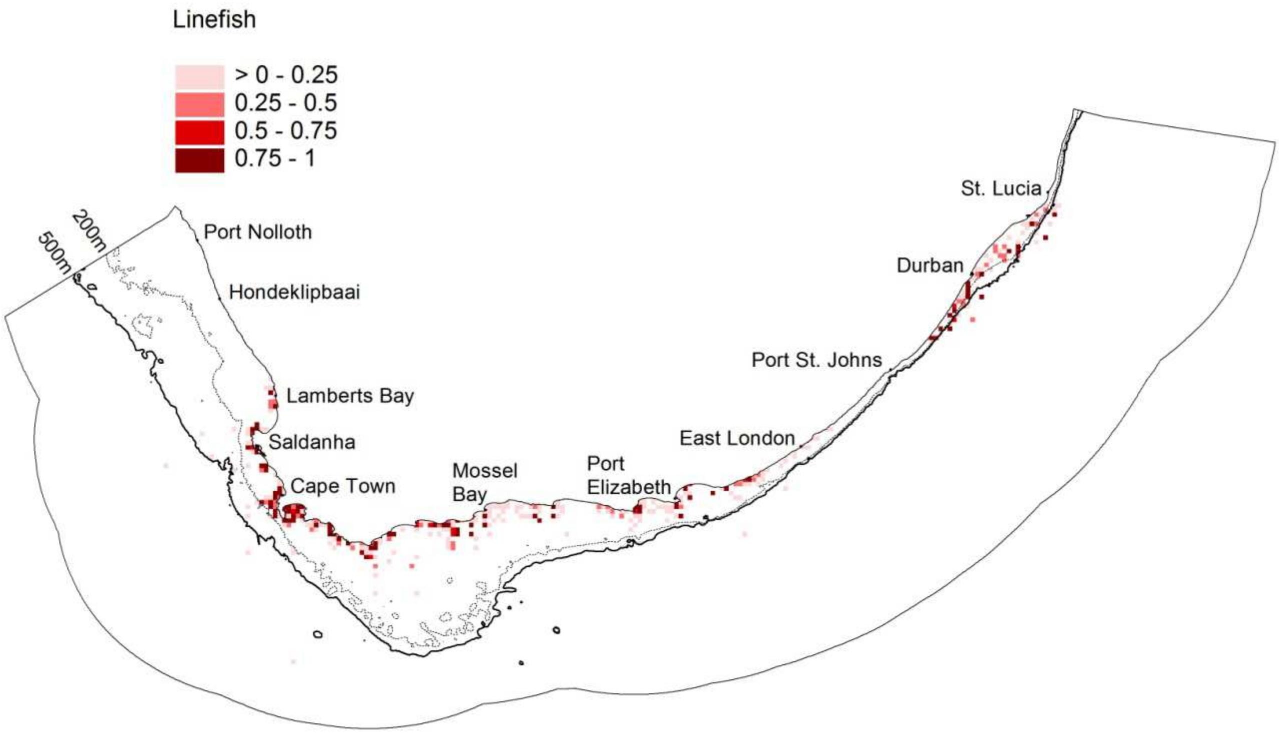


Figure 16: Scaled pressure values reflecting relative fishing effort for the commercial line fishery in South Africa.

Approximately 200 species have been reported in catches for this sector, although only 35 species make up the majority of catches (DAFF 2010). Several factors are thought to be contributing to the demise of linefish stocks. These include increased commercial and recreational fishing effort, a recent upsurge in subsistence/small-scale commercial effort and poor compliance. Furthermore, vulnerable life history traits (e.g. predictable locality, residency, longevity, late maturity, sex change, barotrauma and estuarine dependence for some species) make linefish species particularly susceptible to over-exploitation (Garratt 1985, Buxton 1993, Griffiths 2000, Mann 2000). The traditional linefishery targets sharks when high-value teleosts are not available and is responsible for the highest catches of smoothhound and soupfin shark

(Da Silva and Burgener 2007, Da Silva 2007). Several other species, such as the spiny dogshark and several carcharinids such as dusky sharks and bronze whalers are also commonly caught. South Africa's linefishery was declared in a State of Emergency in 2000 as a result of the critical status of many linefish stocks. Mann (2000) co-ordinated the most recent linefish status reports reflecting that many species are collapsed or overexploited. Since then, further specialised studies on some fish species further confirm the increasingly deteriorating status of linefish (Griffiths 2000, Griffiths and Wilke 2002, Griffiths & Lamberth 2002, Brower *et al.* 2005a, b, Kerwath *et al.* 2007a, Kerwath *et al.* 2007b). Despite new management measures, including substantial commercial effort reductions, there are few published signs of recovery and the catch rates of most linefish are reported to be continuing to decline (DAFF 2010) (see Section 10.1 - *Fisheries species*). However, updated stock assessments and other trends are urgently needed. Recovery of some species may be hampered by exploitation in other fisheries, as linefish also form an important component of the catch or the bycatch of other fisheries sectors (Fennessy 1994, DAFF 2010, Attwood *et al.* 2011).

Linefishing impacts target and non-target fish species and there is evidence that fishing alters reef ecosystems through indirect effects on benthic assemblages (Pinnegar *et al.* 2000, Götz *et al.* 2009 a, b). Declines in reef fish may also have affected the link between the reef ecosystem and the pelagic food web (Attwood *et al.* 2000). Anchoring, particularly on deep reefs may cause localised damage to stylasterine and black corals, gorgonians and other slow-growing habitat-forming reef biota. There are anecdotal reports of such taxa being retrieved on anchors (Atkinson and Sink 2008).

3.2.11 Tuna pole fishery

South African tuna fisheries are described in Shannon *et al.* (1989) and Hampton *et al.* (1999) with a more recent overview published in Atkinson and Sink (2008). Tuna were considered rare in South African waters prior to 1945 and fetched a relatively low price until the late 1980's (Shannon *et al.* 1989). Today, the tuna pole fishery in South African waters represents approximately 200 boats, which mainly target albacore *Thunnus alalunga* and juvenile yellowfin tuna *Thunnus albacores* (Atkinson and Sink 2008, DAFF 2010). The South African tuna pole fishery largely operates on the west coast of South Africa, within the 200 nautical miles fishing zone, particularly between 29° and 32°S, targeting the southern Atlantic tuna stock (Figure 17). Less than 1% of the tuna pole catch is caught eastwards of the 20°E longitude line. Tuna fishermen focus their effort along the shelf edge with highest reported effort between Lamberts Bay and the Southern tip of the Agulhas Bank and in the vicinity of the submarine bank known as Childs Bank (Figure 17). Shannon *et al.* (1989) report that the Cape Valley and the area between Cape Canyon, off Cape Point and Dassen Island respectively, are important tuna fishing areas because of upwelling and the position of the oceanic thermal front close to the coast in these areas.

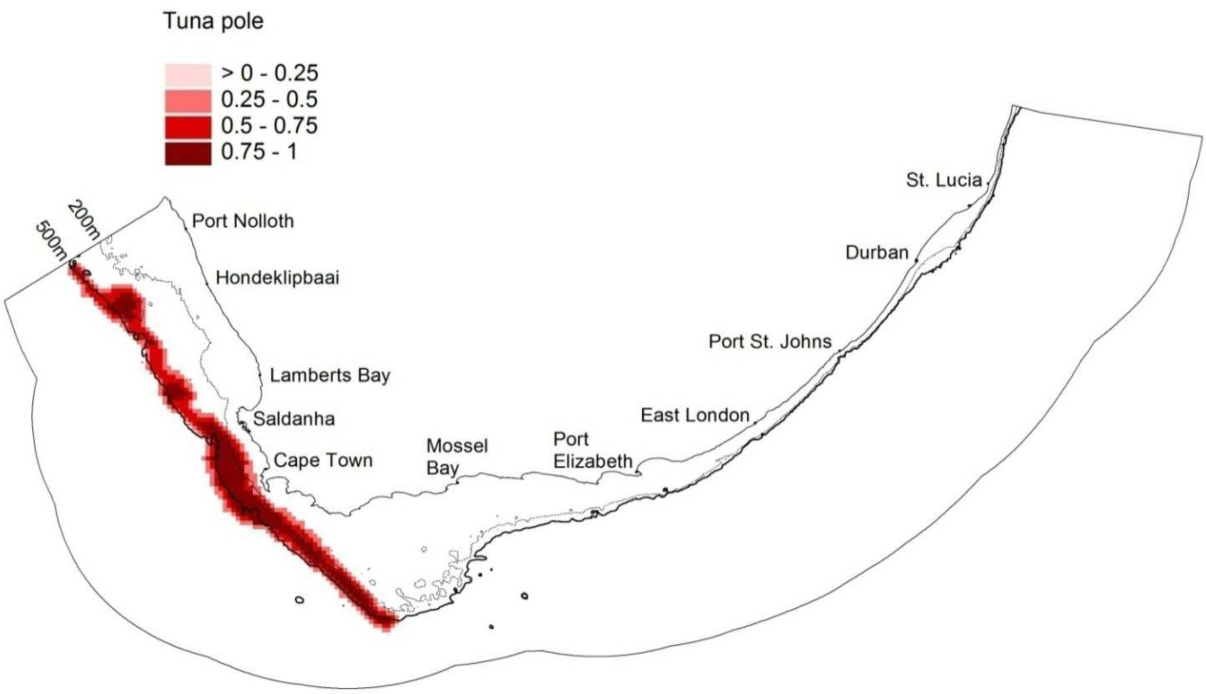


Figure 17: Scaled pressure values reflecting estimated current fishing effort for the tuna pole fishery in South Africa.

The biodiversity concerns associated with this sector are centred on:

- Stock concerns.

The tuna pole fishery is a highly targeted fishery with virtually zero unintentional bycatch. The targeted migratory tuna species are observed through international organizations (RFMOs). The stock status of albacore is considered optimally exploited although age structured models have shown that stock rebuilding is needed to achieve maximum sustainable yield (MSY) (DAFF 2010). There is uncertainty regarding the stock delineation of yellowfin tuna caught in South Africa but the Indian Ocean Tuna Commission has expressed concern about the stock status of Indian Ocean stocks since 2003 and considers current fishing levels to be unsustainable (DAFF 2010).

3.2.12 Shark fishing

Cartilaginous fishes such as sharks, rays and chimeras are captured in South Africa by a number of fisheries. Two main commercial sectors target sharks, 1) the pelagic shark longline fishery that arose as a consequence of shark bycatch from the pelagic longline fishery and 2) a demersal fishery that targets benthic sharks such as the genus *Mustelus* spp. (smooth-hound sharks) and *Galeorhinus* spp. (soupfin sharks) but also takes several other species such as the cowshark (family Hexanchidae) as bycatch. Shortfin mako (*Isurus oxyrinchus*) is also the main target of the shark directed pelagic longline fishery although blue shark (*Prionace glauca*) seems to dominate recent catches (DAFF 2010).

Commercial fisheries effort and catch data were processed to map the relative effort of shark fisheries within the South African EEZ (Figure 18). Highest effort is recorded along the shelf edge between Port Alfred and Lamberts Bay, in the vicinity of Childs Bank off Hondeklipbaai and in inshore areas near Cape Town, Mossel Bay and Port Elizabeth. Targeting of pelagic sharks is concentrated on the shelf edge with highest effort on the eastern edge of the Agulhas Bank, the western edge (an area known as Brown's Bank) and off Port Elizabeth. Effort for demersal sharks is less than that for pelagic species with effort concentrated closer inshore and in shallower water. Fishing for demersal sharks is confined to water depths of less than 100 m (DAFF 2010) and permit conditions prevent the demersal shark sector from operating eastwards of East London. Although more than 30 permits were issued in the demersal shark fishery in 1998, there are currently only 6 permits allocated for this fishery (DAFF 2010). A phase out of the shark directed fishery is planned for 2011 and the rights in this fishery are accommodated within the tuna directed fishery. Currently there is a total upper limit of 2000t for shark catches in the longline fleet and a 10% bycatch limit for the tuna directed sector. These limits will be revised once the fisheries have been combined.

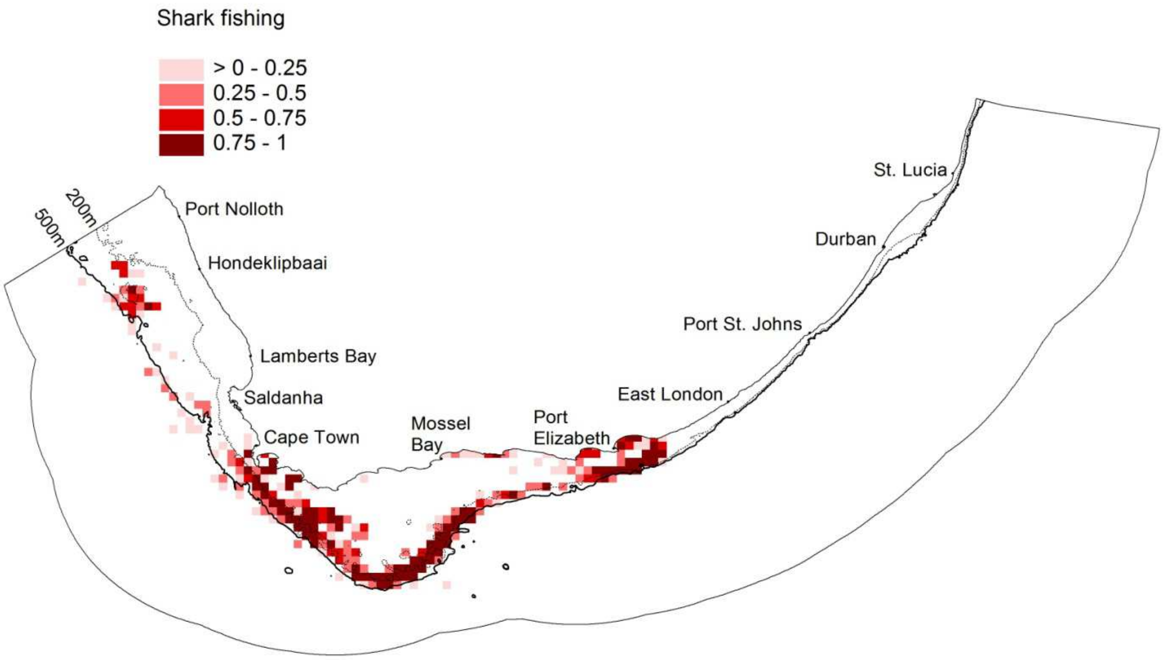


Figure 18: Scaled pressure values reflecting fishing effort for pelagic and demersal sharks in South Africa.

Biodiversity concerns for shark fisheries are centred on the status and vulnerability of target species and the potential ecosystem impacts as a result of removal of top predators. Sharks are long-lived, apex predators of marine ecosystems, displaying low fecundity, slow growth rates and late maturation, making sharks particularly susceptible to overexploitation (Stephens *et al.* 2000). South Africa has only assessed the stock status of 2 shark species, these being smoothhound *Mustelus mustelus* and soupfin sharks *Galeorhinus galeus*, both of which are considered to be overexploited (DAFF 2010). The responsibility of assessing stock status for most pelagic species is assigned to Regional Fisheries Management Organisations (RFMOs) such as the Indian Ocean Tuna Commission (IOTC) and the International Commission for the Conservation of Atlantic Tunas (ICCAT). Stock assessments for Atlantic blue *Prionace glauca* and mako sharks *Isurus oxyrinchus* conducted by ICCAT were inconclusive due to poor quality data and high levels of under-reporting (DAFF 2010). These organisations are unable to adequately assess the stock status of sharks due to poor life-history data. There is global concern about the conservation status of several shark species. South African shark fisheries target several species that are listed as threatened species by the IUCN including soupfin *Galeorhinus galeus* (Vulnerable) and smoothhound *Mustelus mustelus* (Vulnerable), the oceanic white tip *Carcharhinus longimanus* (Vulnerable), longfin mako *Isurus paucus* (Vulnerable), great hammerhead *Carcharhinus longimanus* (Endangered – but not commonly caught in South Africa) and spiny dogfish *Squalus acanthias* (Vulnerable). There are currently concerns in South Africa that mako sharks may be overexploited and that the increased catch rates of blue sharks may represent a switch in targeting from mako to blue sharks (DAFF 2010).

Removal or depletion of shark populations could have negative effects on functioning of marine ecosystems and these fisheries need to be managed with caution. Large predators are important in structuring marine ecosystems and may play a key role in the maintenance and stability of foodwebs (Stevens *et al.* 2000). High bycatch of hake (*Merluccius spp.*) and kingklip (*Genypterus capensis*) in the demersal shark longline fishery is also of concern and bycatch limits are currently in place to restrict targeting of these bycatch species with further reductions in bycatch limits under consideration (DEAT 2005 - Demersal Shark Policy).

3.2.13 Large pelagic longline fishery

The South African pelagic longline fishery dates back to the early 1960s, when the fishery targeted albacore (*Thunnus alalunga*), southern bluefin tuna (*Thunnus maccoyii*) and bigeye tuna (*Thunnus obesus*) in relatively small quantities (Shannon *et al.* 1989, Petersen *et al.* 2007). This fishery expanded as a result of bilateral agreements being introduced which targeted tuna and swordfish, and the establishment of an experimental fishery to target mostly tuna between 1997 and 2004. This culminated in the establishment of a formal commercial sector in 2005 (DAFF 2010) with an allocated country quota for the internationally governed species (e.g. albacore, swordfish and bluefin tuna). At the inception of this experimental fishery (between 1997 and 1999) swordfish were the most abundant species caught, comprising 70% of the landed catch (Kroese 1999). The catch composition changed due to local depletion of swordfish. As fleets moved into temperate and offshore waters, more temperate tuna were caught, such that swordfish comprised only 21% of the catch (Govender *et al.* 2002). The pelagic longline fishery targets highly migratory species and permit holders primarily target large tuna (bigeye, *Thunnus obesus* and yellowfin, *Thunnus albacares*) for the Japanese *sashimi* market, and swordfish (*Xiphias gladius*) for fresh (iced) export. Many of these vessels are reported to fish near the edge of, or on, the continental shelf (Sauer *et al.* 2003, Petersen *et al.* 2009d). The intense fishing effort along the shelf edge is reflected in Figure 19.

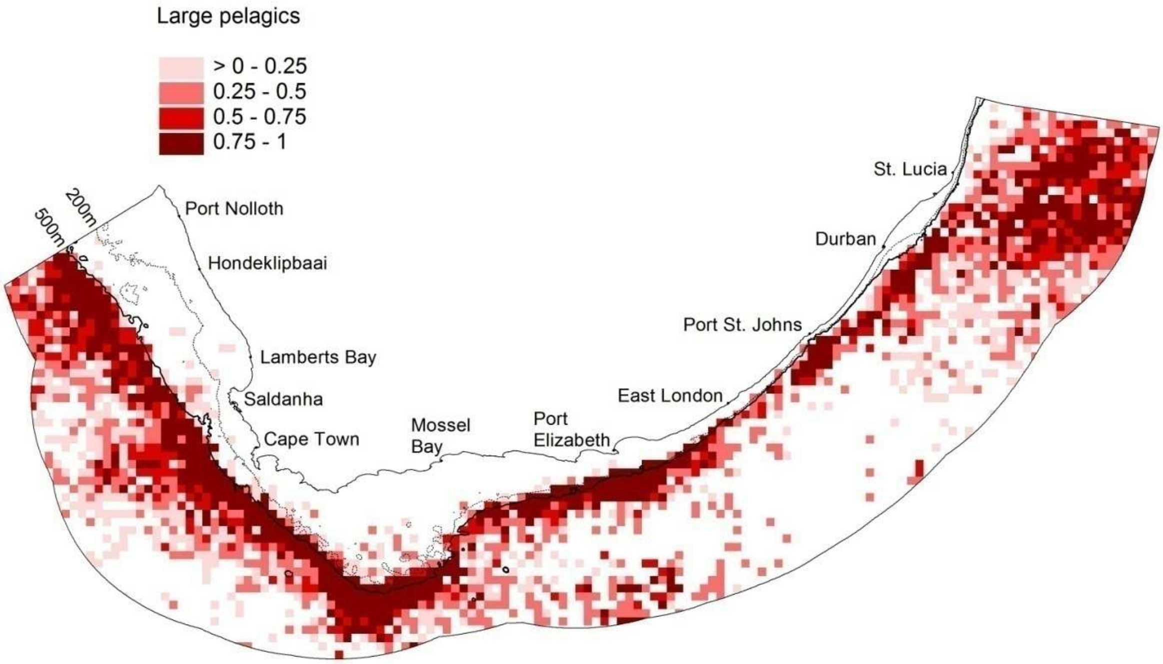


Figure 19: Scaled pressure values reflecting fishing effort (no. of hooks) for the large pelagic longline fishery in South Africa.

Management of these highly migratory species is the responsibility of RFMOs. Albacore (Atlantic and Indian), yellowfin and bigeye tuna are considered optimally exploited (DAFF 2010). The IOTC has expressed concern about yellowfin tuna stocks but the origin of yellowfin tuna caught in South Africa is uncertain. Swordfish are considered to be overexploited in the Indian Ocean but not overexploited in the Atlantic Ocean. Southern bluefin tuna *Thunnus maccoyii* are considered overexploited (DAFF 2010) and globally have been listed as Critically Endangered by the IUCN.

Biodiversity concerns associated with the large pelagic sector include;

- Concern for swordfish stocks in the Indian Ocean and global concern about the stock and conservation status of Southern bluefin tuna.
- Bycatch of 26 species of sharks with estimates ranging between 39 200 to 73 500 sharks per year (Petersen *et al.* 2009d). Several shark species caught by this sector are listed as threatened species, including the endangered scalloped hammerhead and 6 shark species that are listed as vulnerable (Petersen *et al.* 2009d)
- Incidental mortality of 11 seabird species, including 8 threatened species (Ryan *et al.* 2002, Peterson *et al.* 2009b). Annual mortality estimates decreased from approximately 5900 birds in 1998 to 1800 in 2005 (Peterson *et al.* 2009b).

- Incidental mortality of turtles with estimates of approximately 190 turtles caught per year, including 100 endangered loggerhead turtles and 50 critically endangered leatherback turtles (Peterson *et al.* 2009a)
- Interactions between longliners targeting swordfish and killer whales has resulted in concern for these marine mammals that have reportedly been chased or shot at to prevent stealing of bait (Govender *et al.* 2002)

Of these biodiversity concerns, the bycatches of sharks and seabirds are most serious. Shark species most frequently caught by this sector include blue and mako sharks, both of which have shown a decline in catch per unit effort and average length (Petersen *et al.* 2009d), which may be as a result of overfishing. The stock status of many sharks is considered uncertain in South Africa due to a paucity of data. The high global catches of pelagic sharks and their vulnerable biology have raised international concern for these species. The IUCN has listed several sharks caught by this sector as threatened. Considering the overexploited and uncertain fishery status of many South African sharks, their poor international conservation status and the vulnerability of sharks to overexploitation, improved management measures are needed to limit shark bycatch in this fishery. RFMOs have called for a capping of fishing effort on sharks and protection of nursery grounds as precautionary management measures for these species.

The most frequently accidentally caught seabird in this fishery is the white-chinned petrel, a species classified as Vulnerable by the IUCN. There is also concern about catch rates of endangered black-browed albatrosses, endangered yellownosed albatrosses and shy-type albatrosses (Petersen *et al.* 2009d). The critically endangered Tristan albatross has also been caught by this sector within South Africa's EEZ (Peter Ryan unpublished data). Mitigation measures (e.g. tori lines) have helped to reduced seabird bycatch in this fishery but there is a need for further reductions and compliance urgently needs to be improved (Petersen *et al.* 2009d).

3.2.14 Kelp harvesting

Kelp harvesting includes the harvesting of fresh kelp from live stocks as well as the removal of kelp from beaches that has washed up in the surf, referred to as beach-cast kelp (DAFF 2010). The South African seaweed industry is based mainly on the harvesting of the kelp *Eklonia maxima* for abalone mariculture as feed and for use in other kelp-based products, and the red seaweeds *Gelidium* and *Gracilaria* for agar. The harvesting of red algae was not mapped and therefore the potential impact of this activity was not considered in this study.

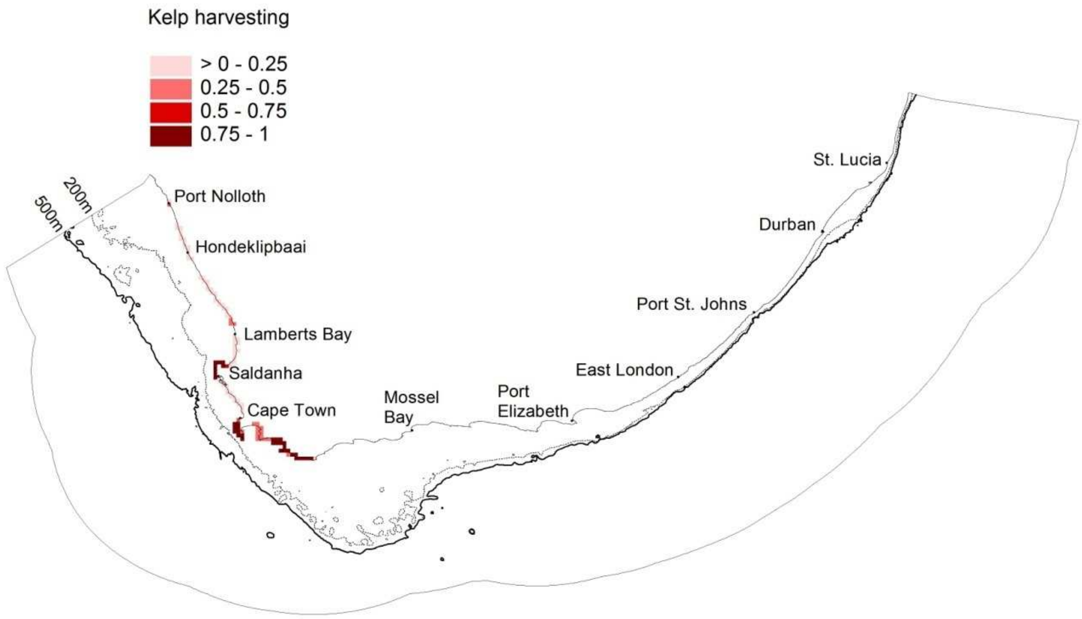


Figure 20: The distribution and scaled pressure values for kelp harvesting in South Africa.

Fresh kelp is harvested along the coastline between Port Nolloth to Cape Agulhas (Figure 20), with large quantities being harvested mainly in the Western Cape driven by the demand for feed for local abalone farms. A study conducted at Danger Point (Levitt *et al.* 2002) on the effects of harvesting of *E. maxima* found that complete removal of whole organisms resulted in a 2 year recovery period with minimal impact on the understory biota, but also showed that optimal sustainable harvesting is possible if only the fronds of plants are collected, resulting in minimal disturbance to the kelp ecosystem. Kelp harvesters are supplied with a "Kelp Harvesting Manual", which sets out best practices to ensure sustainability, and current harvesting levels of kelps are considered sustainable (DAFF 2010). Kelp also provides an important food source to intertidal and subtidal consumers (Bustamante and Branch 1996a, Bustamante and Branch

1996b), with both filterfeeders and grazers on the west coast dependent on kelp-derived organic matter.

Harvesting of beach-cast kelp impacts beach ecosystems because this wrack is an important food source for sandy beach macrofauna (Dugan *et al.* 2003) and interstitial fauna, including microbes (Koop & Griffiths, 1982; see Kirkman and Kendrick 1997 for a review). In addition, kelp wrack play an important role in climate regulation with wrack piles on sandy beaches having higher CO_2 efflux rates than rain forests (Coupland *et al.* 2007). Beach-cast kelp harvesting or beach grooming removes this valuable wrack as well as the wrack-associated organisms, particularly amphipods, with knock-on implications for foraging seabirds (Dugan *et al.* 2003). In addition, it reduces native plant abundance and diversity (Dugan and Hubbard 2010). The impacts on beach fauna can be detrimental to the beach ecosystem, because these animals play an important ecological role in terms of kelp breakdown (Lastra *et al.* 2008) and nutrient remineralisation, which is subsequently important for driving phytoplankton communities (McLachlan *et al.* 1985, Koop and Griffiths 1982).

3.2.15 Shark control program

Shark nets have been set off the beaches of KwaZulu-Natal since 1952 to protect bathers from the risk of shark attack. Further details of the history of the shark control program are published by Davies (1964), van der Elst (1979), Dudley (1997), Dudley and Simpfendorfer (2006), Dudley and Cliff (2010) and Cliff and Dudley (2011). The shark control program had a peak of net installations in 1989 with a total of 45 km of nets at that time (Dudley and Simpfendorfer 2006). Netting has been reduced since then with 28 km of nets reported in 2003 and 23 km nets at present (Cliff and Dudley 2011). In some areas, nets have been replaced with drumlines, a more selective shark fishing device (see Cliff and Dudley 2011). Nets are also removed during the annual sardine run to reduce mortalities on sharks and other species. The shark control program extends from Richards Bay to Port Edward (Figure 21). The scaled pressure values reflected in Figure 21 may underestimate the impact of the shark control program but reflect areas where localised shark depletion may have occurred. The nomadic and migratory nature of many sharks is difficult to account for in such a spatial assessment and the impacts of the shark control program may be far more widespread.

Key biodiversity concerns associated with the shark control program include:

- The overexploited status of several elasmobranch species
- Potential ecosystem effects linked to the removal of sharks

- Bycatch of harmless elasmobranchs, marine mammals and turtles

A large variety of elasmobranch species are captured by the Natal Sharks Board in large-mesh gillnets set along some of KwaZulu-Natal's popular bathing beaches. The impacts on sharks have been examined (Dudley and Cliff 1993, Dudley and Simpfendorfer 2006 and references therein). Dudley and Simpfendorfer (2006) recently assessed the population status of 14 commonly caught species using catch rate and size trends. The nets are deemed to have potentially high impacts on two species; the dusky shark *Carcharhinus obscurus* and the raggedtooth shark *Carcharias taurus,* linked to the low intrinsic rates of population increase for these species. However, neither of these species showed indication of decline between 1987 and 2003 although careful monitoring is recommended for these species. Moderate impacts were estimated for Zambezi sharks *Carcharhinus leucas* and the scalloped hammerhead *Sphyryna leweni* and low impacts were assessed for other shark species (Dudley and Simpfendorfer 2006). Sharks are characterized by slow growth rates, late maturity, low reproductive output and longevity. These lifestyle characteristics make sharks vulnerable to overexploitation which is considered the most significant threat to sharks. Shark control programs add to the already severe pressure on elasmobranchs from other fisheries, particularly longlining and trawl fisheries.

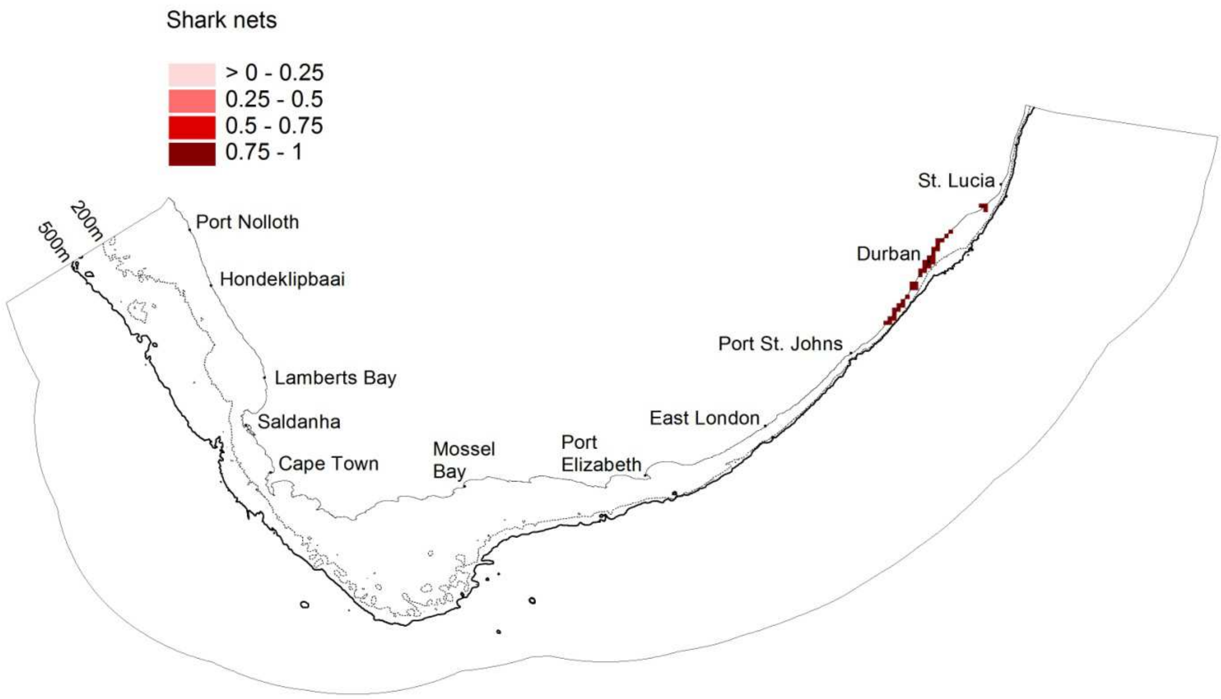


Figure 21: The estimated area of influence of South Africa's shark control program.

The removal of large numbers of top predators by this inshore fishery may also have resulted in ecosystem impacts (Van der Elst 1979, Stephens *et al.* 2000). Van der Elst (1979) showed an increase in the CPUE of small sharks in the 1970s and predicted a 40-fold increase in dusky sharks by the early 1980s, but this prediction was countered by Dudley and Cliff (1993) who found no evidence of increased dusky shark numbers. Ecosystem effects from shark control programs are difficult to quantify and remain poorly understood (Dudley and Simpfendorfer 2006, Dudley and Cliff 2010).

Incidental bycatch of rays, large teleosts, turtles and dolphins and other marine mammals are also associated with shark control programs (Paterson 1979, 1990, Cockcroft 1990, Dudley and Cliff 2010). In South Africa, about 60 dolphins (4 species) are caught a year in the shark nets but there is specific concern about the impact of the shark nets on the Indo-Pacific Humpback Dolphin *Sousa chinensis,* population estimates of which are below 200 in KwaZulu-Natal (Cockcroft 1990). Dudley and Cliff (2010) however report no decline in catches of bottlenose or humpback dolphins in the nets and “pingers” have been deployed on some nets in an attempt to further reduce dolphin catches. Approximately 51 turtles are caught in the nets every year but approximately half of these are released alive (Dudley and Cliff 2010). Increasing problems with the entanglement of baleen whales is a concern in all shark control programs (Dudley and Cliff 2010). Drumlines have been shown to be similarly effective at control of dangerous sharks when compared to shark nets but have lower bycatch (Dudley and Cliff 2010).

3.2.16 Mariculture

Mariculture operations along the South African coast take the form of in-situ marine operations (i.e. those using long-lines, rafts, racks or cages suspended directly in the sea) and land-based operations that abstract sea water, pass it through the culture facility, and then return it to the marine environment. In total 20 species are cultured in operations that have connections to the sea. These include two algae (*Gracilaria gracilis, Ulva lactuca*); four oysters (*Crassostrea gigas**, Ostrea atherstonia, Pinctada capensis, Striostra margaritacea*); three mussels (*Choromytilus meridionalis, Mytilus galloprovincialis**, Perna perna*); two scallops (*Argopecten purpuratus**, Pecten sulcicostatus*), two clams (*Mactra glabrata, Venerupis corrugatus* one abalone (*Haliotis midae*), one ascidian (*Pyura stolonifera*), one prawn (*Litopenaeus vannamei**) and four fish (*Argyrosomus inodorus, Argyrosomus japonicas, Atractoscion aequidens, Seriola lalandi*). Four of these cultured species (indicated by * above) are alien to South African waters. Of these *M. galloprovincialis* and *C. gigas* are recognised as invasive alien species (Mead *et al.*

2011a,b). While *L. vannamei* is currently restricted to culture facilities in South Africa it has escaped and established populations in other regions (Senanan *et al.* 2007).

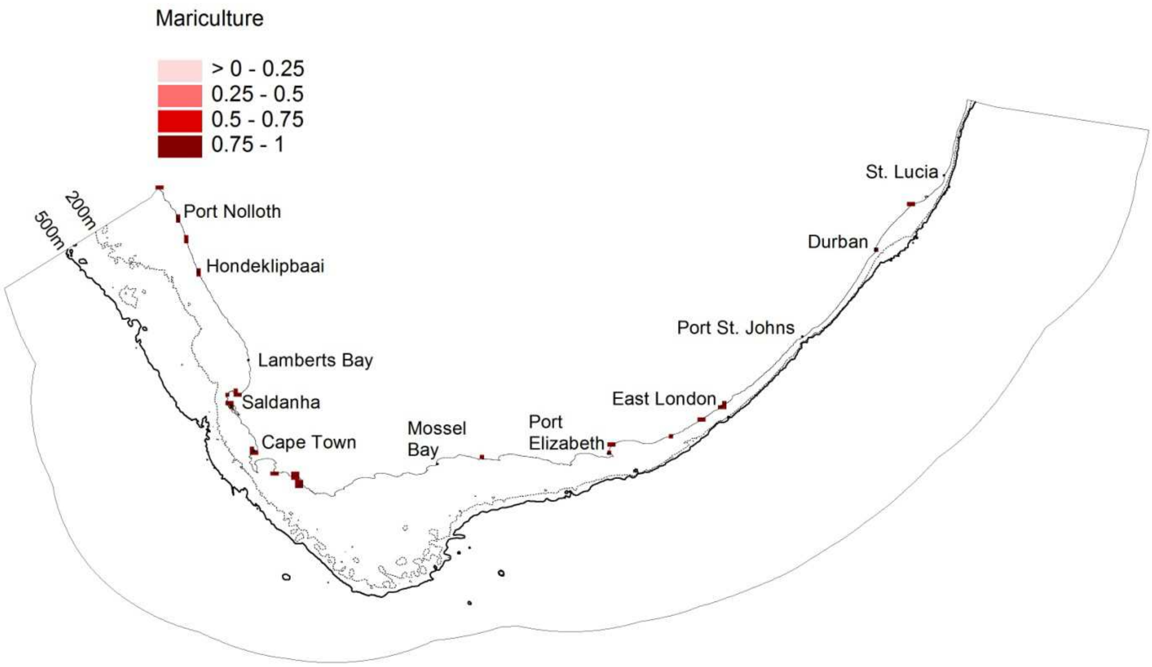


Figure 22: The distribution of current mariculture operations in South Africa.

All operations are mapped in Figure 22. The Saldanha Bay area can arguably be described as the centre of mariculture in South Africa, with 13 permit holders operating in the surrounds. Other areas suporting a number of operations include Hermanus and Gansbaai along the south coast. The KwaZulu-Natal coast has the lowest density of mariculture facilities, with only a single operation at Mtunzini.

Biodiversity concerns associated with mariculture include:

- declines in water quality (oxygen depletion, nutrient enrichment and pollution), associated pollution impacts and toxic effects of chemicals used in farming (Copeley *et al.* 1992, Kerry *et al.* 1995, Black *et al.* 1997, Davies *et al.* 1998, Davies 2000, Crawford *et al.* 2001, Haya *et al.* 2001, McLure 2001, Milewski 2001, Carroll *et al.* 2003, La Rosa *et al.* 2004, Black *et al.* 2004, Boyra *et al.* 2004, Feng *et al.* 2004, Sara *et al.* 2004, Bongiorni *et al.* 2005, Heggoey *et al.* 2005, Pitta *et al.* 2005, Porrello *et al.* 2005, Ruesink *et al.* 2005)
- incubation of microbes, parasites and pathogens (disease), and transfer to wild stocks (Agius and Tanti 1997, Bjørn and Finstadt 2002, Morton *et al.* 2003, Carr and Whoriskey 2004, Bjørn *et al.* 2005, Chambers and Ernst 2005, Heuch *et al.* 2005, Krkošek *et al.* 2007, Ford and Myers 2008)
- impacts associated with the escape of genetically modified fish (Clifford *et al.* 1998, Tymchuk et. al. 2005, Ford and Myers 2008)

- the introduction and spread of invasive alien species (Feng *et al.* 2004, Ruesink *et al.* 2005, Haupt *et al.* 2010)
- localised habitat alteration and impacts (such as changes in wave action and sediment transport)
- attraction of predators and the escape of farmed fish (Pemberton and Shaughnessy 1993, Wuersig and Gailey 2002, Vita *et al.* 2004, Kloskowski 2005)
- entanglement of marine mammals

The environmental effects of mariculture depend on the species, culture method, stocking density, feed type, hydrography of the site and husbandry practices (Wu 1995). While little research has been undertaken on the impacts of mariculture in the South African context, recent local work has highlighted the risk associated with the introduction of alien species (Haupt *et al.* 2010). Internationally, the Code of Practice of the International Council for the Exploration of the Sea (ICES) is commonly applied in an effort to prevent introductions associated with mariculture. Principles of the code include the periodic inspection (including microscopic examination) of material prior to importation and the disinfection and quarantine of imported organisms in the receiving country (ICES 2005). Although South Africa is affiliated to ICES, it is not a member of the organisation and the Code of Practice has not been strictly applied in this country. Additionally, inter-regional translocation of imported mariculture species within South Africa is not controlled. As such, mariculture target species and any associated fauna are often moved to multiple locations along the South African coast (Haupt 2009).

3.2.17 Invasive alien species

While 84 marine alien species have been identified along the South African coast (Section 11 - *Alien and invasive alien species*), only eight are classified to have become invasive (Table **28**). At the time at which spatial analyses were conducted sufficient information existed to enable consideration of only two of these species (both coastal invasions as illustrated in Figure 23). The most widespread and ecologically important invasive alien species along the South African coast is the Mediterranean mussel *Mytilus galloprovincialis*. This aggressive invader is currently the most dominant invertebrate on west and south coast rocky shores, and occupies over 2000 km of coastline (Robinson *et al.* 2005). The European shore-crab *Carcinus maenas* also occurs on the west coast where it supports extensive populations in Table Bay and Hout Bay Harbour (Robinson *et al.* 2005), with small intertidal populations between these points.

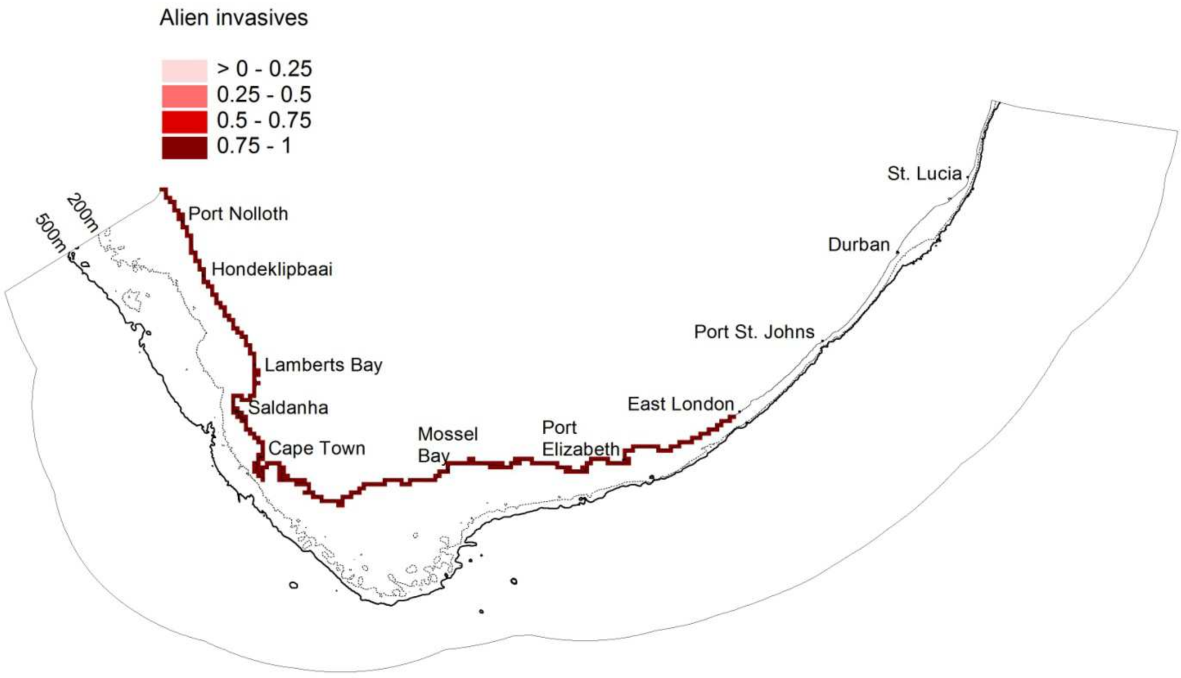


Figure 23: Scaled pressure values reflecting the distribution of invasive alien species in South Africa.

The impacts of *M. galloprovincialis* have been well documented. Along the west coast this species dominates primary rock surfaces at the expense of competitively inferior indigenous mussel and limpet species (Branch and Steffani 2004, Robinson *et al.* 2007). Consequently, there has been an upshore broadening of the width of intertidal mussel beds where this species has invaded (Hockey and van Erkom Schurink 1992). Along the south coast *M. galloprovincialis* co-exists with the indigenous mussel *Perna perna* (Bownes and McQuaid 2006). *M. galloprovincialis* has reduced the numbers of the limpet *Scutellastra granularis* occupying bare rock in the mid-shore, but at the same time has increased its overall density by providing a favourable recruitment substratum for juvenile *S. granularis* (Hockey and van Erkom Schurink 1992). The mean size of *S. granularis* has consequently decreased, as the size of limpets in mussel beds is limited by the size of host mussels (Griffiths *et al.* 1992). In the extreme low-shore, a second limpet species, *Scutellastra argenvillei*, has also been significantly affected by the invasion, although the strength of this effect is mediated by wave action (Steffani and Branch 2003a,b). At high but not extreme intensities of wave action, *M. galloprovincialis* displaces *S. argenvillei* and dominates primary substratum, while at moderate exposure levels the mussel decreases in abundance and *S. argenvillei* maintains dominance of open rock space (Steffani and Branch 2003a,b, Branch and Steffani 2004). Besides impacting on individual species, this invasive mussel has also been shown to significantly alter intertidal communities (Robinson *et al.* 2007).

Presently, the impacts of *Carcinas maenas* are focused within Table Bay and Hout Bay harbours. Here these crabs have almost totally removed mussels from vertical wharf surfaces (C.L. Griffiths, University of Cape Town pers. comm.). Although not currently recorded in Saldanha Bay, concerns have been raised about the potential impacts of this crab should it spread to this area. An invasion of the Saldanha Bay system could be disastrous for local biota of the West Coast National Park which has been predicted to be highly vulnerable to predation by *C. maenas* (Le Roux *et al.* 1990).

Further information about alien and invasive species is provided in thematic section of this report (Section 11 - *Alien and invasive alien species*).

3.2.18 Mining

Types of mining in South African marine and coastal habitats range from dune mining to offshore dredging for heavy metals and diamond mining using heavy earth-moving machinery, diver or ship-based methods. Petroleum exploration and production is dealt with in the following section, 3.2.19 *Petroleum activities,* whilst diamond mining and other mining activities are mapped in Figure 24. In northern KwaZulu-Natal, mining of the coastal dunes for titanium and other heavy metals threatens dune and beach ecosystems and the services these important coastal ecosystems provide (Harris *et al.* 2010). The dunes are a component of the coastal littoral active zone and mining impacts affect beaches through disruption of the sediment budget. The success of rehabilitation efforts on dune ecosystems are debated but long-term impacts on estuaries, wetlands and water supply are recognised (Department of Environmental Affairs and Tourism 2006).

Diamond mining on beaches, in the surfzone, mid-water (40-80 m) and in deep water (110-135 m) employ different methods and have different types of documented impacts (Penney *et al.* 2008, Karenyi 2009). Beach mining reduces species richness, can alter beach habitat type or morphodynamic state, and is considered the greatest extractive threat to sandy beach ecosystems along South Africa's west coast (McLachlan *et al.* 1994, McLachlan 1996, Clark *et al.* 1998, Pulfrich 2004, Karenyi 2009, Harris *et al.* 2010). Recovery times for beach macrofauna vary between 20 and 50 months depending on the type and extent of beach mining (Nel and Pulfrich 2002, Nel *et al.* 2003, Pulfrich *et al.* 2007, Penney *et al.* 2008).

Rocky and mixed shores are also impacted by diamond mining with documented changes in species richness and community structure particularly for more sheltered shores (Parkins and Branch 1995, Pulfrich *et al.* 2003a). Mining-induced sand inundation of rocky shores adjacent to pocket beach mining areas has significant impacts including an increase in dominance of the alien invasive mussel *Mytilus galloprovincialis*, and a loss of various limpet species (Pulfrich *et al.* 2007). Impacts on surf zone biota related to increased sedimentation from mining have been recorded (Clark *et al.* 1998) with potential food web implications. Reduced filter-feeder cover has been linked to mining impacts on reefs but no short- or long-term effects on west coast rock lobster population structure or abundance were detected in impacted areas (Parkins and Branch 1995, Parkins and Branch 1996, Parkins and Branch 1997, Pulfrich *et al.* 2003a). Where large-scale beach mining operations such as those conducted in Namibia are maintained for decades, coastal impacts are more severe and habitat recovery rates are estimated to be longer than 20 years because shoreline habitats may be altered by seawalls (Clark and Nel 2002).

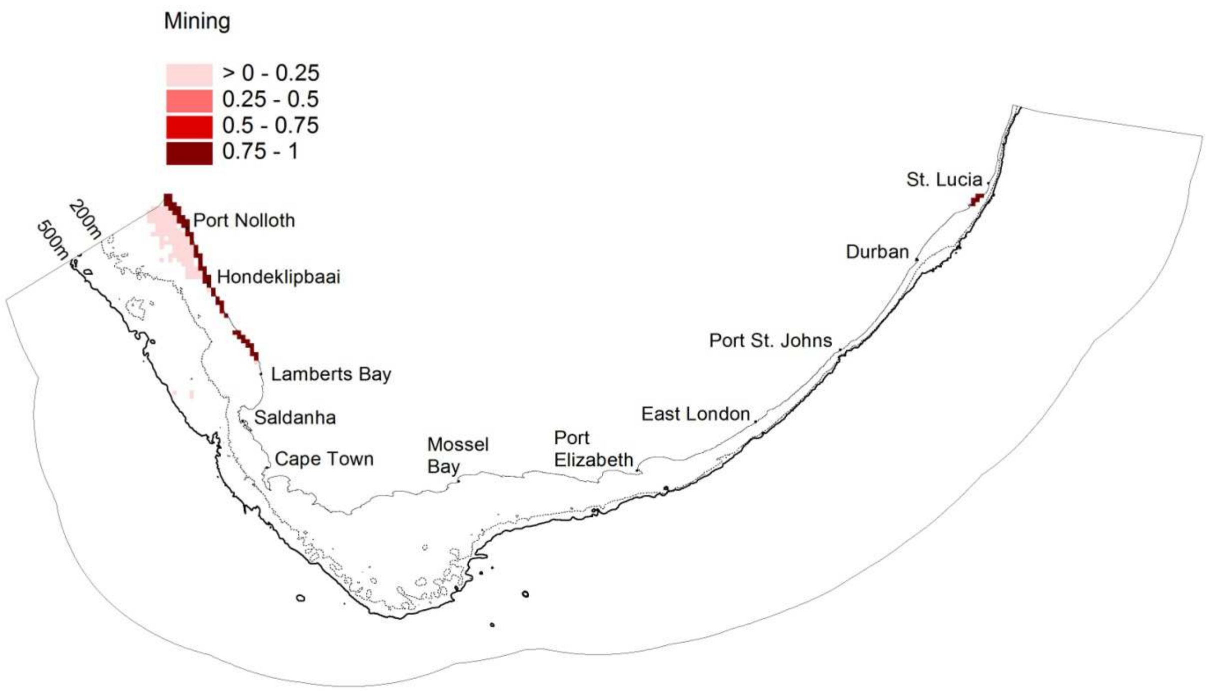


Figure 24: Scaled pressure values reflecting diamond and other mining activities in South Africa.

Diver-based mining takes place by suction pump in gullies and the gravels are processed on board small vessels, with the tailings (the materials left over after the process of separating the valuable fraction from the uneconomic fraction during mining) discharged directly overboard (Penney *et al.* 2008). The rate at which diver-based mining occurs is estimated to be about 300-1000 m^2/yr. The data received from concession holders practicing this type of mining were not measured in area but in total number of dives; therefore this type of mining has not been accurately mapped (Penney *et al.* 2008). Impacts include localised habitat damage, smothering and associated changes in community structure (Parkins and Branch 1995, Parkins and Branch 1996, Parkins and Branch 1997, Pulfrich 1998) although recovery times are reported to be short (less than 2 years) (Pulfrich *et al.* 2003a, 2003b). The cutting of kelp to facilitate diver access also impacts benthic communities but kelp forests are reported to recover within two years (Parkins and Branch 1996, Pulfrich 2007a). However, repeated kelp cutting is considered more detrimental and could lead to the loss of kelp forest habitat (Pulfrich 2007a). Although diver-based mining has been implicated in reduction of rock lobster numbers and habitat degradation, research results reflect no long-term impacts on rock lobster populations, recruitment or their primary reef habitat (Barkai and Bergh 1992, Parkins and Branch 1995 Parkins and Branch 1996, Parkins and Branch 1997, Pulfrich 1998, Pulfrich 2007a, Pulfrich 2007b).

Offshore mining involves prospecting with a megadrill or decadrill and large-scale bulk mining with a crawler or decadrill (Penney *et al.* 2008). Offshore mining impacts benthic communities, which can take up to 5 years to recolonise (Savage 1996, Van der Merwe 1996, Pulfrich & Penney 1999, Winckler 1999, Savage *et al.* 2001, Steffani and Pulfrich 2004). There has been concern over the re-suspension of heavy metals through mining activities (Attwood 2000) however heavy metal concentrations in the tailings have been evaluated and are considered well below the guideline levels (Penny and Pulfrich 2004). The only actively mined offshore area in South Africa's EEZ is that of ML3/2003, De Beers Consolidated Mines, wherein only 0.5% of the area has potentially viable diamond reserves, while only 0.07% is considered economically viable for mining (Penney and Pulfrich 2004). This implies that it is highly unlikely that more than 1% of a mining concession area will ever be mined, and the overall impact from discharged sediment is considered minimal (Roos 2005). There is however, concern that should diamond concentrations occur in a particular unique habitat, the biodiversity of that habitat would largely be lost with the impacts incurred by mining activities (Attwood *et al.* 2000). Our understanding of diamond mining impacts in the offshore environment is constrained by our limited understanding of the natural drivers of biodiversity pattern and the observed high levels of natural variability in west coast offshore ecosystems (Steffani and Pulfrich 2007).

3.2.19 Petroleum activities

An overview of petroleum activities in South Africa's offshore environment is published in Atkinson and Sink (2008) with further detail reported by Sink *et al.* (2010). Oil and gas exploration and production activities have focused on the Agulhas Bank with the development of the Oribi, Oryx and Sable oil fields although the first production license for the west coast was recently issued. More than 300 offshore wells have been drilled in South Africa with most wells having been drilled in less than 250 m water depth on the Agulhas Bank (Figure 25). Limited seismic and drilling exploration (4 wells) has occurred on the east coast, but preliminary data are reported to justify further exploration. An area of the Tugela Basin off the KwaZulu-Natal north coast has recently aroused substantial interest for oil exploration. Globally, petroleum activities are expanding into deeper water and South Africa is no exception. Exploration rights on the south coast have recently been awarded for areas in the 1500 – 1800 m depth range.

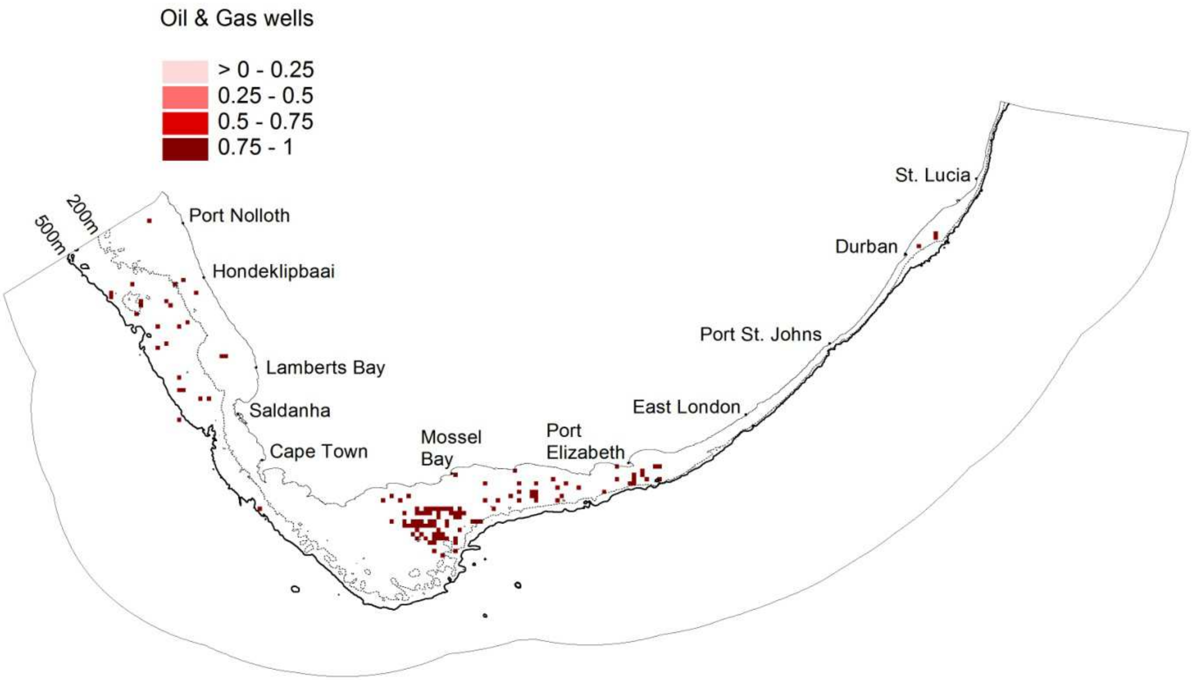


Figure 25: The distribution of oil and gas wells in South Africa.

Biodiversity concerns for this sector in South Africa centre on potential impacts from seismic surveys and the impacts of exploration and production activities on habitats and species. These include localised habitat damage, physical disturbance and smothering, localised pollution impacts, alien and invasive alien species and the risk of catastrophic pollution (Attwood *et al.* 2000, Atkinson and Sink 2008, Wanless *et al.* 2009, Sink *et al.* 2010). Marine seismic surveys can have short-term adverse effects on some marine life (Findlay 2005, MENZ 2005, CCA &

CMS 2001, Atkinson and Sink 2008) with most concern expressed about the potential impact on marine mammals (Gründlingh *et al.* 2006). A recent study in the Oribi-Oryx field and at the FA Platform assessed the potential pollution impacts on the Agulhas Bank for the first time in South Africa (Sink *et al.* 2010). Benthic infaunal assemblages sampled closest to the wellhead were significantly different to those sampled more than 250 m away, suggesting some degree of petroleum impact within a 250 m radius of the sampled wellhead. These changes were most likely a result of physical disturbance rather than petrochemical effects as sediment properties measured (particle size, organic carbon, trace metals and hydrocarbons) showed no significant differences among any sites in this study. A more serious concern is the potential role of this industry in the introduction, hosting and spread of alien species (Page *et al.* 2006, Coutts *et al.* 2007, Wanless *et al.* 2009, Sheehy and Vik 2010). Sink *et al.* (2010) documented at least 5 introduced species, the expansion of two cryptogenic species into deep water and the presence of at least 3 unidentified potentially introduced species through initial limited sampling of petroleum infrastructure on the Agulhas Bank. The risk of introducing or spreading non-indigenous species should be carefully considered in environmental management and decommissioning for this sector, as alien and invasive species can have serious biodiversity and economic impacts. Other operational activities such as lighting, helicopter operations and flaring could also impact on marine life (Blood and Corbett 2006).

The possibility of an oil spill is perceived as the greatest threat posed by this industry to marine biodiversity in South Africa (Attwood *et al.* 2000). Oil spills associated with offshore production platforms can be classified into three groups: small accidental oil spills arising during routine operations, large spills arising after incidents such as the grounding of an oil tanker or collisions with other vessels, and offshore production accidents such as 'blowouts' of wells and pipeline ruptures. A blowout or "loss of well control" can occur if a drilling rig encounters a pocket of sub-sea oil under excessive geological pressure or due to technical failures. Under such conditions an extensive oil spill is likely to develop which is generally considered the greatest possible environmental threat in exploratory drilling. The probability of this occurring is generally considered to be low, although the environmental consequences of oil spills are severe. The oil spill event resulting from the blowout at the *Deepwater Horizon* rig in the Gulf of Mexico in April 2010 and the concomitant impacts on various marine and coastal environmental parameters serve to illustrate the extensive devastating effects such an event could cause (Kerr *et al.* 2010).

3.2.20 Shipping

South Africa is a maritime nation with several major ports. In global terms, the concentration of maritime traffic passing South Africa is not considered to be as high as in areas like the Panama Canal, Suez Canal or Strait of Hormuz (Gründlingh *et al.* 2006) but nonetheless, ship traffic is considerable. In 1999, approximately 1000 bulk carriers, 1000 cargo vessels, 400 tankers, 1000 container vessels and several smaller vessels were estimated to pass around Cape Point each year (State of Environment Report 1999 – www.environment.gov.za/soer/nsoer/index.htm). The International Maritime Organization estimates that approximately 120 million tons of oil and substantial volumes of bunker fuel pass through South African waters every year (IMO 2005), which indicates that South Africa has one of the highest concentration of oil tankers and cargo ships in the world (Figure 26).

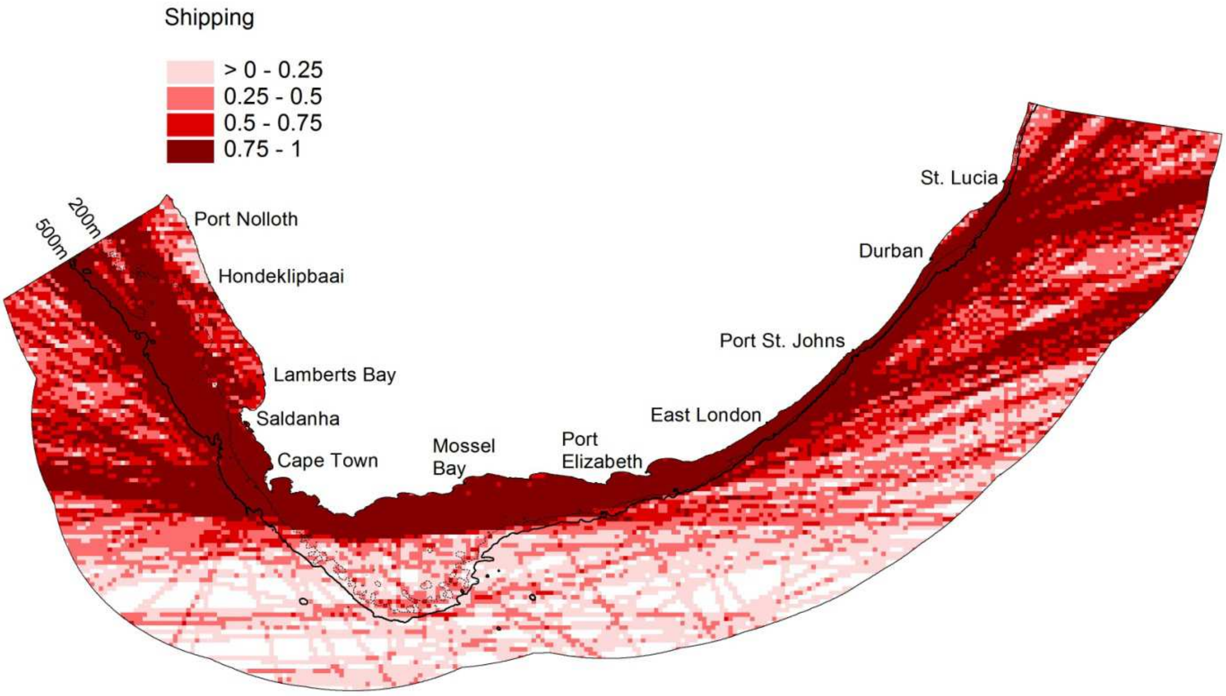


Figure 26: Scaled pressure values reflecting the relative shipping intensity in South Africa.

The main biodiversity impacts associated with shipping stem from oil spills as a result of shipping accidents, invasive alien species introduced through ballast water discharge and hull fouling, dumping of waste materials, and through ship strikes i.e. collisions between vessels and large marine animals such as whales and basking sharks (Atkinson and Sink 2008).

South Africa's oceanographic conditions can be hazardous as reflected by the estimated 2300 vessels lost at sea within South African territorial waters since the 16th century (SAHO 2009).

Operational and accidental oil discharges do occur with an estimated 3.25 events per month (IMO 2005). Between 1983 and 2000 a total of 37 shipping accidents occurred mostly between Saldanha Bay and Cape Point resulting in oil being leaked into the sea or coast, the greatest of which amounted to 175 000 tons (IMO, 2005). The most recent major oil spills along the South African coast were those of the *Apollo Sea* in 1994 and the *Treasure* in 2000. Both of these had significant impacts on seabirds and in particular the endangered, endemic African penguin *Spheniscus demersus* (Underhill *et al.* 1999, Crawford *et al.* 2000).

Oil is a highly hazardous marine pollutant that is harmful to marine life. Contamination can kill seabirds and marine larvae and increases susceptibility to disease from suppressed immune function, reduced growth, and delayed sexual maturity in fish (Holdway 2002). Chronic toxicity of crude oil is greatly detrimental to a wide variety of marine organisms because the oil constituents adhere to and infiltrate their systems. A great number of effects of chronic oil exposure have been documented including behavioural impacts, suppressed growth, induced or inhibited enzyme processes and other molecular effects, physiological responses, reproductive effects, reduced immunity to disease and parasites, histopathological lesions and other cellular effects, tainted flesh and chronic mortality. Impacts on reptiles, birds and mammals include the effects of physical cleaning of oil (for a full list of references see Holdway 2002). Sea birds in particular are most affected since they lose their water repellent properties which cause their wings to become waterlogged, rendering them flightless (Clarke 1984).

Oil spilt in the marine environment tends to spread quickly over the water surface as a slick, while volatile components rapidly evaporate removing some toxic components. The nature of the fuel is an important factor in determining the proportion that will evaporate. The lighter the oil, the greater the power of evaporation to remove it from the sea surface. Remaining fuel may be oxidised by sunlight, bound to suspended sediments, dissolved into the sea water or be degraded by organisms in the water column (Kingston 2002). When a spill occurs in a coastal setting, the intertidal zone may become smothered by oil. Spills of light oils, such as diesel, tend to have less negative impact on the marine environment as much of the spill tends to evaporate. Ecological effects of oil pollution can be toxic (i.e. poisonous to biota) or physical (i.e. the physical smothering of organisms. These effects act at various levels, for example at the level of individual organisms (resulting in physiological responses such as depressed respiration, Garcia de la Parra *et al.* 2006) or at the community level (resulting in decreased diversity and changes in community composition, Serrano *et al.* 2006). Recovery of the intertidal zone following petroleum pollution is determined mainly by the wave exposure level at the affected site and the degree to which the shore is cleaned. The fastest recovery times have been recorded for exposed shores which have been thoroughly cleaned, while sheltered sites and uncleaned sites recover the slowest (Kingston 2002).

The discharge of ballast water from ships entering South African waters brings with it the risk of introducing invasive marine species (see Section 11). More than 22 million tonnes of ballast water are discharged in South African ports and harbours annually (Atkinson and Sink 2008) from sources all around the world. A ballast water risk assessment for the Port of Saldanha in 2004 (Awad *et al.* 2004) showed high risks for South African marine ecosystems associated with international sources of ballast water. Activities to mitigate the risk associated with ballast water have been conducted at all 8 major ports in the country, including baseline biological surveys in 7 ports to establish potential invasive alien species presence. South Africa has been playing an active role at the International Maritime Organization (IMO) Marine Environment Protection Committee as concerns developing international guidelines and regulations. The IMO Ballast Water Convention was adopted by member states in 2004 and ratified in South Africa in 2008. The Department of Transport is currently in the process of developing regulations for its domestic implementation. The Transnet National Port Authority (TNPA) also has developed some ballast water and biofouling regulations within its port plans, supported by the National Ports Act. The Department of Environment has been developing regulations under the Biodiversity Act for the control and management of invasive alien species. It is ultimately imperative that the regulations regarding unintentional marine species introductions (e.g. through ballast water) be coordinated with the regimes being developed under the Department of Transport and TNPA. A Ballast water task force was assembled from 2000 to 2006, but has not recently been active. Re-activation by these primary stakeholders is needed to ensure the appropriate communication in this regard.

The Global Ballast Water Management Programme (GloBallast) was operational in South Africa from the period 2000 until 2005, and is currently expanding the pilot projects from South Africa into the rest of the region. A Regional Strategy on Ballast Water Management is being developed under the ASCLME programme, ultimately to be adopted by the Parties of the Nairobi Convention. Biofouling has also become a major concern at the national and international level, with the IMO currently developing a new set of guidelines and regulations. Many countries have banned the practice of cleaning ships hulls at sea in an effort to prevent the release of organisms into the marine environment. South Africa has not yet implemented such a ban (Attwood *et al.* 2000, Adnan Awad, pers. comm.), although the TNPA has some management guidelines for in-water cleaning in some of its ports. Shipping also generates other waste from bilge effluent, solid waste, sewerage and the loss of cargo at sea.

Many large marine species, especially whales and dolphins, may be vulnerable to collisions with vessels. Most reports of ship strikes involve large whales but collisions also occur with smaller species. Collisions involving large vessel especially, often either go unnoticed or unreported, particularly for the smaller cetacean species. As such quantification of the threat posed by ship strikes is very difficult and has not been done for South African waters. The problem is being addressed at an international level by the International Whaling Commission through its Scientific and Conservation Committees (http://iwcoffice.org/sci_com/shipstrikes.htm).

3.2.21 Coastal development

Coastal development is the greatest pressure along the coast. It can lead to: physical habitat degradation and loss; associated loss of biodiversity and important coastal ecosystem services; interruption of important physical and biological processes; and compromised ecosystem resilience. The construction of buildings, seawalls, harbours and other hard structures is often inappropriately located in the soft, dynamic coastal zone. It consequently replaces beach or dune habitat, and accelerates erosion of the sandy shore particularly at the toe of the wall and through terminal scour at the wall edges (Daniel 2001, Mills *et al.* 2001, Harris 2008). Unfortunately this operates as a negative feedback: houses are developed too close to the shore and because of their high economic value, eventually require defence by seawalls, which raises the vulnerability of houses at the edges of the wall, which ultimately leads to a gradual hardening of the coast (Harris *et al.* 2010). Interrupting the littoral active zone (geologically functional unit comprising the dunes, beach and surf zone) by building too close to the shoreline, affects the resilience of the coast to natural hazards by depriving the beaches of the sand stored up in the dunes. It also blocks other key linkages between dunes and the beach (e.g. nutrient exchanges, and movement paths of high-shore biota). This, in turn, has been shown to alter sandy beach macrofaunal community structure by reducing species diversity and abundance, with additional direct (nesting and/or roosting) and indirect (reduced prey) implications for endemic and threatened seabirds (Dugan *et al.* 2008). Consequently, the loss of habitat and biodiversity in turn suppresses the provision of important coastal ecosystem services (see Section 9 - *Ecosystem services*).

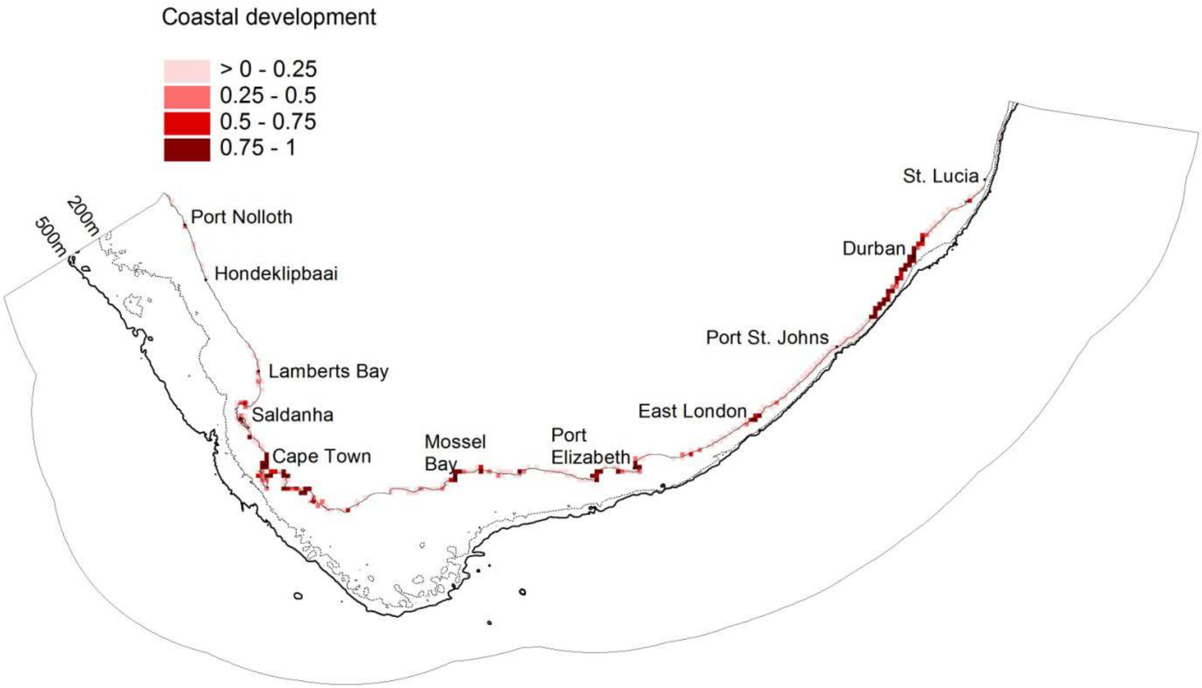


Figure 27: Scaled pressure values reflecting the intensity of coastal development in South Africa.

Inappropriately located coastal development also prevents the natural landward migration of sandy beaches in response to sea-level rise. Consequently, beaches are trapped in a coastal squeeze, where they are narrowed and eventually lost as sea levels rise. Since intertidal ecosystems have distinct zones (associated with tidal gradients), even partial coastal squeeze can lead to the loss of specific zones (starting with the supratidal) and associated species, with knock-on implications for foodwebs and top predators, such as birds (Dugan *et al.* 2008; Harris *et al.* 2010). Of particular concern is the associated loss of vital ecosystem services, such as reduced or locally lost nesting habitat for endemic and/or threatened or endangered seabirds and turtles (e.g. Fish *et al.* 2008). Coastal squeeze is thus considered the greatest threat to sandy beaches and sandy coast types in South Africa because it threatens the ecosystem in its entirety (Harris *et al.* 2010). Coastal squeeze has also been shown to be a threat to rocky shores (Jackson and McIlvenny 2011), but there have been no studies in South Africa that have investigated this to date.

A total of 70% of South Africa's 3113 km long coastline has development located within 100 m of the shoreline (Figure 27). The Northern Cape, former Transkei and northern KwaZulu-Natal coasts are least developed. In stark contrast, there is medium- to high-priority development (such as residential, industrial and commercial buildings, see coastal development pressure mapping in section 3.1.6 above) situated within 20 m of the shore for more than 11% of the coast. Development of this nature is prevalent in (1) the Western Cape, particularly around Cape Town, False Bay and Hermanus; (2) in nodes along the south coast that are usually associated with the rocky headlands of log spiral bays, especially Port Elizabeth in Algoa Bay; (3) in the areas surrounding East London; and (4) along the KwaZulu-Natal south and central coast, around Durban and as far north as Ballito and Sheffield, with a small node at Richards Bay. Thus, broadly speaking, it is the areas associated with ports and harbours that have medium- to high-priority development located precariously close to the shoreline. The coastal cities and urban areas surrounding these ports, all similarly too close to the shore, are thus particularly vulnerable to the effects of sea-level rise and extreme coastal storms. Given the high priority of these buildings, there will be strong motivation to defend many of them with hard engineering. This means that the local beaches are especially vulnerable to coastal squeeze, where the ecosystem will be gradually lost between sea walls and rising sea levels. The proportion of the coast at risk of sea-level rise impacts doubles (to 22%) if any type of development within 50 m of the shore is included, and increases to nearly a third of the national coastline (31%) if this is extended to include any development within 100 m of the shore. Impacts up to 100 m inland (cumulative inland erosion of 40 – 100 m) were shown to occur in erosion hotspots following the March 2007 storm (Smith *et al.* 2010). Thus, there is a strong possibility that localised damages of this nature could occur more frequently in the next decade.

3.2.22 Waste water discharge

The most recent available information on the status of point source waste-water discharges to the marine environment of South Africa is contained in South Africa's National Programme of Action to protect the marine environment from land-based activities (RSA-DEAT 2008) and a national pollution status report prepared for the Western Indian Ocean Land-based Activities (WIO-Lab) programme (Weerts *et al.* 2009). The information contained in this section is largely extracted from these two reports unless otherwise stated.

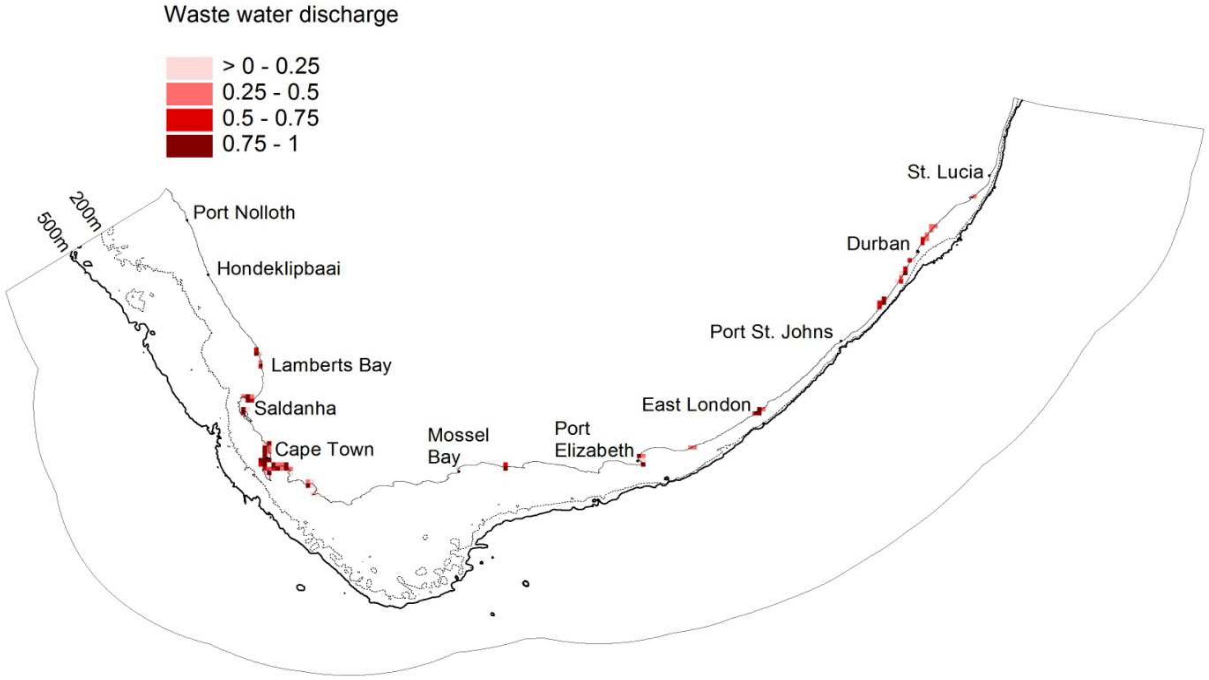


Figure 28: Scaled pressure values reflecting the impact of waste water discharge in South Africa.

South Africa currently has approximately 70 point sources of wastewater to the marine environment, either discharging to the offshore (beyond the surf zone in water depths greater than 2 m), the surf zone (along the beach or within the breaker zone) or directly into estuaries (Figure 28). These wastewater discharges comprise mainly municipal wastewater (domestic sewage, sometimes also including trade effluent), effluent from fish processing operations, wastewater from chemical works, refineries and other industries, and cooling water. A summary of the discharge locations and types of wastewater discharges along the coast is provided in Table 6 below (updated by Weerts *et al.* 2009).

Table 6: Waste water discharge types and locations in South Africa.

DISCHARGE LOCATION	WASTEWATER TYPE	PROVINCE			
		Northern Cape	Western Cape	Eastern Cape	KwaZulu-Natal
Offshore	Municipal		4	1	2
	Refinery		2		
	Industrial				5
Surf zone	Municipal		8	4	5
	Fish processing		13		
	Industrial				1
	Mining	~2			
	Cooling water		1		
Estuary	Municipal		5		10
	Fish processing		1		
	Industrial				
	Desalination			1	
TOTAL		2	34	6	23

There is no readily accessible information on current discharge volumes and effluent composition of wastewater discharges to the marine environment. However, a comparison between municipal wastewater volumes to the marine environment between 1991 and 2004 indicates that volumes of municipal wastewater discharged to the offshore marine environment had not increased significantly (see Table 7 below). However, discharges to estuaries and the surf zone had almost doubled and tripled respectively, reflecting the rapid population growth in coastal areas during this period (RSA-DEAT 2008). Marked increases in coastal populations since 2004 have certainly resulted in further significant increases in domestic sewage and municipal wastewater discharge volumes to sea. The pressures placed by discharges on estuaries and coastal waters is underestimated here, as figures reflected in the tables above and below do not include many municipal or industrial wastewater discharges to coastal freshwaters just above the upper reaches of estuaries.

Since approximately 1985 the design of offshore marine outfalls discharging wastewater to sea in South Africa has followed the receiving water quality objectives approach. Effluent quantities and composition must be within limits to meet site-specific Environmental Quality Objectives, as recommended in the South African Water Quality Guidelines for Coastal Marine Waters (DWAF, 1995). Generally, long-term environmental monitoring programmes at these offshore marine outfalls have not indicated any widespread detrimental impact on the marine environment (RSA-DEAT 2008; Weerts *et al.*, 2009).

Table 7: Estimated annual discharge volumes for estuaries, the surf zone and marine discharges in South Africa (RSA-DEAT 2008).

TYPE	ESTIMATED VOLUME (million m^3/yr)	
	1991	2004
Offshore marine outfalls (mainly preliminary treatment)	110.6	122.5
Surf zone discharges (mainly secondary treated plus disinfection)	33.6	109.0
Estuarine discharges (mainly secondary treated plus disinfection)	21.4	55.5

Rapidly increasing discharge to less dynamic and more sensitive areas such as the surf zones and estuaries is of greater concern. In these environments, effluents from malfunctioning or overloaded treatment facilities are adversely affecting the ecosystem, albeit in a localised manner (RSA-DEAT 2008). Many of the discharges are also inappropriately placed close to beaches (Harris *et al.* 2010) and while sandy beaches can help buffer pollution impacts through the ecosystem services provided by these ecosystems (see Section 9 - *Ecosystem services*), excess sewage loading results in impacts to beaches by raising an anoxic sediment layer that is uninhabitatble for most fauna (Brown and McLachlan 2002). Storm damage has also led to damage to reticulated sewage infrastructure and wasterwater discharge on beaches. This presents health hazards and causes losses of beach amenities. Ballito beaches lost their blue flag status because of such impacts during the March 2007 storm, for example (Harris *et al.* 2010).

Many of the country's offshore marine outfalls are monitored (Table 8), but the majority of effluent discharges to surf zones and estuaries are not. As a means of tracking coastal pollution in general (including that arising from non-point sources) the Department of Environmental Affairs initiated the Mussel-Watch Programme in 1985 to monitor heavy metal concentrations in the tissues of mussels at 42 sites in the Western and Northern Cape (DEAT 2009). The programme was later expanded to Durban and East London in 2004. Sessile organisms such as mussels are suitable for pollution monitoring and are good indicators of water quality as they bio-accumulate pollutants released into the marine environment. Levels of lead in mussel tissue have significantly declined since 1985 with an exception of sites in the False Bay area, Western Cape which continue to be unacceptably high (DEAT 2009). This Mussel-Watch Programme provides a measure of the levels of marine pollution around the coast and should be expanded to the use of biomarkers which measure molecular, cytological, physiological or morphological attributes of organisms, in order to assess pollutant exposure and/or its effects.

Table 8: Estimated daily discharge volumes of different industrial wastewater types in South Africa (2004 volumes, adapted from RSA-DEAT 2008)

INDUSTRY TYPE	ESTIMATED VOLUME (m^3/day)
Mining	128 800
Fishing processing	44 834
Chemical/Textile	15 460
Oil Refinery	8 254
Paper and pulp	~120 000
Mixed industrial	~213 000
Desalination effluent	Unknown
Cooling water (power stations)	Unknown

Until recently the disposal of land-derived wastewater to the marine environment was governed by the Department of Water Affairs under the National Water Act (NWA) (1998). Licence agreements (currently issued under the NWA, 1998) for offshore marine outfalls require regular effluent monitoring, as well as long-term environmental monitoring (usually annually or bi-annually). However, most of the licence agreements for wastewater discharges to the surf zone and estuaries require only effluent monitoring and do not include environmental monitoring programmes, i.e. the effect on the receiving environment is not assessed. In 2004 the DWA issued the *Operational Policy for the Disposal of Water containing Waste to the Marine Environment of South Africa* (RSA-DWAF, 2004). This was an attempt to improve matters with regard to the management and control of wastewater sources added to the marine environment in South Africa. The document interprets legislation and consolidates policy into easily understandable and clear ground rules and implementation procedures. In line with international trends and the national objective of efficient and effective management of South Africa's resources, priority is given to a receiving water quality management approach, where the South African water quality guidelines for coastal marine waters provides further guidance (DWAF, 1995). The policy provides Basic Principles and Ground Rules as a framework within which disposal practices for land-derived wastewater will be evaluated by government when marine disposal is a possible alternative for the disposal of wastewater. It also provides a management framework within which such disposal needs to be conducted. However, in 2008, the responsibility for the licensing and control of wastewater discharges to the marine environment shifted to the Department of Environmental Affairs with the promulgation of the National Environmental Management: Integrated Coastal Management Act (RSA 2008). The transfer process is currently in progress and it will be crucial for DEA, particularly those personnel allocated roles and responsibilities in this regard, to collaborate with the regional offices of DWA (until recently fulfilling this role) to ensure transfer of skills and expertise, as well as transfer of the related historical data and data management systems (RSA-DEAT 2008).

O'Donoghue and Marshall (2003) investigated trends in marine pollution research in South Africa over a 40 year period from 1960 to 2003. Based on analyses of published literature, rather than unpublished reports and environmental consultant investigations, they found a marked decline in the quantity of research outputs in the latter 20 years of their study period (O'Donoghue & Marshall 2003). This was incongruent with global patterns where there is substantial effort currently being invested in field of marine pollution research. Marine pollution research in South Africa has been concentrated at the three major urban coastal areas with most investigations undertaken in the Western Cape, followed by the Eastern Cape and then KwaZulu-Natal (O'Donoghue & Marshall 2003). In South Africa, the number of marine pollution research outputs as well as the type of methods used was not in keeping with global patterns even for those from other developing countries such as Argentina and Chile (O'Donoghue & Marshall, 2003). The lack of appropriate data to quantify the effects of land-based activities (including wastewater discharges) on the marine environment was also been highlighted by Weerts *et al.* (2009).

The establishment of appropriate long-term monitoring and research programmes to detect trends related to the effects of land-based activities on the marine environment is a key challenge and should be a priority for South Africa. A further challenge lies in aligning efforts to reduce the impacts of land-based activities on the marine environment with socio-economic priorities such as poverty alleviation and job creation. Ultimately, solutions to mitigate and reduce impacts from land-based marine pollution sources, such as wastewater discharges will need scientists and managers to move beyond monitoring and assessment studies, towards active intervention in innovative technologies to reduce waste loads and to improve the quality thereof prior to disposal to the marine environment. This does not only apply to point source wastewater discharges, but also to more challenging issues such as urban stormwaters and solid waste. Education and awareness are also powerful tools through which to communicate the importance and benefits of sound waste treatment and disposal practices, not only aimed at the public but also political decision-makers. One of the primary aims of South Africa's National Programme of Action (RSA-DEAT 2008), is to coordinate and strengthen relevant national, provincial and local initiatives playing a role in the control of land-based activities (including pollution) in the coastal marine environment (Weerts *et al.* 2009).

3.2.23 Freshwater flow reduction

Freshwater flow reduction has severe consequences for marine biodiversity and resources through impacts on physical habitat, reduced nutrient inputs and alterations to important ecological processes (Gillanders and Kingford 2002, Lamberth and Turpie 2003, Louw 2003 in Van Ballegooyen *et al.* 2007, van Ballegooyen *et al.* 2007, Lamberth *et al.* 2009, Porter 2009). In South Africa, reduced river inputs have a significant impact on estuarine, marine and coastal ecosystems around the entire South African coastline although impacts are expected to be more severe in the more oligotrophic marine environment of the east coast (van Ballegooyen *et al.* 2007). The impacts of altered freshwater flow reduction extend offshore with correlations between flow reduction and patterns in catches of commercial linefish documented more than 40 km offshore on the Tugela Banks (Lamberth *et al.* 2009).

Based on reductions in the 20 largest catchments in South Africa (those that contribute 1% or more of total MAR in the region), the total freshwater flow to the marine environment has been reduced by more than 11 300 million m^3/ year (see Table 5 in Section 3.1.8 - *Freshwater flow reduction*). The greatest reduction is on the west coast (approximately 6 900 million m^3/year) but there are significant reductions along both the south (2 900 million m^3/year) and east coasts (1 500 million m^3/year). The larger river systems that have experienced the greatest flow reduction are expected to have driven the most change in marine ecosystems (Figure 29). These include the Orange River on the west coast, the Thukela and Mzimvubu Rivers in KwaZulu-Natal and the Breë River in the Agulhas Bioregion.

The reduction of river flow leads to a reduced sediment supply to the coast with implications for beach and subtidal habitats. Reduced sediment input can change beach morphodynamic state, altering the beach biodiversity, accelerating beach erosion and can even lead to the loss of beach habitat (Harris *et al.* 2010). In the subtidal environment, riverine inputs provide important sediment inputs for the maintenance of unconsolidated sediment habitats such as mud banks.

Reduced river inputs reduce the spatial extent of such habitats (van Ballegooyen *et al.* 2007), which may have implications for fisheries such as South Africa's sole fisheries. Many of these habitats are also important for ecological processes. For example the endemic and threatened white steenbras *Lithognathus lithognathus* spawns on submarine fluvial fans, a localised habitat of limited extent, associated with mixed mud and sand banks deposited by rivers in the southeast Cape coast (Bennett 1993). Changes in salinity and water temperature linked to flow alteration also impact thermohaline fronts which affects plankton feeding communities and the fish, birds and mammals that feed on the concentrated food associated with these habitats (van Ballegooyen *et al.* 2007).

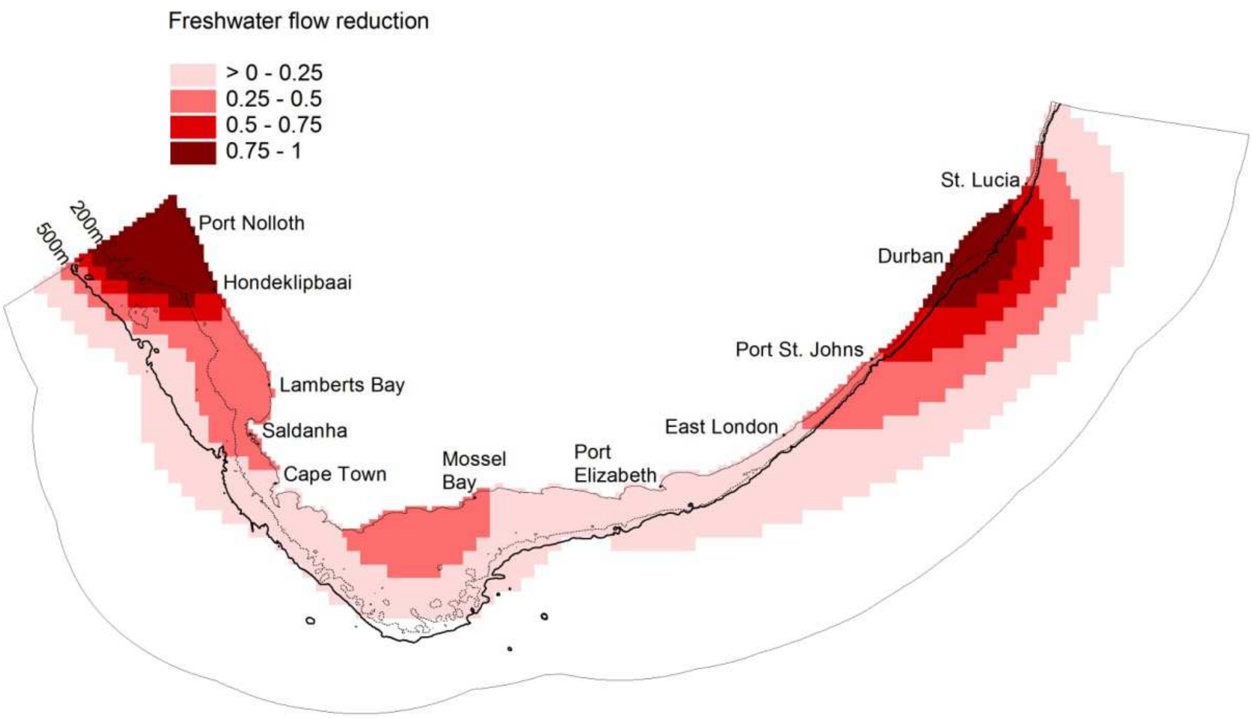


Figure 29: Scaled pressure values reflecting the impact of freshwater flow reduction in South Africa.

Important processes that can be compromised through altered freshwater flow include nursery functions, environmental cues, productivity and food web processes. Increased frequency of estuary mouth closures and associated conditions due to reduced freshwater flow can also disrupt lifecycles and connectivity and deprive fish and invertebrates of the important nursery function of estuaries (Whitfield 1998). On the south coast, freshwater seepage from dune aquifers constitutes an important source of nitrogen for surf-zone phyoplankton (particularly accumulation-forming diatoms), and researchers caution against the use of groundwater from such aquifers without considering the ecological needs of marine and coastal ecosystems

(Campbell and Bates 1991). Sediment delivery is also an important ecological process associated with freshwater input. Sediment provides turbidity and a refuge for fish which is a key component of estuarine, coastal and offshore nursery areas (Whitfield 1988, Lamberth *et al.* 2009). Reduced turbidity can alter predation pressure and the catchability of fisheries resources (van Ballegooyen *et al.* 2007). Altered freshwater flow leads to changes in important environmental cues such as those relevant for spawning, recruitment and migration (Louw 2003 in Van Ballegooyen *et al.* 2007, Lamberth *et al.* 2009). Changes in spawning intensity have been correlated with altered freshwater flow (Quiñores and Montes 2001, Demetriades *et al.* 2000).

Catchment-derived nutrients are an important component of marine and coastal foodwebs stimulating phytoplankton production. The impacts of reduced nutrient supplies will travel through marine and coastal ecosystems via foodwebs (van Ballegooyen *et al.* 2007). Reduced detritus may also impact on marine and coastal foodwebs as river-associated detritus and associated epiphytes are believed to be an important food source for microorganisms, filter feeders, detritivorous fish and invertebrates (Berry *et al.* 1979, Schleyer 1981, Berry and Schleyer 1983, Whitfield 1998, Porter 2009). In KwaZulu-Natal, an isotope study showed that suspended riverine particulate organic matter (terrestrial, aquatic plant material and plankton) plays an important role in supporting inshore filter-feeder communities i.e. intertidal and subtidal assemblages dominated by the sea-squirt known as red bait *Pyura stolonifera*, mussels *Perna perna*, and oysters *Striostrea margaritacea* and *Saccostrea cuccullata* (Porter 2009). Porter (2009) found that between 8 and 33% of filter-feeder diets consisted of material introduced to the sea by rivers and concluded that rivers play an important trophic role in promoting filter-feeder biomass in the Natal Bioregion. He also demonstrated the links between river, inshore and pelagic ecosystems, highlighting the need for adequate freshwater supplies for the maintenance of the integrity of marine and coastal ecosystems.

Changes in freshwater flow and associated variations in turbidity, nutrients and sediment supply can impact fisheries resources, alter catch composition and decrease the economic returns of fisheries (Lamberth and Turpie 2003, Lamberth *et al.* 2009). Fisheries resources in South Africa that have or may have been compromised by reduced freshwater input include linefish (Lamberth *et al.* 2009), prawns (Demetriades *et al.* 2000), soles and kobs and filter feeding invertebrates such as mussels *Perna perna* and redbait *Pyura stolonifera* in the intertidal and shallow subtidal (Porter 2009). Lamberth *et al.* (2009) identified significant relationships between flow and the catches of 14 linefish species (more than 90% of the total catch) on the Thukela Banks in KwaZulu-Natal. Most fish responded negatively with reduced catches correlating with reduced flow (after a lag phase) with slinger *Chrysoblephus puniceus* and squaretail kob *Argyrosomus thorpei* showing a strong relationship to flow alteration.

The ecological needs of the marine and coastal environment should be considered in the allocation of freshwater resources to ensure healthy functioning marine ecosystems that support productive and sustainable fisheries.

3.2.24 Recreational fishing

Recreational fisheries in South Africa include line fisheries, rock lobster fisheries and harvesting of intertidal resources such as mussels, redbait and oysters (Dye *et al.* 1994a, Dye *et al.* 1994b, Griffiths and Branch 1997, Tomalin and Tomalin 1997, Tomalin and Kyle 1998, Griffiths *et al.* 2004, Cockcroft and Mackenzie 2007). Recreational fishing for intertidal resources has less impact than those harvesting far greater volumes of resources for subsistence or commercial use (Dye *et al.* 1994a, Dye *et al.* 1994b, Lasiak and Field 1995, Tomalin and Kyle 1998, Sink 2001). The abalone fishery was closed in 2008 (DAFF 2010) due to unsustainable fishing largely caused by illegal fishing for this high value resource. The recreational abalone fishery has remained closed. Recreational fisheries receive less research attention than their commercial counterparts and their impacts are less well understood (Brouwer *et al.* 1997, Griffiths and Lamberth 2002). Only linefishing, for which spatially reference data were available, was included in this assessment.

Recreational line fishing is a popular activity in South Africa, as illustrated in Figure 30 and Figure 31, and has shown remarkable increases in the number of participants and advancements in fishing technology in the past few decades (Brouwer *et al.* 1997, McGrath *et al.* 1997). This sector is economically and socially important (McGrath *et al.* 1997, Griffiths and Lamberth 2002, Beckley *et al.* 2008) but recreational fisheries and their impacts are not well understood (Brouwer *et al.* 1997). Based on existing data and recognising the need for updated information, some trends and impacts of shore fishing and boat-based fishing can be inferred. The recreational linefishery may be divided into shore- (approximately 450 000 participants), boat- (12 800 participants) and spearfishing (7 000 participants) (Brouwer *et al.* 1997; Mann *et al.* 1997; Sauer *et al.* 1997). Target species vary around the coast (Brouwer *et al.* 1997) with more than 150 species harvested by recreational fishers in South Africa (Griffiths and Lamberth 2002).

In 1994, the first nationwide survey was initiated to evaluate participation in and the management of the South African shore-angling fishery (Brouwer *et al.* 1997) and as the former Transkei coast fell outside the jurisdiction of the South African government at that time, a separate study was initiated in 1997 in this region to complete the national survey (Mann *et al.* 2003). Estimates suggest that approximately 412 000 participants were active on the South African coastline in 1995 and the estimated rate of increase is 2% per annum (Mann *et al.* 1997, McGrath *et al.* 1997). These anglers catch an estimated 4.5 million fish per year, i.e. 1500 fish per km per year, and this combined with pressure from other fishing sectors has led to serious decline for many linefish species.

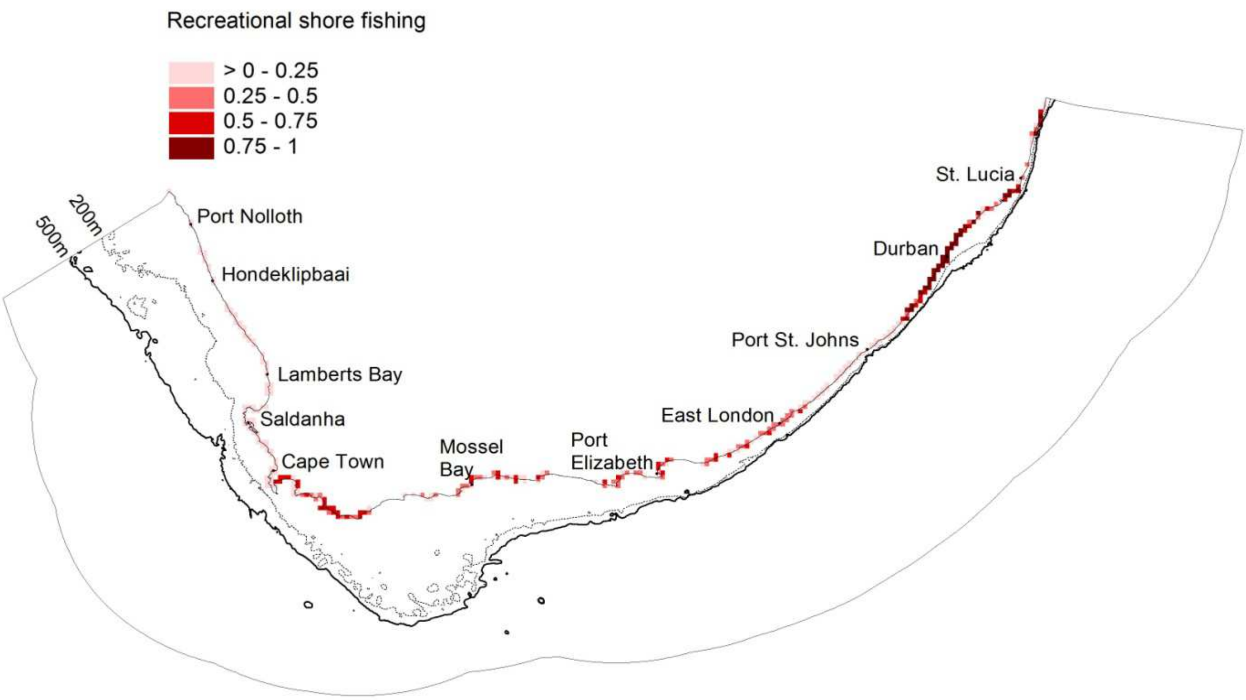


Figure 30: Scaled pressure valuses reflecting recreational shore fishing effort in South Africa.

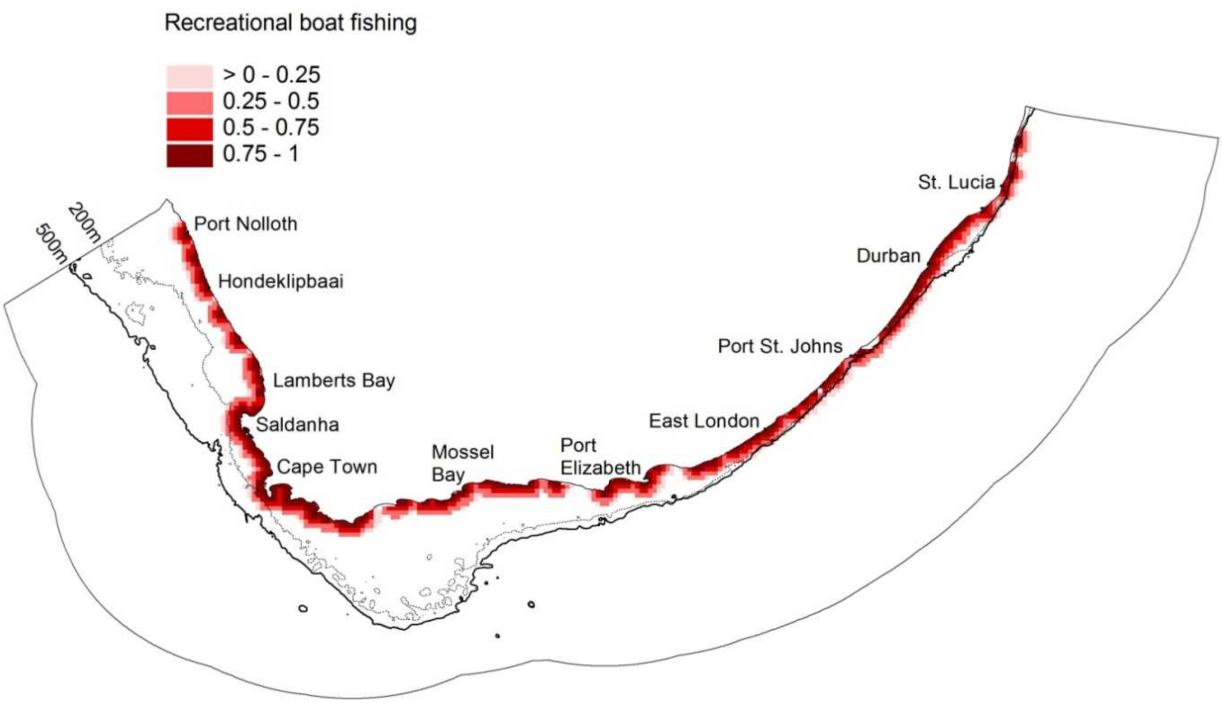


Figure 31: Scaled pressure valuses reflecting recreational boat fishing effort in South Africa.

Recreational shore angling is most intense along the east and south coast (Figure 30). Brouwer *et al.* (1997) found highest angler densities were recorded on the KwaZulu-Natal coast (4.65 anglers.km.$^{-1}$), followed by the southern (2.29 anglers.km.$^{-1}$) and Eastern Cape coasts (0.360 anglers.km.$^{-1}$) with lowest effort recorded on the west coast (0.12 anglers.km.$^{-1}$). Shad (elf), kob and galjoen were considered the most sought-after species (Brouwer *et al.* 1997). White stumpnose *Rhabdosargus globiceps* and white steenbras *Lithognathus lithognathus* are also important on the west coast and blacktail *Diplodus sargus capensis*, bronze bream *Pachymetopon grande* and strepie *Sarpa salpa* are important on the south and east coasts.

It is difficult to accurately reflect recreational boat-based fishing effort across South Africa but modelled fishing intensity based on access from 261 launch sites shows that much of South Africa's near-shore habitat is accessible to skiboat fishers (Figure 31). The commercial linefishery has higher fishing effort than boat-based recreational fishers (Mann *et al.* 2003) with commercial fishing accounting for approximately 79% of the linefish catch (Griffiths and Lamberth 2002). Recreational skiboat fishermen target reef fish including endemic sparids (Mann *et al.* 1997b. Brouwer 2002) and have contributed to the overexploited status of many reef-associated species (Griffiths and Lamberth 2002).

Recreational angling is internationally recognised as a pressure on marine biodiversity at the genetic, species and ecosystem level (Lewin *et al.* 2006). Biodiversity concerns associated with recreational fishing in South Africa include:

- The poor stock and conservation status of many target species.
- Impacts associated with fishing including pollution and the impacts of bait collection.
- Low levels of awareness, high levels of poaching and poor compliance.

Trends in recreational shore angling catches reflect the decline in resources (Coetzee *et al.* 1989, Hughes 1989, Bennet 1991, Bennett *et al.* 1994). Many species targeted by the recreational linefish sectors are also impacted by other commercial sectors and there is serious concern about the overexploited status of many species (Griffiths 2000, Lamberth and Griffiths 2002). Griffiths and Lamberth (2002) assert that recreational anglers are directly responsible for the depletion of several species of sparids, galjoen *Dichistius capensis* and kobs although several species have also been impacted by estuarine degradation and other pressures (Griffiths 1997, Lamberth and Turpie 2003). Overexploited species of greatest conservation concern that are still targeted by recreational fishers include sparids such as red steenbras *Petrus rupestris* and white steenbras *Lithognathus lithognathus*, black musselcracker *Cymatoceps nasutus* and red stumpnose *Chrysoblephus gibbiceps*, rockcods *Epinephelus* spp. and dusky kob *Argyrosomous japonicus*.

Although it is often assumed that catch-and-release fishing results in low mortality and minimum sub-lethal effect, this type of fishing does have negative impacts (Cooke and Suski 2005, Bartholomew and Bohnsack 2005 and references therein, Lewin 2006). Bartholomew and Bohnsack (2005) undertook a meta-analysis of release mortality studies (n=274) and found that mortality estimates range from 0-95% with a mean value of 18%. Mortality varied greatly by species and within species with key mortality factors including anatomical hook location, use of natural bait, use of J-hooks and handling and playing times. Bartholomew and Bohnsack (2005) specifically caution that this type of fishing may conflict with the goals of no-take MPAs. Lewin (2006) further cautions that mortality rates may be higher during the reproductive period, indicating that catch-and-release fishing may be less successful where anglers are targeting spawning fish.

Recreational anglers may impact on intertidal communities through bait collection (Weinburg and Branch 1991) and fishing activities inside MPAs often create management problems around bait collection (Lemm and Attwood 2003). The recreational fishery was first regulated in 1985, with revisions in 1992 and the introduction of a national permit system in 1999 (Lamberth and Griffiths 2002). However, compliance efforts vary around the coastline and poor levels of enforcement for this sector are of concern (Brouwer *et al.* 1997, Lamberth and Griffiths 2002). In addition, there are low levels of awareness about complex fishing regulations (Brouwer et. al 1997, Sauer *et al.* 1997) and a lack of compliance with regulations is also a concern. For example, 38% of recreational spearfishers (Mann *et al.* 1997) and between 22% and 58% (of recreational anglers (Sauer *et al.* 1997) confessed to selling their catch, and in the Pondoland area, 39% of skippers admitted to selling their catches (Fennessy *et al.* 2003). Restaurant owners in KwaZulu-Natal also admit to purchasing fish from recreational anglers. Some recreational anglers also fish illegally inside prohibited areas (MPAs), exceed bag and size limits and catch prohibited species. There is scope for improving voluntary compliance within recreational fisheries through improved presentation of the regulations, education to support responsible angler practices and co-operative research and enforcement efforts (Brouwer *et al.* 1997, Mann *et al.* 2003). Catch reductions and increased protection from fishing within new and existing Marine Protected Areas is needed to support the recovery of species targeted by the recreational linefish sectors (Government of South Africa 2010).

3.2.25 Subsistence harvesting

Subsistence fishing was only recently recognised as a sector in South Africa and includes various fishing methods targeting more than 30 species (Griffiths and Branch 1997) from a range of habitats (Branch *et al.* 2002, Clark *et al.* 2002). The subsistence sector has an estimated 29 233 participants of which the majority (75%) are found on the East coast in KwaZulu-Natal and the former Transkei (Clark *et al.* 2002). This pattern is reflected in Figure 32. The dominant activity on the east coast is the harvesting of intertidal and subtidal invertebrates including mussels, oysters, redbait and limpets, crabs and octopus as well as fish (Hockey and Bosman 1986, Siegfried 1988, Kyle *et al.* 1997a b, Clark *et al.* 2002). On the west coast, boat-based harvesting of near-shore subtidal species such as fish and lobsters is the dominant activity (Clark *et al.* 2002). High value resources such as rock lobsters, oysters and abalone are also caught by this sector although these resources are usually sold leading Clark *et al.* (2002) to classify this as small-scale commercial fishing. South Africa is currently developing a small-scale fisheries policy and this sector should be considered independently in future assessments.

Key biodiversity concerns linked to subsistence harvesting include;

- Overexploitation of intertidal resources (Hockey and Bosman 1986, Hockey *et al.* 1998, Tomalin and Kyle 1998, Lasiak 1991, Branch and Odendaal 2003)

- Changes in abundance and sex ratios of limpets (Branch & Odendaal 2003, Lasiak 2006)
- Transformation of intertidal habitats due to clearing of mussel beds with wide-bladed implements (Siegried *et al.* 1985, Siegfried 1988, Lasiak and Dye 1989, Hockey and Bosman 1986, Lasiak and Field 1995, Dye *et al.* 1997, Sink 2001)
- Reduced recruitment of key resources due to changes in stock and community structure (Harris *et al.* 1998)

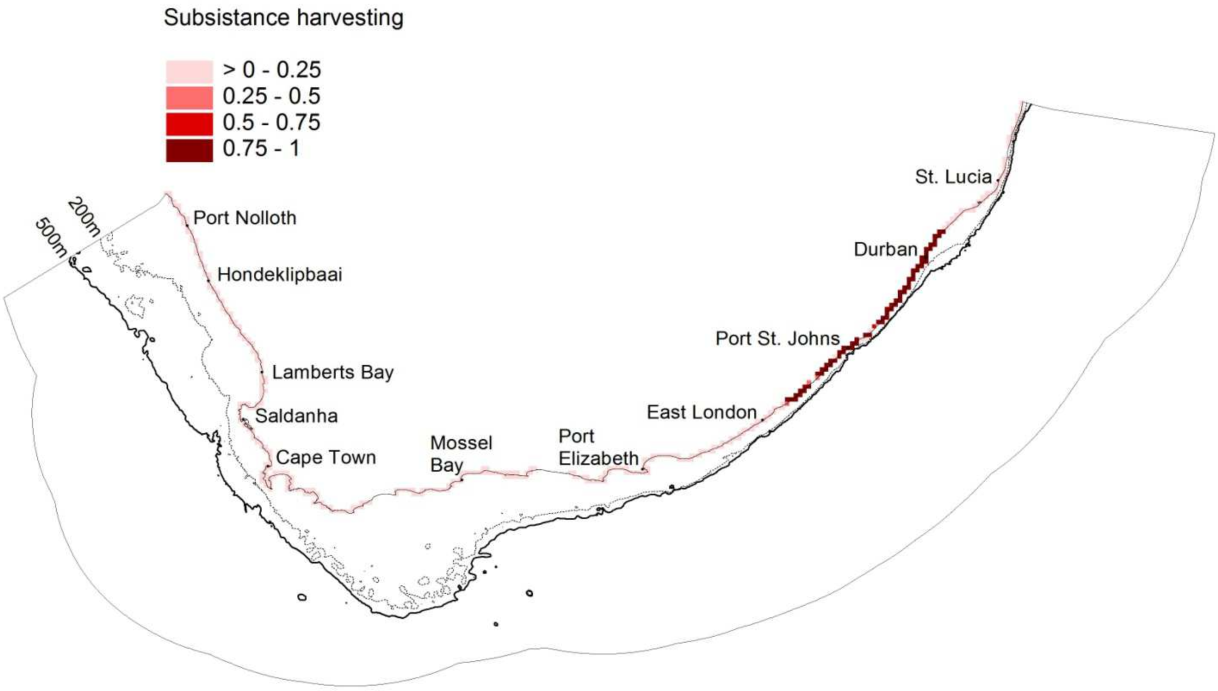


Figure 32: Standardised pressure values reflecting the relative intensity of subsistence harvesting in South Africa.

Mussel harvesting has led to stock concerns in many areas along the east and south coast (Lasiak and Dye 1989, Tomalin and Kyle 1998). Limpet harvesting has decimated populations of *Cymbula oculus* in the former Transkei area (Branch and Odendaal 2003). By comparing harvested areas to those in MPAs, Branch and Odendaal (2003) showed that harvesting dramatically reduced the abundance and size of limpets and skewed sex ratios with much lower recruitment success outside of MPAs. Changes in community structure are also of concern as the loss of mussel habitat to articulated corallines (Dye *et al.* 1997, Sink 2001) may lead to changes in recruitment success (mussels preferentially settle into mussels) and changes in food and energy flow in coastal habitats (Harris *et al.* 1998, Sink 2001). The greater impact of subsistence versus recreational mussel harvesting is related to both the larger quantities required by subsistence harvesters and the tools and methods involved (Sink 2001). Co-management initiatives have helped reduce harvesting impacts in northern KwaZulu-Natal.

3.2.26 Coastal disturbance

Virtually the entire South African shoreline is accessible by foot, and thus potentially vulnerable to human disturbance in some form. However, this analysis considered only the popular areas (recreational beaches) or those that are easily accessible (by vehicle), where human impacts are likely to be most concentrated. These impacts could include:

- Trampling of coastal fauna, such as macrofauna on sandy beaches (Moffett *et al.* 1996, Brown and McLachlan 2002) or rocky shore biota (Bally and Griffiths 1989);
- Disturbance of breeding (Leseberg *et al.* 2000, Brown and McLachlan, 2002) or foraging birds (Thomas, *et al.* 2001);
- Disturbance to surf zone fish and elasmobranches by bathers (Brown and McLachlan, 2002); or boat launching and beach-driving related activities (e.g. Schlacher *et al.* 2007).

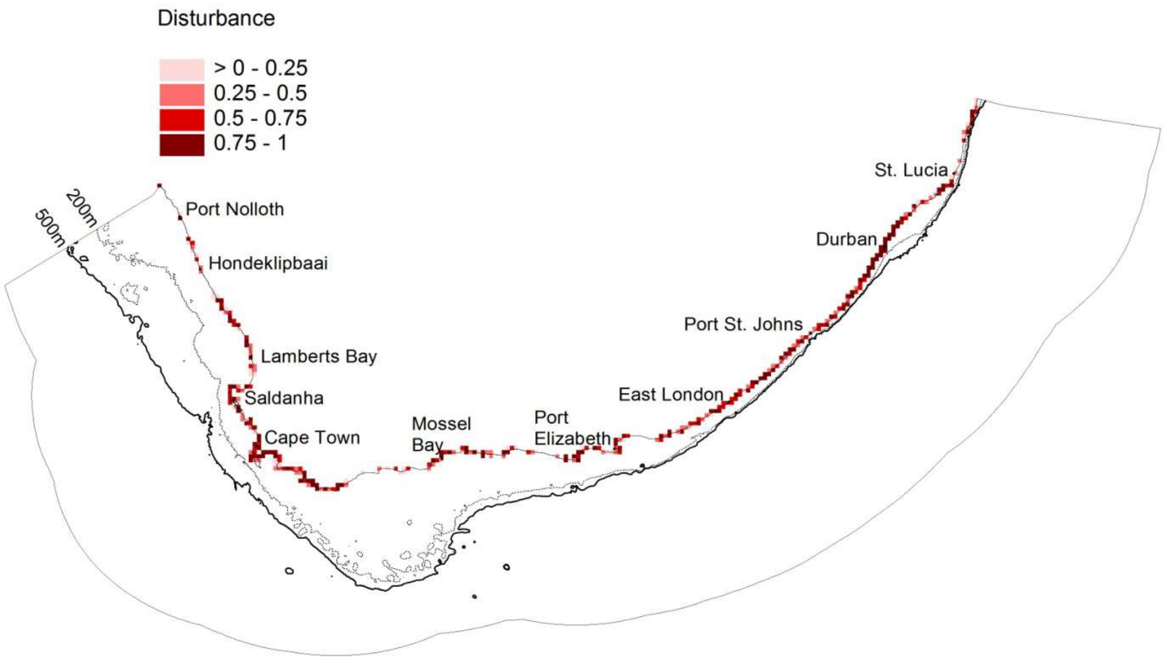


Figure 33: Scaled pressure values reflecting the relative intensity of coastal disturbance in South Africa.

Almost half (43%) of South Africa's coastline is exposed to these types of disturbance. The south coast (between Cape Agulhas and Algoa Bay) and north-west coast are least accessed, primarily because of the long stretches of cliff and rock in the south (e.g. Tsitsikamma), and closed-access diamond mining areas in the northwest. However, there are still some very popular spots along the south coast, including De Hoop, Mossel Bay, Sedgefield, Knysna, Plettenberg Bay, Cape St Francis, Jeffrey's Bay and Port Elizabeth that have high coastal disturbance, particularly in the holiday seasons (Figure 33).

3.2.27 Cumulative pressures

Figure 34 shows cumulative pressures from all pressure layers used in this assessment. This map reflects the intense pressure along the coastline and shelf edge and on the shelf close to major economic centres. This map is illustrative and only reflects summed pressures without considering the types of habitats and the differential impact of different pressures in different habitat types. The expected impact of these pressures is reflected in the maps of ecosystem condition based on cumulative impact scores that consider the distribution of the range of pressures, the distribution of habitat types and the potential impact of each pressure on each habitat or broad ecosystem group using the pressure-ecosystem matrix.

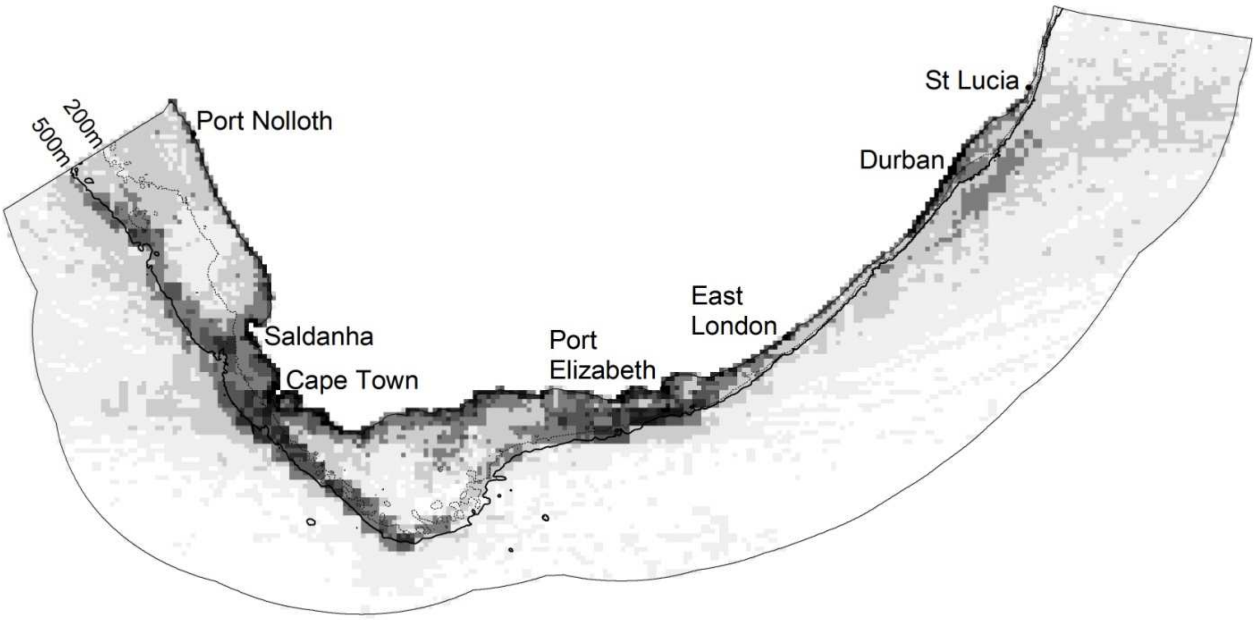


Figure 34: Total normalised pressure values for all pressure layers used in this assessment.

3.3 Limitations of the pressure datasets and maps

Although the mapping of a diverse range of pressures on marine and coastal ecosystems represents a significant advance in this assessment, there are some limitations to these datasets and maps. Pressures that were not included in this assessment include abalone fishing, recreational mussel, oyster, bait and rock lobster fisheries, recreational and commercial white mussels *Donax serra* harvesting, net fisheries and small experimental fisheries such as those for octopus and whelks (DAFF 2010). The experimental hoop-net fishery for whelks *Bullia laevissima* and three spotted swimming crab *Ovalipes trimaculatus* takes place on sandy seabed areas in the subtidal between False Bay and Cape Town harbour (DAFF 2010) was also not included in this assessment. Oil pollution from documented oil spills was not mapped and non-extractive recreational activities were not considered in this assessment.

Some pressure maps require improvement. The map of recreational fishing effort is incomplete and based on outdated information. A standardised national survey of recreational fishing effort is a key research priority. The subsistence fishing dataset is outdated and needs to be improved using more recent information. Many of the commercial fisheries layers are coarsely mapped with effort documented at the scale of 20 or 10 minute grid blocks. This does not match the finer scale of habitat mapping where several habitat types are found within any one fishing grid. Fishing may be confined to a single habitat type but the coarse effort data did not allow this to be determined and therefore the mapped value of fishing effort for the entire grid block was assumed (Figure 35). Finer scale pressure mapping would facilitate an improved assessment.

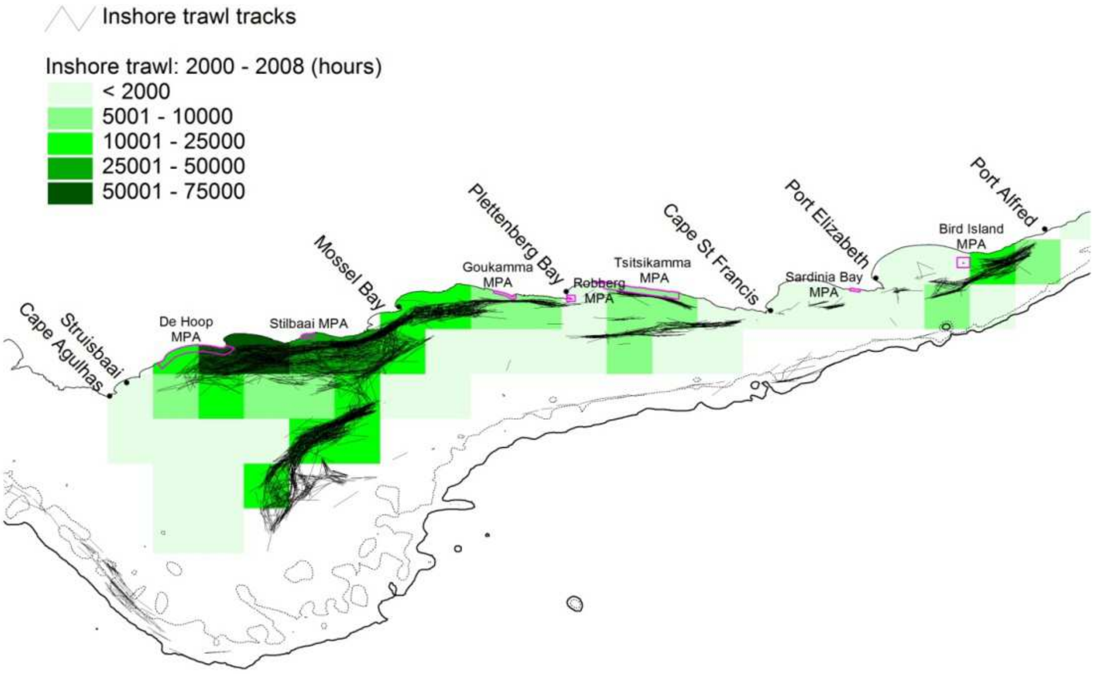


Figure 35: Coarse data reflecting trawling effort at a scale of 20 minute commercial fishing grids compared with trawl tracks as mapped from observer data.

4 Protected Areas

A GIS spatial layer for South Africa's MPAs was first developed in 2004 through the previous National Spatial Biodiversity Assessment (Lombard *et al.* 2004). Since then, two new MPAs have been proclaimed, the Still Bay MPA and the Amathole MPA which includes the Gonubie, Kei and Gxulu areas, the three previous closed areas near East London (see Lombard *et al.* 2004) that have now been proclaimed as MPAs (Figure 37 and Figure 38). The Amathole MPA was proclaimed after the analyses for protection levels were conducted for this assessment and thus the contribution of the Amathole MPA was not included in the protection level assessment. A revised MPA GIS layer was produced in 2009 for use in protected area planning (Sink et al. 2011) and this MPA layer was used in this assessment. It includes 22 MPAs, including Still Bay but excluding Amathole.

A revised MPA layer and map (Figure 38) was produced in October 2011. A map of the Still Bay MPA is presented (Figure 37) but all other MPAs can be found in Lombard *et al.* (2004). MPAs were mapped from co-ordinates published in the Government Gazette (Marine Living Resources Act). Data on coastal terrestrial protected areas were obtained from the National Protected Areas Expansion Strategy dataset (Government of South Africa 2010) and were also used in the analysis although they are not reflected in the MPA statistics or maps presented below. The terrestrial segments of protected areas were included in the protection level assessment for coast types and did make some contribution to protection levels for these habitat types.

South Africa has 23 gazetted MPAs (see Table 9, Figure 36 and Figure 38). Currently, a total of 0.42% of South Africa's mainland marine territory (including the territorial sea and mainland EEZ but excluding the Prince Edward Islands) falls within MPAs, 0.17% of which is "no-take". The proclamation of the approximately 10 km long Still Bay MPA has advanced coastal protection from a total of 21.47% (9.14% no-take) of South Africa's coastline in 2004 to 21.75% (9.26% no take) in 2011. Proclamation of the Amathole MPA resulted in the protection of 23.17% of the coastline in MPAs adding 52 km. Note that these estimates are based on the previously estimated 3656 km long coastline that overestimated coastline length due to the inclusion of rocky shore typology within the line. Future calculations should use the revised 3113 km estimate of coastline length. Also note that "area based estimates" rather than length of coastline protected are preferable and area based targets will be developed for inshore MPA targets in the future (Government of South Africa 2010).

Table 9: An overview of South Africa's 23 Marine Protected Areas.

Marine Protected Area	Year established	Size (km^2)	Zoned	% no take	Type of use in extractive use zones
Malgas Island	2000	0.9	No	0	Commercial rock lobster, limited recreational and commercial boat based line fishing.
Marcus Island	2000	0.4	No	0	Commercial rock lobster, limited recreational and commercial boat based line fishing.
Jutten Island	2000	1.6	No	0	Commercial rock lobster, limited recreational and commercial boat based line fishing.
Langebaan Lagoon	1985, revised in 2000	47.1	Yes	22	Commercial and recreational fishing in controlled A Zones, limited commercial net fishing (motorised) in Restricted B Zones
Sixteen Mile Beach	2000	107.1	No	0	Commercial linefish, rock lobster and abalone and recreational rock lobster fishing.
Table Mountain National Park	1977, revised in 1994	956.0	Yes	0.02	Multiple commercial and recreational fisheries.
Helderberg	2000	2.4	No	100	-
Betty's Bay	1990	20.1	No	0	Recreational shore angling
De Hoop	1985	288.9	No	100	-
Stilbaai	2008	31.9	Yes	62%	Limited commercial linefishing, commercial oyster harvesting and recreational shore angling.
Goukamma	1990	34	No	0	Recreational shore angling.
Robberg	1990	26.2	No	0	Recreational shore angling.
Tsitsikamma	1964	264.4	No	100	-
Sardinia Bay	1990	12.9	No	100	-
Bird Island	2004	70.6	No	100	-
Dwesa Cwebe	1975, revised in 2000	191.5	No	100	-
Amathole	2011	246.5	No	0	Recreational shore angling.
Hluleka	1991	40.9	No	100	Recreational shore angling.
Pondoland	1991, revised in 2004	1237.3	Yes	47.8	Commercial linefishing, recreational shore and boat based linefishing, subsistence fishing.
Trafalgar	1979	8.3	No	0	Recreational shore angling.
Aliwal Shoal	2004	124.7	Yes	1.7	Shore and boat based angling, commercial linefishing, subsistence harvesting.
St Lucia	1976	442.0	Yes	30.3	Shore angling (all species), recreational linefishing (pelagic species only).
Maputaland	1987	384.5	Yes	33.8	Shore angling (all species), recreational linefishing (pelagic species only)

Seven of South Africa's MPAs do not permit any form of extractive use and are therefore considered "no-take" MPAs (Figure 38). Nine MPAs allow some form of extractive use throughout the entire MPA. The remaining 7 MPAs are zoned with both "no-take and extractive use zones.

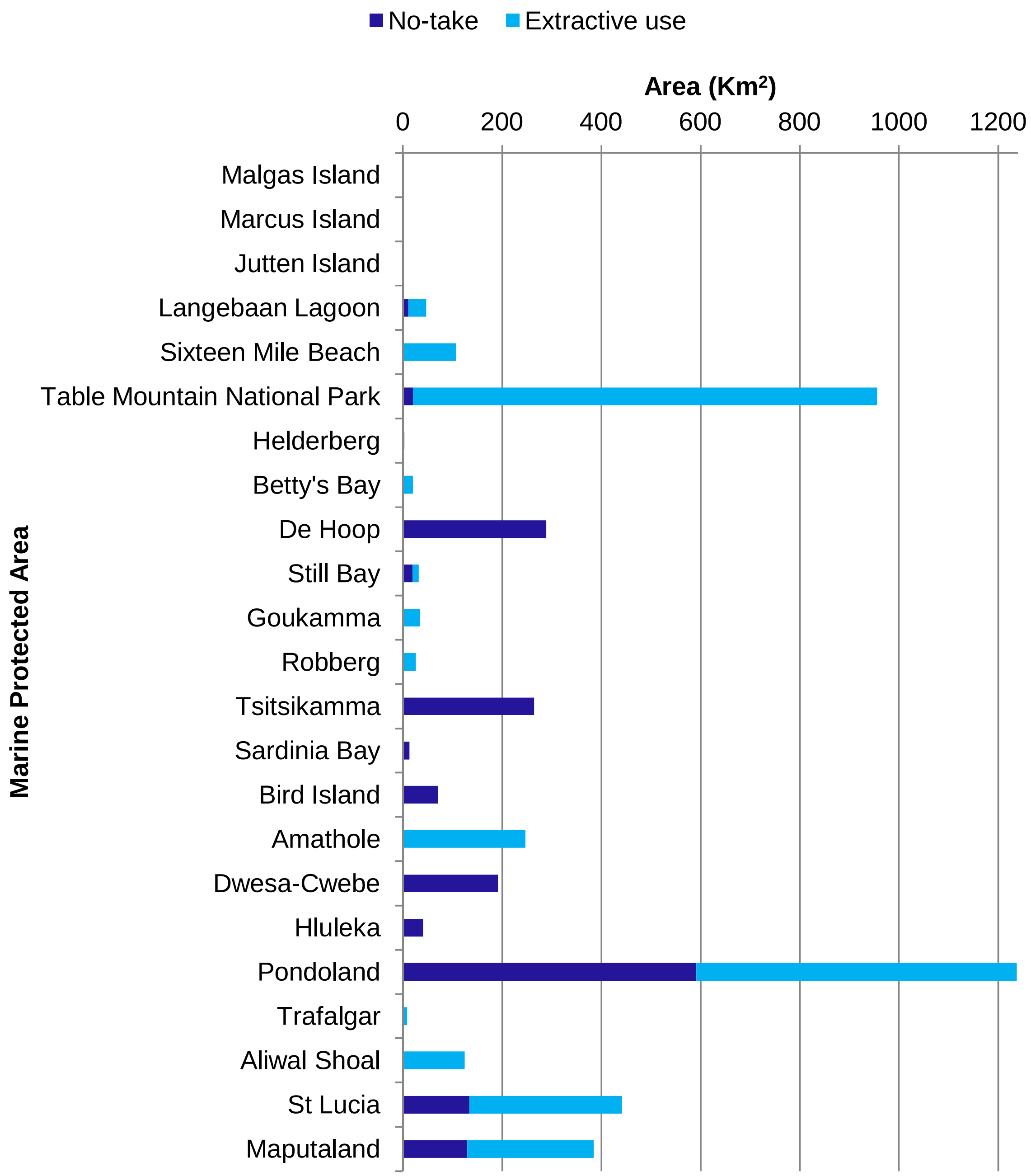


Figure 36: Histogram showing the area included in no-take and extractive use zones within South Africa's 23 Marine Protected Areas.

The Marine Living Resources Act clarifies the intention of MPAs in South Africa:

a. For the protection of marine fauna and flora and the physical features on which they depend;
b. To facilitate fishery management by protecting spawning stock, allowing stock recovery, enhancing stock abundance in adjacent areas as well as providing pristine communities for research; or
c. To diminish any conflict that arises due to competing users in that area.

More specific objectives of South Africa's MPAs are noted in some of the gazette notices that proclaim MPAs but very specific MPA objectives need to be developed and gazetted for every MPA. This is essential to support proper review of the biodiversity and fisheries management objectives of South Africa's MPA network. Table 10 shows the ecozones and broad ecosystem groups included in South Africa's MPA network.

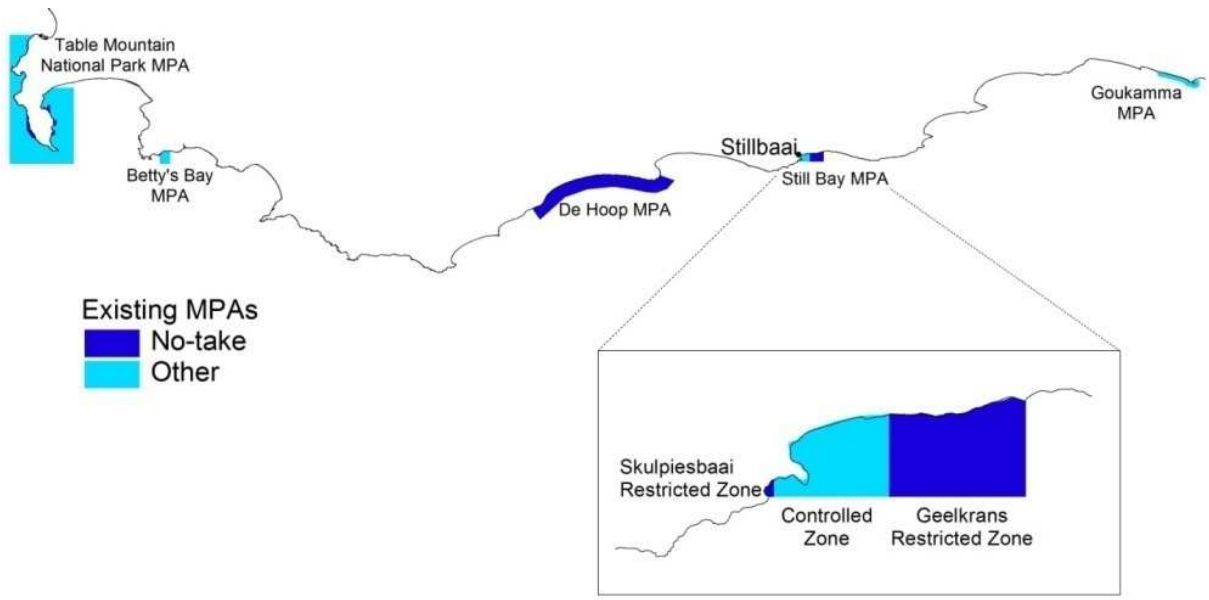


Figure 37: Map showing South Africa's Still Bay MPA on the south coast.

Table 10: Ecozones and broad ecosystem groups included in South Africa's 23 Marine Protected Areas. The state of key resources and the achievement of fishery management objectives of MPAs should be reviewed and important species within each MPA including threatened, protected and other species of concern should also be documented building on the excellent work of south Africa's previous Marine Reserves Task Team.

Marine Protected Area	**Ecozones**	**Broad Ecosystem Group**
Malgas Island	Southwestern Cape inshore	Island-associated
Marcus Island	Southwestern Cape inshore	Island-associated
Jutten Island	Southwestern Cape inshore	Island-associated
Langebaan Lagoon	Southwestern Cape inshore	Lagoon
Sixteen Mile Beach	Southwestern Cape inshore & inner shelf	Rocky, mixed and sandy coast, rocky inshore, sandy inshore, island associated.
Table Mountain National Park	Agulhas inshore & inner shelf, Southwestern Cape inshore & inner shelf, Southern Benguela outer shelf	Rocky, mixed and sandy coast, rocky inshore, sandy inshore, rocky shelf and unconsolidated shelf.
Helderberg	Agulhas inshore	Sandy coast.
Betty's Bay	Agulhas inshore & inner she	Rocky, mixed and sandy coast, rocky inshore, rocky shelf.
De Hoop	Agulhas inshore & inner shelf	Rocky, mixed and sandy coast, rocky inshore, rocky shelf, unconsolidated shelf.
Stilbaai	Agulhas inshore & inner shelf	Rocky, mixed and sandy coast, sandy inshore, rocky inshore, rocky and sandy shelf.
Goukamma	Agulhas inshore & inner shelf	Rocky, mixed and sandy coast, sandy inshore, rocky inshore.
Robberg	Agulhas inshore & inner shelf	Rocky, mixed and sandy coast, rocky inshore, sandy inshore, rocky and unconsolidated shelf.
Tsitsikamma	Agulhas inshore & , inner shelf	Rocky and mixed coast, rocky and sandy inshore, rocky and sandy shelf.
Sardinia Bay	Agulhas inshore	Rocky, mixed and sandy coast, rocky and sandy inshore.
Bird Island	Agulhas inshore & inner shelf	Island associated.
Amathole	Agulhas inshore & inner shelf	Rocky, mixed and sandy coast, rocky and mixed inshore, rocky and unconsolidated shelf.
Dwesa Cwebe	Agulhas inshore, inner and outer shelf and Natal inshore and shelf	Rocky, mixed and sandy coast, rocky and mixed inshore, rocky and unconsolidated shelf.
Hluleka	Natal inshore and shelf	Rocky, mixed and sandy coast, rocky and sandy inshore, unconsolidated shelf.
Pondoland	Natal inshore, shelf and slope and Southwest Indian upper bathyal	Rocky, mixed and sandy coast, sandy and rocky inshore, unconsolidated shelf, rocky shelf, unconsolidated and rocky shelf edge, and deepsea sediment.
Trafalgar	Natal inshore	Mixed and sandy coast, rocky and sandy inshore.
Aliwal Shoal	Natal inshore and shelf.	Rocky, mixed and sandy coast, rocky and sandy inshore, rocky shelf, unconsolidated shelf.
St Lucia	Delagoa inshore, shelf and slope.	Rocky, mixed and sandy coast, sandy and rocky inshore, unconsolidated shelf, rocky shelf, unconsolidated and rocky shelf edge, and deepsea sediment.
Maputaland	Delagoa inshore, shelf and slope.	Rocky, mixed and sandy coast, sandy and rocky inshore, unconsolidated shelf, rocky shelf, unconsolidated and rocky shelf edge, and deepsea sediment.

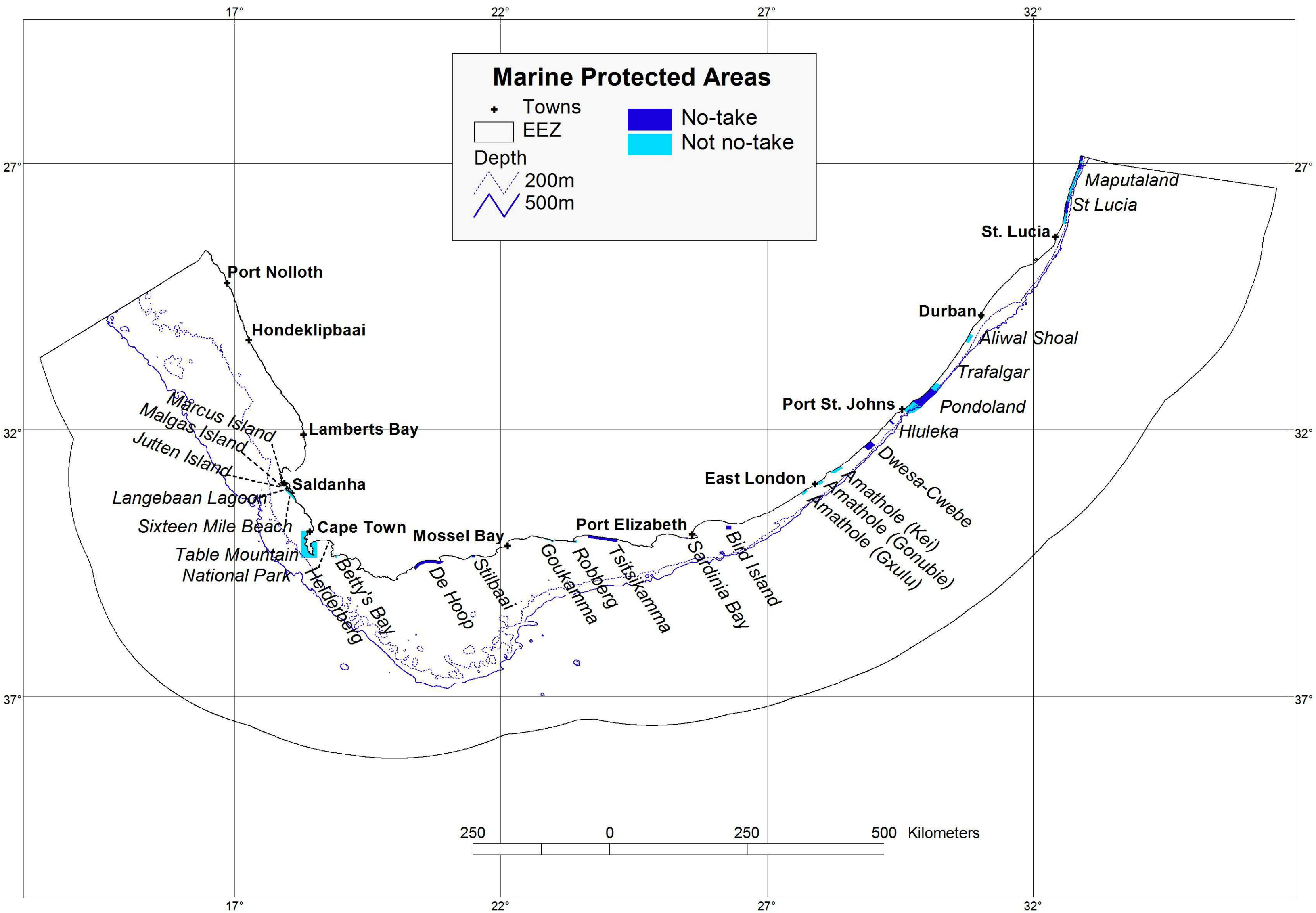


Figure 38: Existing MPAs in South Africa.

5 Biodiversity targets

The National Spatial Biodiversity Assessment 2004 (Lombard *et. al.* 2004) did not use biodiversity targets in assessing the threat status of biozones but rather ranked threats per biozone to provide an expert-based assessment of relative threat status per biozone. A range of targets (20-50%) were used in assessments of habitat representation for South Africa's MPA network and 20% targets were used in analyses to identify potential areas to improve representation of intertidal habitats in MPAs. Lombard *et al.* (2004) used a standard 20% target to assess protection levels with a target of 20% of length (supratidal and intertidal biozones) or 20% of area (subtidal biozones).

A standard 20% biodiversity target was used in the 2011 assessment of ecosystem threat status and ecosystem protection levels. South Africa does not have ecologically determined biodiversity targets for marine ecosystems. The 20% biodiversity target is a default value commonly used in South Africa when targets derived from the underlying characteristics (e.g. species area curves) of biodiversity features are not available. A review of approaches and targets for marine habitats has been undertaken by the South African National Biodiversity Institute (Porter *et al.* 2011), that will inform target setting for marine ecosystems in the future.

6 Ecosystem Threat Status Assessment

6.1 Assessment Methodology

The ecosystem threat status of an ecosystem was determined by evaluating the area of each habitat in a specific condition against a series of thresholds (Figure 39 and Table 11). This method was designed to give comparable categories and results for the marine and coastal environment to those used in the South African National terrestrial, freshwater and estuarine conservation assessments, and to ensure that the assessment remains within a systematic framework (sensu Margules and Pressey 2000).

1. Habitat maps produced
2. Pressure maps produced
3. Calculation of cumulative impact scores (weighted based on an ecosystem - pressure matrix)
4. Condition map produced
5. Comparison of condition to biodiversity thresholds for each habitat
6. Ecosystem threat status assigned

Figure 39: Schematic showing steps to determine ecosystem threat status

Four ecosystem threat categories (Table 11) were defined that are comparable with those used in the South African National terrestrial, freshwater and estuarine conservation assessments (Driver *et al.* 2005 and Driver *et al* .in prep). The categories were:

Critically Endangered: These are habitat types where the area in good condition is less than the identified biodiversity target (20%). Conceptually, these are habitat types where there are very few remaining areas of pristine or natural habitat, and it is expected that important components of biodiversity pattern have been lost and that processes have been heavily modified.

Endangered: These are habitat types where the area in good condition is less than the identified biodiversity target plus 15% (i.e. 35%). Conceptually, this is a "red flag" category for habitat types that are approaching the point where it is expected that important components of biodiversity pattern and process will be lost.

Vulnerable: These are habitat types where the remaining area in good condition is greater than the identified biodiversity threshold plus 15% (i.e. are not Critically Endangered or Endangered), but where the remaining area of habitat type in good or fair condition is less than 80%. Conceptually, these are habitat types where there are sufficient areas of intact biodiversity of this type to meet the biodiversity target, but outside of these areas there has been habitat degradation and some loss of ecosystem processes.

Least threatened: These are habitat types where the area that is estimated to be in good condition is greater than the identified biodiversity target plus 15% (i.e. they are not Critically Endangered or Endangered), and where the area of habitat type in good or fair condition is greater than 80%. Conceptually, there are sufficient areas of intact biodiversity of this habitat type to meet the biodiversity target, and it is anticipated that there has been little broad modification of ecosystem processes. Relatively large portions of the habitat type are perceived to be in a relatively pristine or natural state based on the available pressure data.

Table 11: Condition thresholds for each ecosystem threat status category

Condition Thresholds	Less than 20% Good	Less than 35 % Good	Less Than 80% Good and Fair	More than 80% Good and Fair
Ecosystem Threat Status	**Critically endangered**	**Endangered**	**Vulnerable**	**Least Threatened**

6.1.1 Cumulative impact scores

The framework for calculating cumulative impact scores (I_c) generally follows Halpern *et al.* (2008, 2009). I_{cj} was separately calculated for each habitat found within a 5' grid square, as a grid square could include a variety of ecosystems that may not all be subject to the same pressures (e.g. fishing for west coast rock lobster may impact the hard ground habitat within the unit of assessment but not the unconsolidated sediment) and could potentially respond differently to specific pressure types (i.e. a particular habitat may be impacted more heavily or take longer to recover from any one pressure). The cumulative impact for a habitat at a site was calculated as:

$$I_{cj} = \sum_{i=1}^{n} \beta_i \times W_{ij}$$

Where β_i is the normalised pressure value (scaled between 0 and 1) of intensity of an anthropogenic driver at location *i*, and W_{ij} the impact weight for anthropogenic driver *i* and habitat *j*.

The impact weights W_{ij} were estimated using a group consensus process (6 experts) supplemented by additional consultation with individual experts and reference to available literature (see Table 2 and Table 4 for Ecosystem and Pressures references collectively including over 600 citations). This expert-driven process relied on expertise from more than 30 marine and coastal biodiversity and fisheries specialists in the South African marine field.

The calculation of impact weights followed a simplified version of the procedure described by Teck *et al.* (2009). Key differences in method from Teck *et al.* (2009) were that a guided group consensus method was used during the scoring process (rather than an individual survey method) and that impacts were aggregated into "functional impact" and "recovery" categories rather than being subdivided into further categories. The group and individual interactions were guided by the same group moderator to ensure consistency of scoring. The draft values were iteratively refined and updated (with the involvement of key specialists with local knowledge) until stable values were obtained. As there were 136 unique habitat types (ecosystems) and 27 different anthropogenic drivers of ecosystem change, for the purposes of the preparation of the impact weights, the habitat types were grouped into 13 categories (Table 12) based on similarity of habitat type and their likely responses to pressures. For example, all the different sandy coast types were grouped together, as were unconsolidated sediments. However, where the evaluation process identified problems caused by the lumping of categories (e.g. subtropical reefs in shallow versus deeper water), these were then split into separate evaluation categories.

The impact weights W_{ij} were subdivided into two key components, namely functional impact and recovery. Functional impact was a broad evaluation of the degree to which the natural state of any given ecosystem (including component species, community structure, physical habitat structure and ecosystem function) is impacted by a specific activity. This concept incorporates the issue of spatial scale or extent of a single act of an activity, and impacts on trophic structure of communities, both of which are dealt with separately by Teck *et al.* (2009). Initially these issues were separated out, but it was too difficult to usefully disaggregate these components. The expert groups evaluated the functional impacts based on their own knowledge for South

Africa with reference to a substantial body of published literature. Experts evaluated on a scale of 0-10 the known level of impact of each pressure on the overall state of a set of broad habitat types. Experts were guided by (but not necessarily limited to) the following scoring values and cutoffs, but also used intermediate values: Pressures were designated as "not applicable" if it was known that any specific pressure type does not occur in that habitat in South Africa; 1 = Minor impact limited to a specific species with minimal impact on overall system functioning, 2 = Minor impact limited to a few (<10) specific species with minimal impact on overall system functioning, 5 = Moderate impact on natural state of habitat, including impacts on a range of species and some impacts on trophic structure and may include localised physical habitat damage, 10 = Extremely heavy impact on the natural state of a habitat (including major changes in trophic structure and/or damage to physical structure). Values should be interpreted as a relative evaluation of the impacts of different pressure types on a habitat type and of the relative impact of the same level of a specific pressure type on different habitat types.

The second component of the impact weights was recovery, which was a measure of the time required for the habitat (including affected species, physical habitat structure, and community trophic structure) to return to a natural state following cessation of disturbance by a given activity. Recovery scores were evaluated by experts with reference to available literature. Scores represent on a scale of 0-10 the anticipated time taken for recovery of a habitat once a specific pressure type has been removed from a site. Experts were guided by the following scoring values and cutoffs, and were also free to use intermediate values: "Not applicable" indicates that the specific pressure type is not known to occur in that habitat type; 1 = Very quick recovery (less than 1 year); 2 = Quick recovery (more than one year but less than 2 years); 5 = Average recovery time (more than 2 years but less than 5 years); 8 = Slow recovery time (more than 5 years but less than ten years); and 10 = Very slow recovery or permanent damage (e.g. by long-term irreversible changes in habitat or trophic structure). Values should be interpreted as a relative evaluation of the recovery time of a habitat or ecosystem after being subject to a pressure and of the relative recovery time between different habitat types after the same level of a specific pressure type has been experienced.

The impact weights W_{ij} were then calculated by an equal weighted average of the functional impact and recovery scores (Table 12). The cumulative impacts of all pressures for the habitat types at a site were then calculated using the formula detailed above.

The resultant cumulative impact score I_{cj} was then discounted by set proportions in protected areas (both declared Marine Protected Areas and formal terrestrial protected areas which have a coastal component). This was done because the data on which the pressure layers were based were often too coarse to reflect actual pressure values within (usually small) protected areas. For example, most of the trawling data were based on 20' grids which often included portions of Marine Protected Areas that generally exclude trawling (see Offshore Marine Protected Area project (Sink et al. 2011) for details on existing spatial management). Although ideally the pressure layers would be modified for a specific MPA based on the activities excluded and on the specific habitat types present, this was not possible within the time constraints of the current project. South African MPAs do not have a standardised zonation and there are many iterations of management types in different zones of MPAs (Figure 38). No-take zones of MPAs were accounted for separately from other iterations that include various types and intensities of other anthropogenic impacts including many types of fishing (Table 9). The no-take zones are the one category of zonation that is standardised in excluding all extractive resource use and which was mapped during the previous National Spatial Biodiversity assessment (Lombard *et al.* 2004). Cumulative pressures within "no-take" MPAs were discounted by 80% (as although specific activities are excluded within the MPA, these areas are still subject to broad regional impacts such as reductions in runoff as well as being impacted by adjacent activities) while "extractive zones" of MPAs were only discounted by 30%. This lower reduction was justified by the fact that extractive use is often the major driver of change, and that some activities such as recreational fishing may in fact be focused on extractive use zones of MPAs (Attwood *et al.* 1997, Pradevand and Hiseman 2006, Tunley 2009). Nevertheless, as a range of specific activities such as trawling or urban development may be limited in these areas, a pressure discount is still justified.

Table 12: Impact weights reflecting the equal weighted average of the functional impact and recovery scores for different groups of habitat types per pressure. Red colouring reflects the pressures with the greatest impact per group of habitat types whereas orange reflects intermediate impacts and green pressures with the lowest expected impact.

Pressures	Lagoon	Mixed shore	Rocky coast	Sandy coast	Coral communities	Island-associated	Rocky inshore	Unconsolidated inshore	Canyons	Rocky offshore	Seamounts	Unconsolidated offshore	Offshore pelagic
Inshore demersal trawl	n/a	n/a	n/a	n/a	n/a	10	n/a	n/a	10	10	n/a	7.5	4
Offshore demersal trawl	n/a	n/a	n/a	n/a	n/a	10	n/a	n/a	10	10	n/a	6.5	4
Demersal longline	n/a	n/a	n/a	n/a	n/a	6	n/a	n/a	6	6	n/a	4	4
Small pelagics	n/a	n/a	n/a	n/a	n/a	8	3.5	3.5	3.5	3.5	n/a	3.5	6
Midwater trawl	n/a	n/a	n/a	n/a	n/a	4	n/a	n/a	4	4	n/a	4	4
Crustacean trawl	n/a	n/a	n/a	n/a	n/a	n/a	10	8	10	10	n/a	8	4.5
South coast rock lobster trap fishery	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	5	5	n/a	3.5	n/a
West coast rock lobster fishery	n/a	6	6	n/a	n/a	6	6	n/a	n/a	6	n/a	n/a	n/a
Squid fishery	n/a	1	1	1	n/a	2.5	2	1	2	2	n/a	1	2.5
Linefishing	4.5	6.5	6.5	5	9	9	9	5	9	9	n/a	5	3.5
Tuna pole fishery	n/a	n/a	n/a	n/a	n/a	3	n/a	n/a	2.5	2.5	n/a	2.5	3
Shark fisheries	n/a	7.5	7.5	7.5	8	8	8	8	8	8	n/a	8	9
Large pelagic fishery	n/a	n/a	n/a	n/a	n/a	7	n/a	n/a	6	6	6	4.5	7
Kelp harvesting	n/a	5	3	5	n/a	6.5	6.5	n/a	n/a	n/a	n/a	n/a	n/a

Pressures	Lagoon	Mixed shore	Rocky coast	Sandy coast	Coral communities	Island-associated	Rocky inshore	Unconsolidated inshore	Canyons	Rocky offshore	Seamounts	Unconsolidated offshore	Offshore pelagic
Shark control program	n/a	6.5	6.5	6.5	7.5	n/a	7.5	7.5	n/a	7.5	n/a	7.5	8.5
Mariculture	8	3	3	3	n/a	4	3	4	n/a	3	n/a	4	3
Alien Invasive Species	7.5	8	8	3.5	n/a	7.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Petroleum activities	n/a	n/a	n/a	n/a	n/a	n/a	5.5	4.5	5.5	5.5	n/a	4.5	2
Shipping	5.5	1.5	1.5	1.5	1	2	1	1	1	1	1.5	1	2.5
Coastal development	10	10	9	10	6.5	6	5	4.5	n/a	5	n/a	4.5	3
Waste water discharge	5.5	5	5	4	6.5	6.5	6.5	5	n/a	6.5	n/a	5	2.5
Freshwater flow reduction	5	6	4.5	6	4.5	4.5	4.5	4.5	4.5	4.5	n/a	4.5	4.5
Recreational Boat Fishing	4.5	6.5	6.5	4.5	6.5	7.5	6.5	4.5	6.5	6.5	n/a	4.5	3
Recreational shore fishing	4.5	6.5	6.5	4.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Subsistence harvesting	2	8	8	2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Mining (see also petroleum activities)	n/a	8	7	8	n/a	n/a	7.5	6.5	n/a	7.5	n/a	6.5	2
Coastal Disturbance	2.5	3.5	3.5	2.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

6.1.2 Ecosystem Condition

Ecosystem condition at a site was classified based on the cumulative impact scores. The categories are aligned with those used in the freshwater (Ronel Nel, pers. comm.) and estuarine assessments (Van Niekerk & Turpie 2011). The freshwater and estuarine condition classification system uses six condition categories (A-F) which are grouped into three categories (Good, Fair and Poor – see Table 13). These three condition categories were used in the marine and coastal assessment. "Good" condition sites are those sites which, based on the low levels of pressure, are expected have both biodiversity pattern and process largely intact and hence can be considered to be in a largely "natural" or "pristine" state. "Fair" condition sites are subject to a range of pressures and anthropogenic drivers of change, and it is expected that biodiversity pattern and/ or ecological processes are being impacted. These sites can be considered to be degraded. "Poor" condition sites are those sites which are expected will have experienced significant loss of biodiversity pattern or have disrupted ecological processes.

Table 13: Categories of ecosystem condition under different pressure intensities with expected biodiversity impacts.

Pressures	Few pressures, low intensities	Range of pressures, moderate intensities	Many pressures, high intensities
Condition	Good	Fair	Poor
Expected biodiversity impact	Patten and process intact	Some ecosystem degradation	Loss of biodiversity pattern and disruption of ecological processes.

Note that this table is a simplified interpretation of pressures as condition categories were based on cumulative impact scores which also account for the differential impact of different pressures in different habitat types using an ecosystem-pressure matrix.

Condition of an ecosystem at a site was classified based on the cumulative impact scores at that site (See Figure 40 for coastal and benthic habitat types, and Figure 41 for pelagic habitat types). Field-based ecosystem-wide evaluations of site condition have yet to be established in South Africa for marine habitats and hence no reference sites exist against which the cumulative impact scores (and the classification thresholds used to subdivide categories) could be calibrated. Numerical thresholds in the cumulative impact scores had to be defined in order to classify the site condition. This was done separately for the coastal, benthic and pelagic habitat types. Histograms were drawn of the cumulative impact scores, and these were subdivided on the basis of natural breaks in the distributions. The subdivisions values were also guided by spatial comparisons of values in highly impacted areas (e.g. heavily fished areas near major commercial and industrial centres) compared to habitat types with few anthropogenic drivers of ecosystem change, as well as by cross referencing to cumulative impact scores in global studies (Halpern *et al.* 2008).

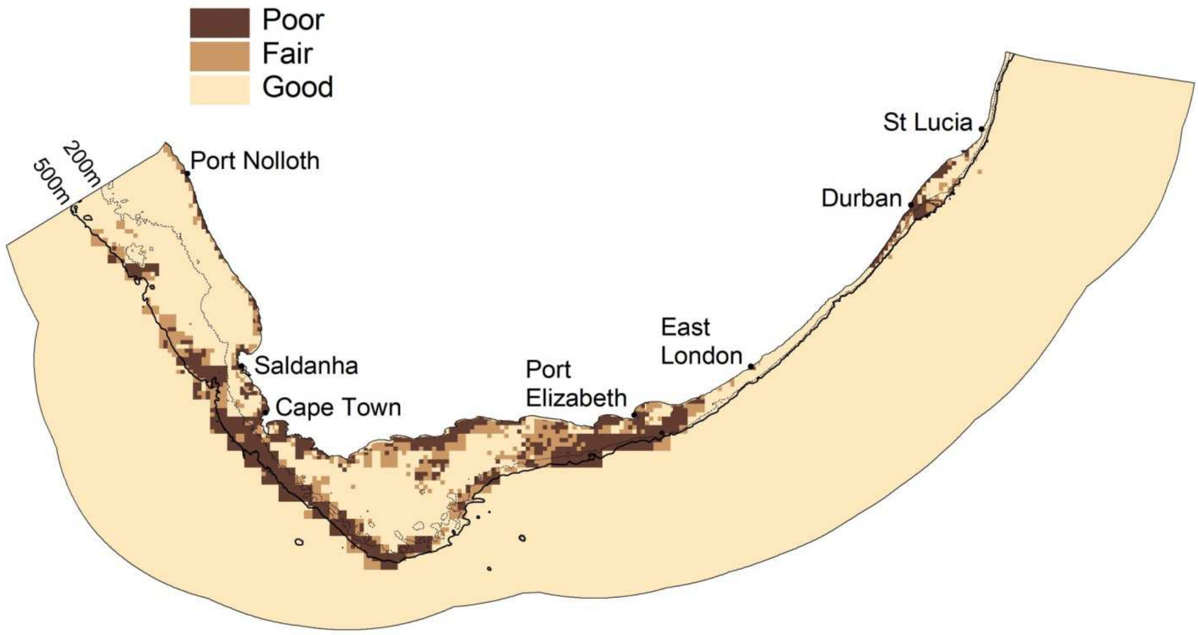


Figure 40: Ecosystem condition for the coastal and offshore benthic environment in South Africa.

The assessment of condition is based on the underlying assumption that habitats and ecosystems are in a worse condition when they are subject to high levels of pressures or anthropogenic drivers of ecosystem change, and that condition will tend to worsen as pressure intensities increase. Although the assumption appears logical, this assessment would be more robust if this was corroborated by independently estimated assessments of condition. This assessment can therefore be interpreted as an assessment of *relative* ecosystem condition. If one is not willing to accept the underlying assumption, then the assessment can be interpreted as a relative assessment of areas subject to higher levels of cumulative pressures (or anthropogenic drivers of ecosystem change) rather than being an absolute assessment of condition. The condition assessment is independent of the spatial extent of each habitat type.

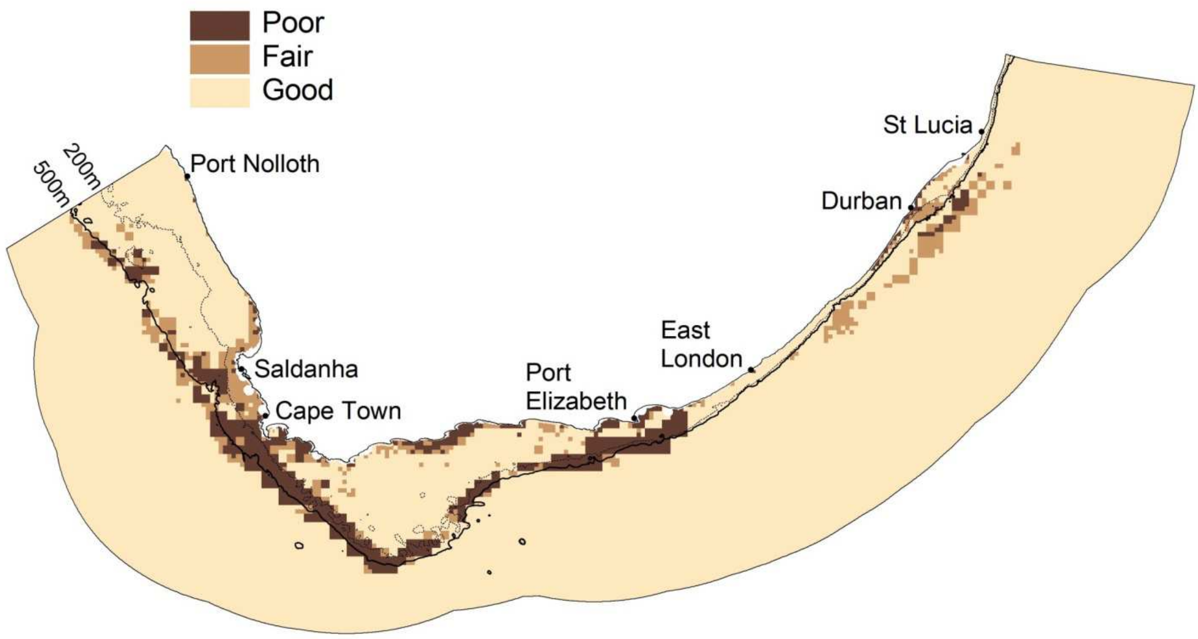


Figure 41: Ecosystem condition for the offshore pelagic environment in South Africa.

Figure 40 shows the results of the ecosystem condition of coastal and offshore benthic habitat types based on the cumulative impact scores. Poor condition along the coast and shelf edge is caused by the high levels of multiple pressures in these areas. Habitat types that are considered heavily impacted yet with slow recovery for some demersal activities, such as trawling, are assigned into poor condition categories. These include some reefs, hard grounds and canyons where such activity occurs. The map of ecosystem condition, Figure 41, for the pelagic environment also reflected the heavy pressure on shelf edge "habitat types". The concentration of both pelagic and demersal fishing drives this pattern. As hake is also considered a key component of pelagic ecosystems, the removal of large volumes of hake from pelagic habitat types was also considered to impact pelagic ecosystems, although this impact is considered moderate.

6.2 Ecosystem threat status results

The ecosystem threat status of 136 marine and coastal habitat types was assessed (Table 14, Figure 42, Figure 43 and Figure 44). This included 58 coastal, 62 offshore benthic and 16 offshore pelagic habitat types grouped into a total of 14 broad ecosystem groups. A total of 64 habitat types (47%) are considered threatened, with 17% of habitat types critically endangered, 7% endangered, 23% vulnerable and 52% least threatened. Although 47% of habitat types are considered threatened, the overall area of threatened habitat types is less than 30%. This reflects the small spatial extent of many threatened habitat types whereas many of the deepsea habitat types that have far greater extent are least threatened.

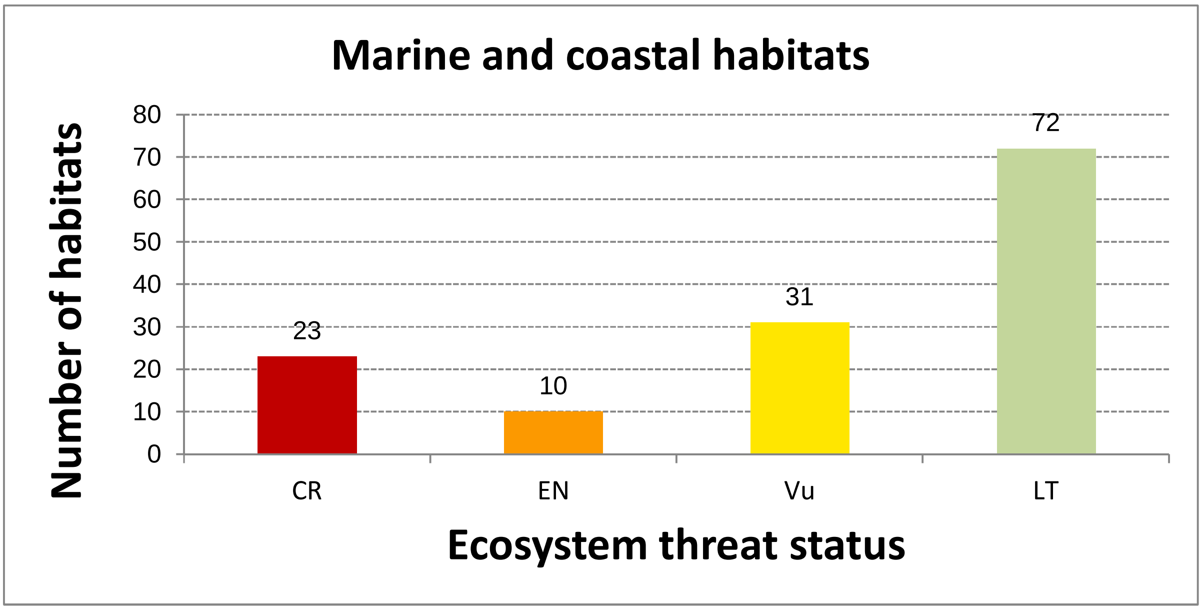


Figure 42: Number of habitat types in each ecosystem threat status category in South Africa Cr is Critically Endangered, En is Endangered, Vu is Vulnerable and LT is least Threatened.

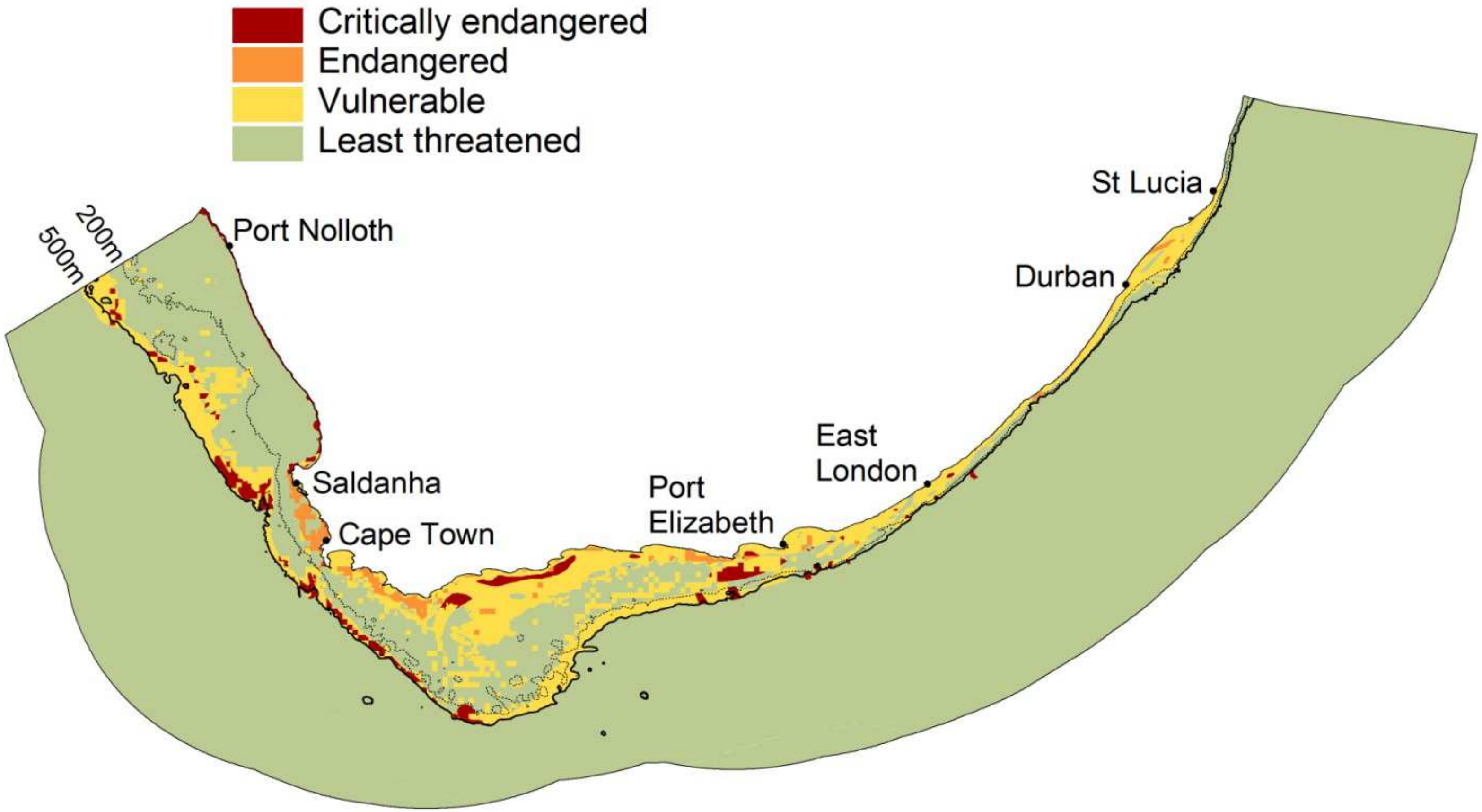


Figure 43: Ecosystem threat status for coastal and offshore benthic habitat types in South Africa.

Table 14: Ecosystem threat status and protection levels for marine and coastal habitat types in South Africa.

Habitat type	Total Size (km^2)	Threat Status	Final Protection Level
Agulhas Boulder Shore	48.97	LT	Moderately protected
Agulhas Canyon	1119.72	CR	Not protected
Agulhas Dissipative Sandy Coast	98.86	VU	Moderately protected
Agulhas Dissipative-Intermediate Sandy Coast	350.3	LT	Moderately protected
Agulhas Estuarine Shore	43.12	LT	Moderately protected
Agulhas Exposed Rocky Coast	266.26	VU	Well protected
Agulhas Gravel Inner Shelf	1321.88	LT	Poorly protected
Agulhas Gravel Outer Shelf	1481.08	VU	Hardly protected
Agulhas Gravel Shelf Edge	1788.12	LT	Not protected
Agulhas Hard Inner Shelf	4279.1	EN	Poorly protected
Agulhas Hard Outer Shelf	11537.35	VU	Not protected
Agulhas Hard Shelf Edge	4162.91	VU	Not protected
Agulhas Inner Shelf Reef	44.1	VU	Poorly protected
Agulhas Inshore Gravel	46.47	EN	Moderately protected
Agulhas Inshore Hard Grounds	751.61	VU	Moderately protected
Agulhas Inshore Reef	42.89	CR	Moderately protected
Agulhas Intermediate Sandy Coast	71.85	LT	Moderately protected
Agulhas Island-associated	868.31	VU	Poorly protected
Agulhas Mixed Sediment Inner Shelf	627.47	LT	Not protected
Agulhas Mixed Sediment Outer Shelf	1308.17	CR	Not protected
Agulhas Mixed Shore	478.52	VU	Moderately protected
Agulhas Muddy Inner Shelf	2684.52	CR	Not protected
Agulhas Muddy Outer Shelf	1772.1	VU	Not protected
Agulhas Muddy Shelf Edge	170.7	VU	Not protected
Agulhas Outer Shelf Reef	6.49	LT	Not protected
Agulhas Reflective Sandy Coast	3.69	LT	Moderately protected
Agulhas Sandy Inner Shelf	26175.18	VU	Poorly protected
Agulhas Sandy Inshore	1708.76	VU	Moderately protected
Agulhas Sandy Outer Shelf	32869.31	LT	Not protected
Agulhas Sandy Shelf Edge	4067.46	VU	Not protected
Agulhas Shelf Edge Reef	4.01	LT	Not protected
Agulhas Sheltered Rocky Coast	20.5	CR	Moderately protected
Agulhas Very Exposed Rocky Coast	31.81	VU	Moderately protected
Delagoa Sandy Shelf Edge	641.31	LT	Moderately protected
Delagoa Canyon	92.47	LT	Moderately protected
Delagoa Inshore Reef	71.02	LT	Well protected
Delagoa Mixed Shore	48.3	LT	Well protected
Delagoa Sandy Inshore	104.35	LT	Well protected
Delagoa Sandy Shelf	290.85	LT	Well protected
Delagoa Shelf Edge Reef	2.59	LT	Moderately protected
Delagoa Shelf Reef	75.04	LT	Well protected
Delagoa Very Exposed Rocky Coast	0.12	LT	Moderately protected
Namaqua Boulder Shore	0.56	CR	Not protected
Namaqua Exposed Rocky Coast	146.3	LT	Poorly protected
Namaqua Hard Inner Shelf	2656.36	LT	Not protected
Namaqua Inner Shelf Reef	0.94	CR	Not protected

Habitat type	Total Size (km^2)	Threat Status	Final Protection Level
Namaqua Inshore Hard Grounds	233.02	CR	Not protected
Namaqua Inshore Reef	3.44	CR	Not protected
Namaqua Island-associated	280.02	CR	Hardly protected
Namaqua Mixed Shore	241.19	EN	Poorly protected
Namaqua Muddy Inner Shelf	11165.61	LT	Not protected
Namaqua Muddy Inshore	164.41	VU	Not protected
Namaqua Sandy Inner Shelf	5394.52	LT	Not protected
Namaqua Sandy Inshore	823.95	CR	Not protected
Namaqua Sheltered Rocky Coast	9.35	CR	Hardly protected
Namaqua Very Exposed Rocky Coast	12.01	VU	Poorly protected
Natal Boulder Shore	2.58	CR	Not protected
Natal Canyon	483.1	VU	Moderately protected
Natal Estuarine Shore	0.49	LT	Well protected
Natal Exposed Rocky Coast	75.04	LT	Moderately protected
Natal Gravel Shelf	1097.29	LT	Moderately protected
Natal Gravel Shelf Edge	773.52	LT	Moderately protected
Natal Inshore Gravel	0.22	LT	Not protected
Natal Inshore Reef	245.29	EN	Moderately protected
Natal Mixed Sediment Shelf	1.79	LT	Moderately protected
Natal Mixed Sediment Shelf Edge	29.17	LT	Well protected
Natal Mixed Shore	157.2	VU	Moderately protected
Natal Muddy Inshore	52.99	EN	Moderately protected
Natal Muddy Shelf	501.86	EN	Moderately protected
Natal Muddy Shelf Edge	61.8	LT	Moderately protected
Natal Sandy Inshore	1236.45	VU	Moderately protected
Natal Sandy Shelf	6348.09	VU	Poorly protected
Natal Sandy Shelf Edge	2412.8	LT	Poorly protected
Natal Shelf Edge Reef	17.59	LT	Hardly protected
Natal Shelf Reef	522.89	VU	Moderately protected
Natal Very Exposed Rocky Coast	4.23	LT	Poorly protected
Natal-Delagoa Dissipative Sandy Coast	3.97	LT	Moderately protected
Natal-Delagoa Dissipative-Intermediate Sandy Coast	153	LT	Moderately protected
Natal-Delagoa Estuarine Shore	43.27	LT	Moderately protected
Natal-Delagoa Intermediate Sandy Coast	198.38	VU	Moderately protected
Natal-Delagoa Reflective Sandy Coast	49.91	VU	Moderately protected
South Atlantic Abyss	66313.9	LT	Not protected
South Atlantic Abyss With Ferro-Manganese Deposits	77098.41	LT	Not protected
South Atlantic Lower Bathyal	88302.14	LT	Not protected
South Atlantic Upper Bathyal	37313.55	LT	Not protected
Southeast Atlantic Seamounts	1579.28	LT	Not protected
Southern Benguela Canyon	785.91	CR	Not protected
Southern Benguela Carbonate Mound	1449.17	LT	Not protected
Southern Benguela Dissipative Sandy Coast	68.89	LT	Moderately protected
Southern Benguela Dissipative-Intermediate Sandy Coast	120.25	LT	Moderately protected

Habitat type	Total Size (km^2)	Threat Status	Final Protection Level
Southern Benguela Estuarine Shore	12.07	LT	Moderately protected
Southern Benguela Gravel Outer Shelf	433.37	CR	Not protected
Southern Benguela Gravel Shelf Edge	29.88	CR	Not protected
Southern Benguela Hard Outer Shelf	10612.87	VU	Hardly protected
Southern Benguela Hard Shelf Edge	4532.03	CR	Not protected
Southern Benguela Intermediate Sandy Coast	123.8	LT	Poorly protected
Southern Benguela Muddy Outer Shelf	6054.24	LT	Not protected
Southern Benguela Muddy Shelf Edge	567.29	CR	Not protected
Southern Benguela Outer Shelf Reef	1.57	EN	Not protected
Southern Benguela Reflective Sandy Coast	47.14	LT	Poorly protected
Southern Benguela Sandy Outer Shelf	56235	LT	Hardly protected
Southern Benguela Sandy Shelf Edge	13237.94	VU	Not protected
Southwest Indian Abyss	249366.14	LT	Not protected
Southwest Indian Abyss With Ferro-Manganese Deposits	3719.47	LT	Not protected
Southwest Indian Lower Bathyal	218081.26	LT	Not protected
Southwest Indian Lower Bathyal With Ferro-Manganese Deposits	7191.38	LT	Not protected
Southwest Indian Seamounts	3735.34	LT	Not protected
Southwest Indian Upper Bathyal	84965.89	LT	Hardly protected
Southwestern Cape Boulder Shore	19.86	CR	Moderately protected
Southwestern Cape Exposed Rocky Coast	50.5	EN	Moderately protected
Southwestern Cape Hard Inner Shelf	1317.75	EN	Moderately protected
Southwestern Cape Inshore Hard Grounds	51.27	CR	Moderately protected
Southwestern Cape Inshore Reef	5.66	CR	Moderately protected
Southwestern Cape Island-associated	1045.93	EN	Poorly protected
Southwestern Cape Lagoon	129.14	VU	Moderately protected
Southwestern Cape Mixed Shore	48.97	VU	Moderately protected
Southwestern Cape Sandy Inner Shelf	1652.1	LT	Moderately protected
Southwestern Cape Sandy Inshore	206.83	VU	Moderately protected
Southwestern Cape Sheltered Rocky Coast	1.05	CR	Moderately protected
Southwestern Cape Very Exposed Rocky Coast	1.45	CR	Moderately protected

Habitat type	Total Size (km^2)	Threat Status	Final Protection Level
Pelagic habitat Ab3	54826.01	VU	Not protected
Pelagic habitat Bc1	143761.43	LT	Not protected
Pelagic habitat Aa1	30753.09	LT	Hardly protected
Pelagic habitat Ab1	53723.89	LT	Poorly protected
Pelagic habitat Ab2	68494.74	LT	Hardly protected
Pelagic habitat Ba1	9556.09	LT	Not protected
Pelagic habitat Ba2	125407.71	LT	Not protected
Pelagic habitat Bb1	71597.23	LT	Not protected
Pelagic habitat Bb2	63743.61	LT	Not protected
Pelagic habitat Bc2	97897.1	LT	Not protected
Pelagic habitat Ca1	169809.59	LT	Not protected
Pelagic habitat Ca2	59214.68	LT	Not protected
Pelagic habitat Cb1	22464.3	LT	Poorly protected
Pelagic habitat Cb2	28765.42	LT	Poorly protected
Pelagic habitat Cb3	31410.51	VU	Not protected
Pelagic habitat Cb4	30745.02	LT	Not protected

The following primary results emerged from the ecosystem threat assessment.

- 23 marine and coastal habitat types (17%) are critically endangered. Fourteen of these are coastal habitat types and the remainder are offshore benthic habitat types. Most of these are rocky habitat types in the coast, inshore, shelf and shelf edge areas, some are unconsolidated inshore, shelf and shelf edge habitat types and one island-associated habitat type is critically endangered.
- 10 marine and coastal habitat types (7%) are endangered. Six of these are coastal habitat types and the rest are offshore benthic habitat types. Most of these are rocky shelf and shelf edge habitat types with some are unconsolidated inshore and shelf habitat types. One of the three island-associated habitat types is endangered.
- 31 marine and coastal habitat types (23%) are vulnerable. Sixteen of these are coastal habitat types, 13 are offshore benthic habitat types and two are offshore pelagic habitat types. Along the coast, vulnerable habitat types include sandy, rocky and mixed coast types, South Africa's only lagoon ecosystem and one island-associated habitat. Vulnerable offshore habitat types include rocky and unconsolidated outer shelf and shelf edge habitat types and two offshore pelagic habitat types.
- 72 marine and coastal ecosystems (52%) are least threatened. These included all deepsea (upper and lower bathyal zone) ecosystems and most offshore pelagic habitat types.

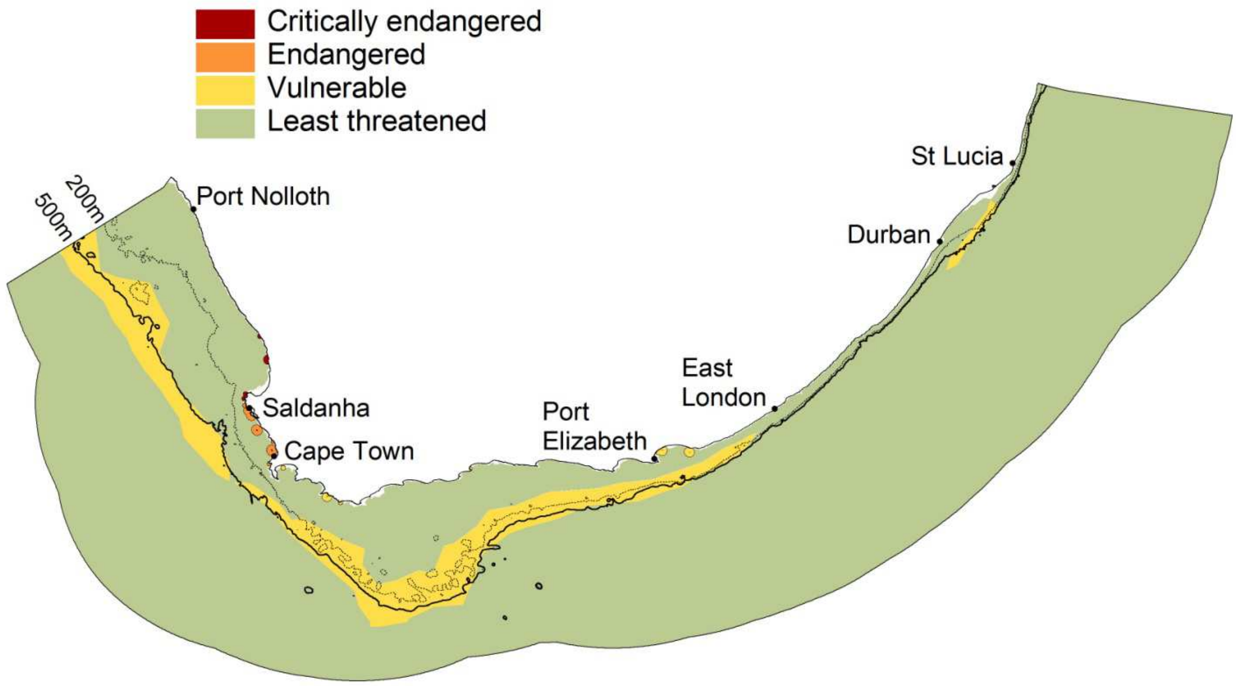


Figure 44: Ecosystem threat status for offshore pelagic habitat types in South Africa.

Coastal versus offshore habitat types

A higher proportion of coastal habitat types were threatened compared to offshore habitat types with more threatened benthic habitat types than pelagic habitat types in the offshore environment. Of the 58 coastal habitat types, 36 (62%) are threatened with 14 critically endangered, six endangered, 16 vulnerable and 22 least threatened habitat types (Table 15). Most of the critically endangered coast types are rocky coast types in Namaqualand and the southwestern Cape, including three boulder shore habitat types, one of which is from the Natal ecoregion. Agulhas Sheltered Rocky Coast is the only critically endangered coast type in that ecoregion. Three inshore habitat types and the island-associated ecosystem in Namaqualand are critically endangered. Inshore reefs in the Agulhas ecoregion and southwestern Cape are critically endangered as are inshore hard grounds in the southwestern Cape. Two coast types are endangered; Namaqua Mixed Shore and Southwestern Cape Exposed Rocky Coast. Three inshore habitat types are endangered, Agulhas Inshore Gravel, Natal Muddy Inshore and Natal Inshore Reef. Southwestern Cape Island-associated is endangered whereas Agulhas Island-associated is vulnerable. Two sandy coast habitat types from the Delagoa-Natal ecoregion; three sandy inshore habitat types (Natal, Agulhas and Southwestern Cape) and the Namaqua

Muddy Inshore habitat are vulnerable. South Africa's only marine lagoon ecosystem at Langebaan is vulnerable.

Table 15:Threatened marine and coastal habitat types in South Africa.

Threat Status	Coastal	Offshore
CR	Agulhas Inshore Reef	Agulhas Canyon
	Agulhas Sheltered Rocky Coast	Agulhas Mixed Sediment Outer Shelf
	Namaqua Boulder Shore	Agulhas Muddy Inner Shelf
	Namaqua Inshore Hard Grounds	Namaqua Inner Shelf Reef
	Namaqua Inshore Reef	Southern Benguela Canyon
	Namaqua Island-associated	Southern Benguela Gravel Outer Shelf
	Namaqua Sandy Inshore	Southern Benguela Gravel Shelf Edge
	Namaqua Sheltered Rocky Coast	Southern Benguela Hard Shelf Edge
	Natal Boulder Shore	Southern Benguela Muddy Shelf Edge
	Southwestern Cape Boulder Shore	
	Southwestern Cape Inshore Hard Grounds	
	Southwestern Cape Inshore Reef	
	Southwestern Cape Sheltered Rocky Coast	
	Southwestern Cape Very Exposed Rocky Coast	
EN	Agulhas Inshore Gravel	Agulhas Hard Inner Shelf
	Namaqua Mixed Shore	Natal Muddy Shelf
	Natal Inshore Reef	Southern Benguela Outer Shelf Reef
	Natal Muddy Inshore	Southwestern Cape Hard Inner Shelf
	Southwestern Cape Exposed Rocky Coast	
	Southwestern Cape Island-associated	
VU	Agulhas Dissipative Sandy Coast	Agulhas Gravel Outer Shelf
	Agulhas Exposed Rocky Coast	Agulhas Hard Outer Shelf
	Agulhas Inshore Hard Grounds	Agulhas Hard Shelf Edge
	Agulhas Island-associated	Agulhas Inner Shelf Reef
	Agulhas Mixed Shore	Agulhas Muddy Outer Shelf
	Agulhas Sandy Inshore	Agulhas Muddy Shelf Edge
	Agulhas Very Exposed Rocky Coast	Agulhas Sandy Inner Shelf
	Namaqua Muddy Inshore	Agulhas Sandy Shelf Edge
	Namaqua Very Exposed Rocky Coast	Natal Canyon
	Natal Mixed Shore	Natal Sandy Shelf
	Natal Sandy Inshore	Natal Shelf Reef
	Natal-Delagoa Intermediate Sandy Coast	Pelagic habitat Cb3
	Natal-Delagoa Reflective Sandy Coast	Pelagic habitat Ab3
	Southwestern Cape Lagoon	Southern Benguela Hard Outer Shelf
	Southwestern Cape Mixed Shore	Southern Benguela Sandy Shelf Edge
	Southwestern Cape Sandy Inshore	

Of the 78 offshore habitat types, 28 (35%) are threatened with nine critically endangered, six endangered and 16 vulnerable. Only two of the threatened habitat types are pelagic, whereas 26 are benthic habitat types. All of the critically endangered habitat types are shelf or shelf edge habitat types including two canyon habitat types (Agulhas and Southern Benguela), four shelf edge habitat types, one reef habitat type (Namaqua Inner Shelf) and two unconsolidated shelf habitat types in the Agulhas bioregion. Of the critically endangered unconsolidated habitat types, two are mud habitat types, two are Southern Benguela Gravel habitat types and one is a mixed sediment habitat. No offshore habitat types in the Natal and Delagoa bioregions were critically endangered with the most threatened offshore ecosystem in these bioregions being the endangered Natal Muddy Shelf. The three other endangered offshore habitat types are all reef or hard ground habitat types in the Agulhas ecoregion and the southwestern Cape. Vulnerable offshore habitat types included reef and hard shelf habitat types in all ecoregions except the Delagoa ecoregion, Natal Canyon and seven unconsolidated shelf or shelf edge habitat types. Five of these are in the Agulhas ecoregion (Agulhas Sandy Inner Shelf, Gravel and Muddy Outer Shelf and Muddy and Sandy Shelf Edge). The Natal Sandy Shelf and Southern Benguela Sandy Shelf Edge are the remaining vulnerable offshore benthic habitat types. Only two of the 16 pelagic habitat types are vulnerable: Pelagic habitat types Ab3 and Cb3 along the Southern Benguela and Agulhas shelf edge respectively.

Broad Ecosystem Groups

Rocky coast is the broad ecosystem group with the most number of threatened habitat types (11), followed by rocky shelf edge (9) and rocky (8) and unconsolidated shelf habitat types (8) as illustrated in Figure 45. All rocky shelf edge and island-associated (3) habitat types are threatened, indicating that increased conservation attention is needed for these broad ecosystem groups. Other priority broad ecosystem groups include rocky and sandy inshore (5 to 30 m depth range) habitat types, unconsolidated shelf edge habitat types and mixed and sandy coast types. South Africa's only lagoon ecosystem is vulnerable indicating that this unique ecosystem should not be placed under any additional anthropogenic pressure. Only two of 16 offshore pelagic habitat types are threatened. No deepsea unconsolidated sediment or seamount habitat types were threatened.

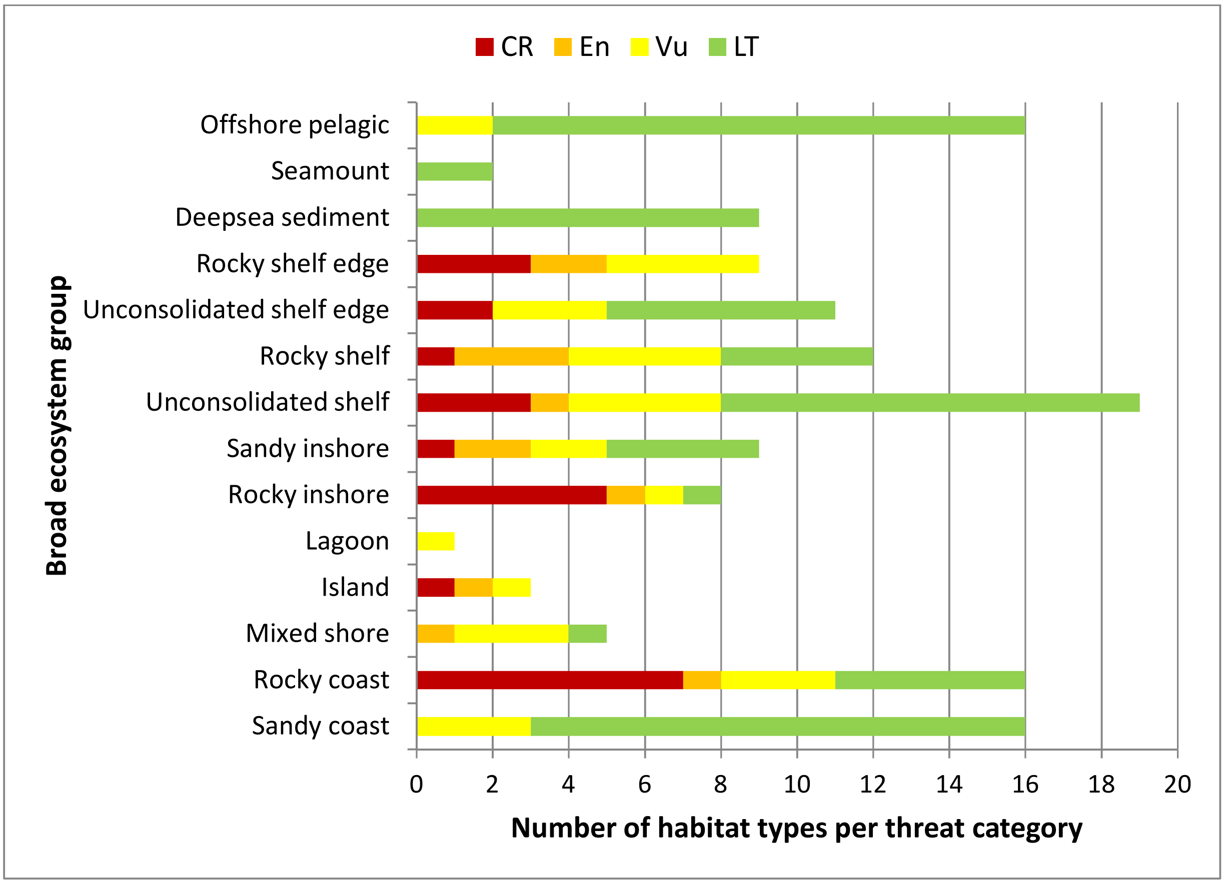


Figure 45: Number of habitat types per ecosystem threat category for each broad ecosystem group.

Ecoregions and ecozones

The shelf ecoregion with the most threatened habitat types is the Southern Benguela. Within this ecoregion, the Namaqua inshore and inner shelf, the Southern Benguela shelf edge and Southwestern Cape inshore have the most critically endangered and endangered habitat types. These threatened coastal habitat types reflect pressure from diamond mining and inshore fisheries in Namaqualand and the Southwestern Cape. Seven of 16 vulnerable coastal habitats are in the Agulhas ecoregion, reflecting the need to cap or reduce pressure in the coastal zone in that area. Offshore, habitat types in the Southern Benguela and Agulhas ecoregions are most threatened, reflecting the heavy fishing pressures in these areas. More habitats have threatened ecosystem status in the Agulhas ecoregion than the Natal ecoregion. The Delagoa ecoregion had the least threatened habitat types.

7 Protection level assessment

7.1 Assessment Methodology

The previous National Spatial Biodiversity Assessment (Lombard *et. al.* 2004) assessed protection levels for 34 biozones and examined protected areas target achievement using different options that account for different types and zones of MPAs for several species, 42 intertidal habitat types (12 broad categories and 5 bioregions) and 23 subtidal biozones using the software C-plan. Priority areas for target achievement of intertidal analyses were also identified. The same categories were used to assess protection levels for the 136 marine and coastal habitat types classified and mapped in the 2011 assessment (Table 16).

Table 16: Categories of protection levels used in biodiversity assessments in South Africa. Biodiversity targets of 20% of area were used for all habitat types in the 2011 National Biodiversity Assessment.

Protection status	**Description**
Well protected	≥100% of target in an MPA & sufficient no-take
Moderately protected	50 to <100% of target in an MPA
Poorly protected	5 to <50% of target in an MPA
Hardly protected	1 to <5% of target in an MPA
Zero protection	No formal protection

The level of protection of each habitat type was evaluated against the 20% biodiversity target. Habitats were classified as "Zero protection" if there was no formal protection; as "Hardly protected" if under 5% of target was met in protected areas; as "Poorly protected" if from 5% to just under 50% of biodiversity target is met in protected areas; as "Moderately protected" if from 50% to just under 100% of the biodiversity target is met in protected areas; and as "Well protected" if the biodiversity target is fully met *and* 15% of that habitat type is met in no-take zones. The National Protected Area Expansion Strategy set a 15% area target for no-take MPAs in the offshore environment and 25% of the coastline for coastal MPAs. The National Protected Area Expansion Strategy no-take area target (15%) was applied as a filter to ensure that no habitat types were inaccurately reported as well protected when in fact there was insufficient protection from fishing. Habitat types where the biodiversity targets are fully met, but where there is insufficient no-take area, were down-graded to a "Moderately protected" classification. The steps outlined in the evaluation are illustrated in Figure 46 below.

1. Habitat maps produced
2. MPA map revised
3. Calculation of percentage of habitat type represented in Protected Area network

⇩

4. Comparison of % habitat type represented with biodiversity targets for each habitat

⇩

5. Preliminary ecosystem threat status assigned

⇩

6. For habitat types that were preliminarily assigned to well protected categories, cross-checking with no-take targets was undertaken to ensure that only those that had sufficient area in no-take zones were considered well protected

⇩

7. Final ecosystem threat status assigned

Figure 46: Schematic showing steps to determine ecosystem protection levels

7.2 Ecosystem protection level results

The revised marine and coastal Protected Area map was used to assess the representation of all 136 marine and coastal habitat types in South Africa's Marine Protected Area network, as illustrated in Figure 48 and Figure 50. Forty percent of habitat types have zero protection and only 6% of habitat types are considered well protected. A further 7% are hardly protected, 12% poorly protected and 35% moderately protected, as shown in Figure 47.

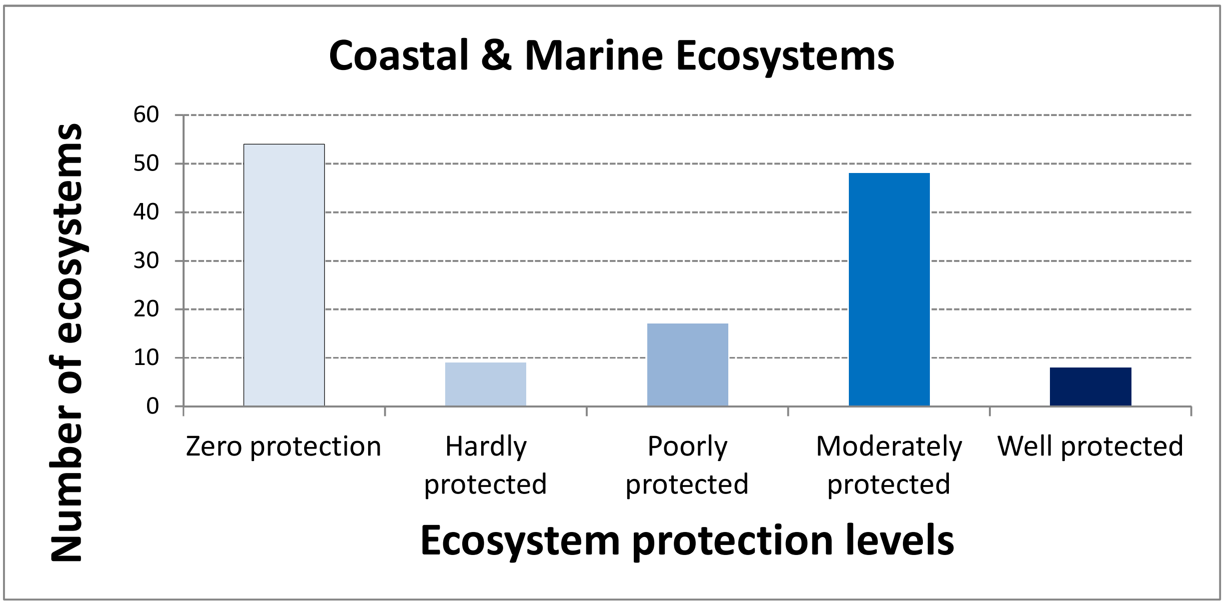


Figure 47: Numbers of marine and coastal habitat types in different ecosystem protection level categories in South Africa.

The following primary results emerged from the protection level assessment.

- 54 marine and coastal habitat types (40%) have zero protection (Table 20). Seven of these are coastal habitat types and 47 are offshore habitat types, of which 36 are benthic and 11 are pelagic. Unprotected coastal habitat types include five from the Namaqua ecoregion and two from the Natal ecoregion. Offshore, many types of rocky and unconsolidated shelf and shelf edge habitat types are not included in South Africa's Marine Protected Area network. Ten of South Africa's 11 deepsea habitat types are not included in any MPAs.
- 9 marine and coastal habitat types (7%) are hardly protected. Two of these are coastal habitat types and seven are offshore habitat types. Most of these are rocky shelf and shelf edge habitat types (including Natal shelf reef) with some unconsolidated habitat types including and two offshore pelagic habitat types.
- 17 marine and coastal habitat types (12%) are poorly protected. Eight of these are coastal habitat types, six are offshore benthic habitat types and three are offshore pelagic habitat types. Along the coast, poorly protected habitat types include three from Namaqualand and two of South Africa's island-associated types. Poorly protected

offshore habitat types include four from the Agulhas bioregion, two from the Natal bioregion and three pelagic habitat types.

- 48 marine and coastal habitat types (35%) are moderately protected. Thirty-six of these are coastal habitat types and 12 are offshore benthic habitat types, mostly from the Delagoa and Natal shelf. No offshore pelagic habitat types are moderately protected.
- Only eight marine and coastal habitat types (6%) are well protected (Table 18). Five of these are coastal habitat types and 3 are offshore benthic habitat types. No offshore pelagic habitat types are well protected. The coastal habitat types include three from the Delagoa bioregion, Natal Estuarine Shore and Agulhas Exposed Rocky Coast. The well protected offshore habitat types are Delagoa Sandy Shelf, Delagoa Shelf Reefs and Natal Mixed Sediment Shelf Edge.

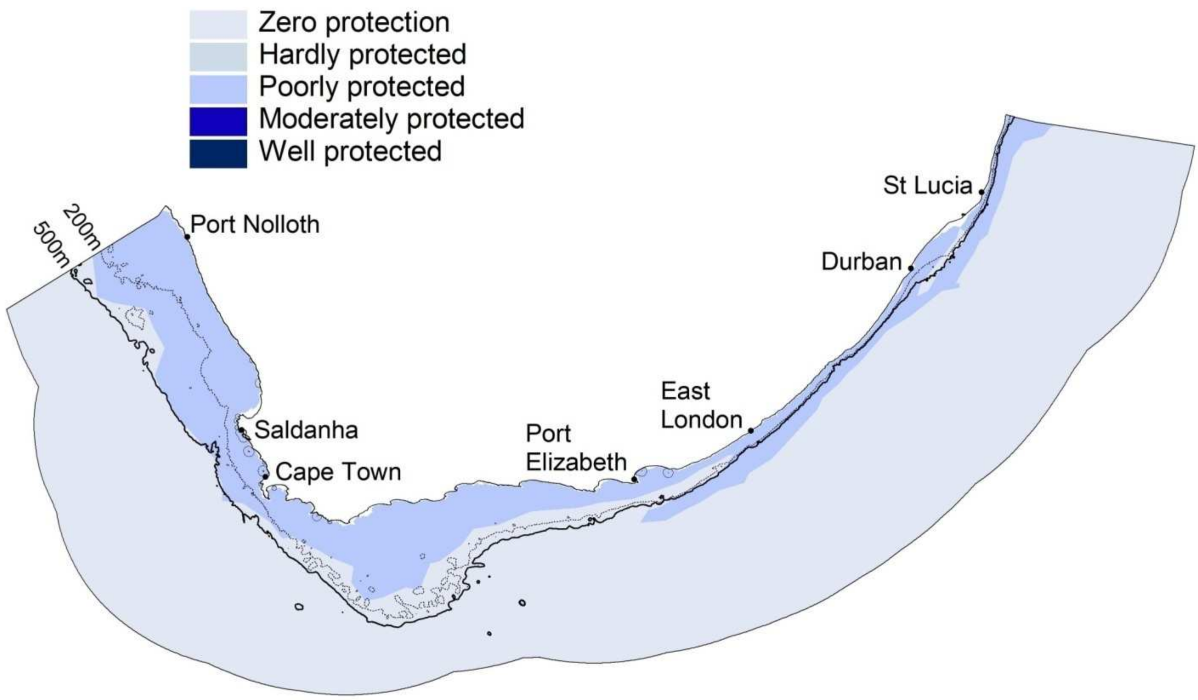


Figure 48: Ecosystem protection levels for offshore pelagic habitat types and island-associated ecosystems in South Africa

The recently proclaimed Amathole MPA was not included in the current assessment. Habitat types that now receive additional protection in this MPA include the following Agulhas habitat types; Sandy Inshore, Sandy Inner Shelf, Inner Shelf Reef, Inshore Gravel, Gravel Inner Shelf. The protection level of Agulhas Sandy Inner Shelf, Inner Shelf Reef and Gravel Inner Shelf may improve slightly whereas the remaining two habitat types will remain unchanged. This is because none of these three areas within the Amathole MPA are zoned as no-take and full protection of some areas that include these habitat types is needed for them to be considered well protected.

Coastal versus offshore habitat types

A far higher proportion of coastal habitat types are represented in South Africa's MPA network compared to offshore habitat types (Figure 49), reflecting the need to proclaim Offshore Marine Protected Areas. This primary conservation action was identified in 2004 (Lombard *et al.*) but no such MPAs have been proclaimed. Significant progress has been achieved in selecting potential areas for proclamation (Sink et al. 2011). Most of the coastal habitat types are moderately protected with only 8 of 53 (9%) well protected, reflecting a need to strengthen protection of coastal habitat types (see Table 20 and Table 21 for lists of habitat types that still need protection in no-take zones). The National Protected Area Expansion Strategy (Government of South Africa 2010) emphasises the need to strengthen existing MPAs through the establishment of more no-take zones and through other mechanisms that will reduce the impact of exploitation within MPAs. The Marine Reserves Task Group (1997) also expressed concern about exploitation in MPAs and the resultant compromise in integrity.

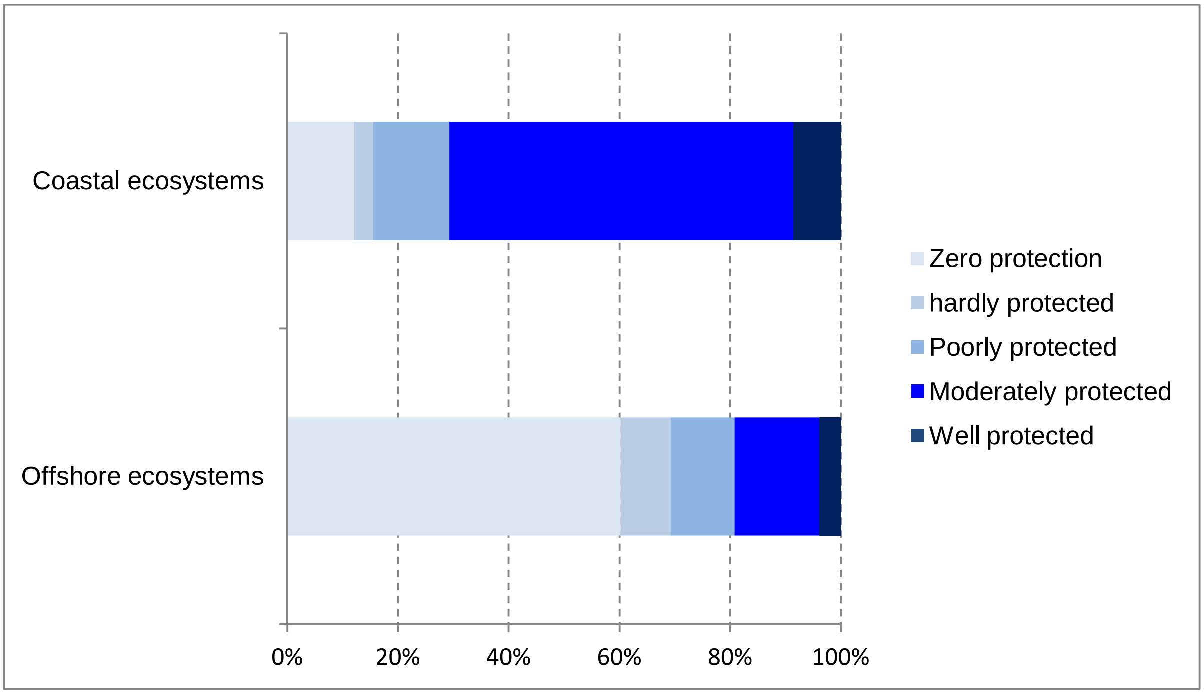


Figure 49: Percentage of coastal and offshore habitat types in different protection level categories.

Broad Ecosystem Groups

Seamounts are the only broad ecosystem groups not represented in South Africa's MPA network. Mixed shores and sandy coast types are the most well represented broad ecosystem groups but even for these, only a small proportion of habitat types can be considered well protected. Many unconsolidated and rocky shelf and shelf edge habitat types need protection. These productive habitat types support important fisheries yet remain unprotected. Offshore pelagic, seamount and deepsea sediments need protection although this is less of a priority as these habitat types experience less pressure than the shelf and shelf edge habitat types in the offshore environment.

Table 17: Habitat types with zero protection in South Africa's MPA network

Habitat type	Total Size (km^2)	Threat Status
Agulhas Canyon	1119.72	CR
Agulhas Mixed Sediment Outer Shelf	1308.17	CR
Agulhas Muddy Inner Shelf	2684.52	CR
Namaqua Boulder Shore	0.56	CR
Namaqua Inner Shelf Reef	0.94	CR
Namaqua Inshore Hard Grounds	233.02	CR
Namaqua Inshore Reef	3.44	CR
Namaqua Sandy Inshore	823.95	CR
Natal Boulder Shore	2.58	CR
Southern Benguela Canyon	785.91	CR
Southern Benguela Gravel Outer Shelf	433.37	CR
Southern Benguela Gravel Shelf Edge	29.88	CR
Southern Benguela Hard Shelf Edge	4532.03	CR
Southern Benguela Muddy Shelf Edge	567.29	CR
Southern Benguela Outer Shelf Reef	1.57	EN
Agulhas Hard Outer Shelf	11537.35	VU
Agulhas Hard Shelf Edge	4162.91	VU
Agulhas Muddy Outer Shelf	1772.1	VU
Agulhas Muddy Shelf Edge	170.7	VU
Agulhas Sandy Shelf Edge	4067.46	VU
Namaqua Muddy Inshore	164.41	VU
Southern Benguela Sandy Shelf Edge	13237.94	VU
Pelagic habitat Ab3	54826.01	VU
Pelagic habitat Cb3	31410.51	VU
Agulhas Gravel Shelf Edge	1788.12	LT
Agulhas Mixed Sediment Inner Shelf	627.47	LT
Agulhas Outer Shelf Reef	6.49	LT

Habitat type	Total Size (km^2)	Threat Status
Agulhas Sandy Outer Shelf	32869.31	LT
Agulhas Shelf Edge Reef	4.01	LT
Namaqua Hard Inner Shelf	2656.36	LT
Namaqua Muddy Inner Shelf	11165.61	LT
Namaqua Sandy Inner Shelf	5394.52	LT
Natal Inshore Gravel	0.22	LT
South Atlantic Abyss	66313.9	LT
South Atlantic Abyss With Ferro-Manganese Deposits	77098.41	LT
South Atlantic Lower Bathyal	88302.14	LT
South Atlantic Upper Bathyal	37313.55	LT
Southeast Atlantic Seamounts	1579.28	LT
Southern Benguela Carbonate Mound	1449.17	LT
Southern Benguela Muddy Outer Shelf	6054.24	LT
Southwest Indian Abyss	249366.14	LT
Southwest Indian Abyss With Ferro-Manganese Deposits	3719.47	LT
Southwest Indian Lower Bathyal	218081.26	LT
Southwest Indian Lower Bathyal With Ferro-Manganese Deposits	7191.38	LT

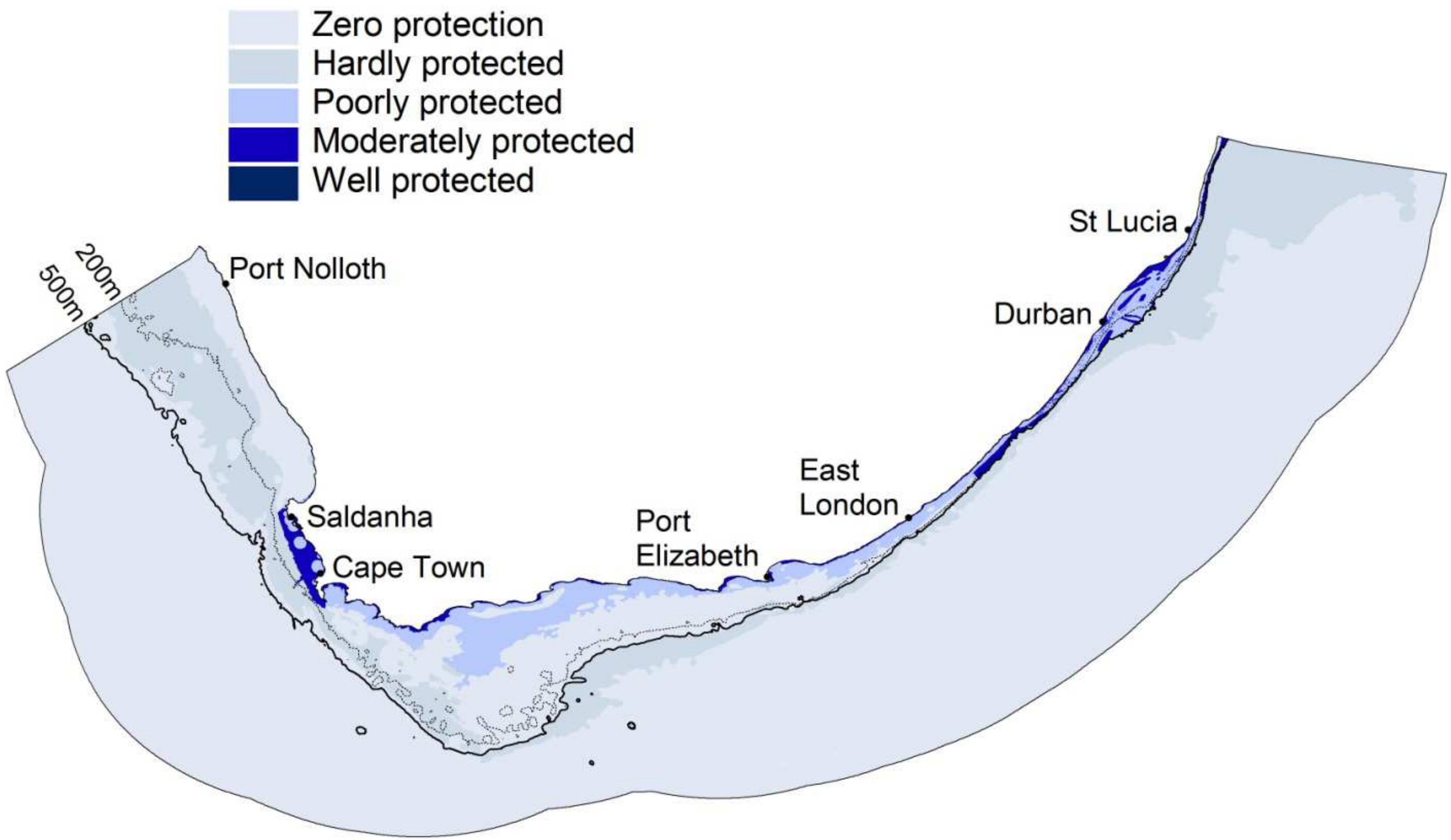


Figure 50: Ecosystem protection levels for coastal and offshore benthic habitat types in South Africa.

Ecoregions and ecozones

Along the coast, the Namaqua inshore and Namaqua inner shelf are the only coastal ecozones that are not represented in South Africa's MPA network (Figure 51). Unprotected inshore habitat types are also found in the Natal ecoregion. Offshore, protection levels are poorer in the Southern Benguela and Agulhas ecoregions as MPAs in Pondoland and KwaZulu-Natal make some contribution to the shelf ecoregions in the Natal and Delagoa ecoregions and to the upper bathyal zone of the Southwest Indian ecoregion. Many offshore benthic habitat types have no protection. The lower bathyal and abyss ecozones of both the Southeast Atlantic and Southwest Indian deepsea ecoregions are completely unprotected.

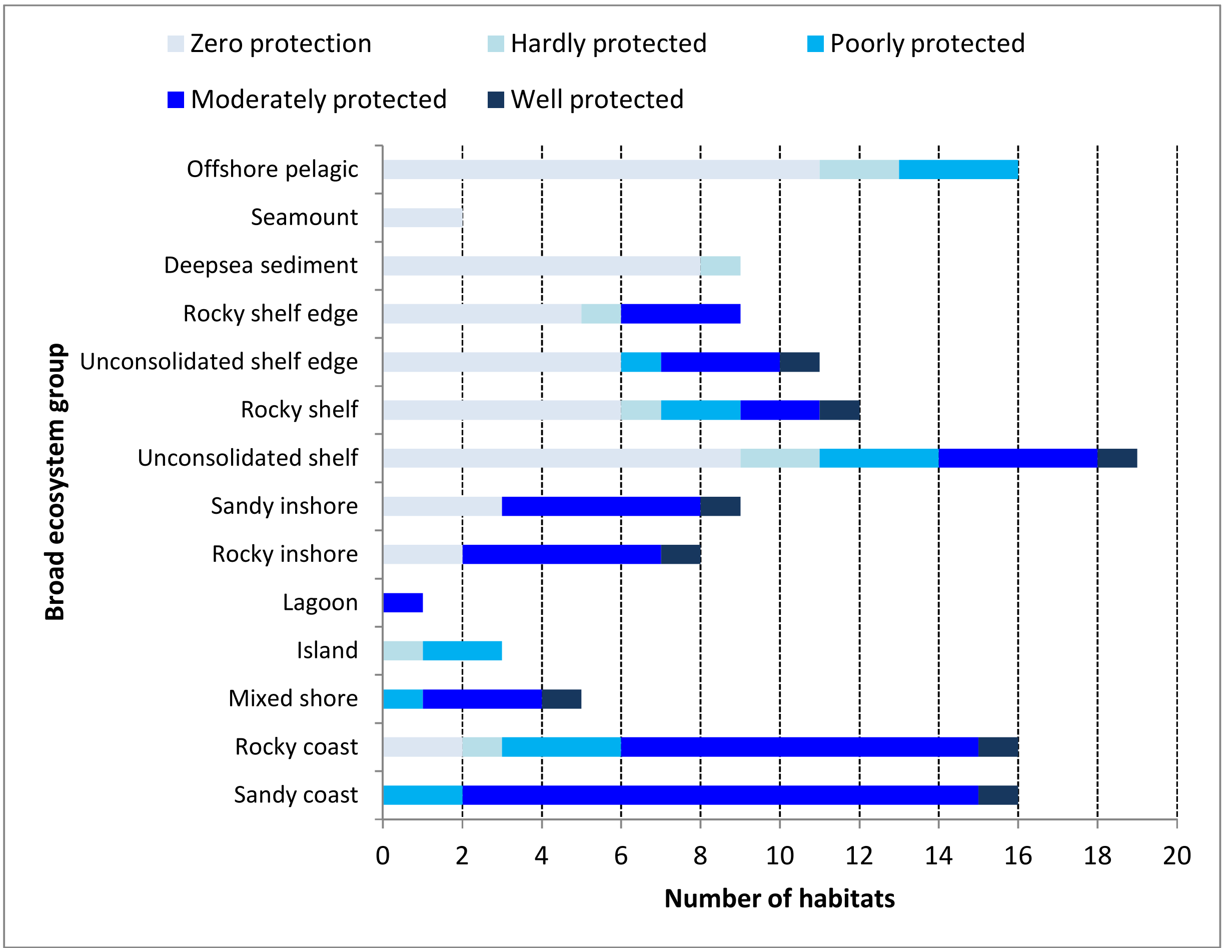


Figure 51: Number of marine and coastal habitat types per protection level category for each broad ecosystem group in South Africa.

Critically endangered habitat types with zero protection

These 13 habitat types (Table 19) are priority habitat types that require improved management and reduction of human impacts and that need to be represented in our MPA network. Inshore and along the coast, most of these are Namaqua habitat types that reflect the poor ecosystem threat status due to multiple pressures, particularly diamond mining and fisheries, in these ecozones. The absence on a Marine Protected Area in Namaqualand is the key driver of the poor protection levels of these habitat types. Offshore, priority habitat types include potential Vulnerable Marine Ecosystems, such as submarine canyons and hard grounds on the shelf and shelf edge along the west and south coast (Southern Benguela and Agulhas ecoregions).

Table 18: Well protected marine and coastal habitat types in South Africa.

Habitat type	Total Size (km^2)	Threat Status	Final Protection Level
Agulhas Exposed Rocky Coast	266.26	VU	Well protected
Delagoa Inshore Reef	71.02	LT	Well protected
Delagoa Mixed Shore	48.3	LT	Well protected
Delagoa Sandy Inshore	104.35	LT	Well protected
Delagoa Sandy Shelf	290.85	LT	Well protected
Delagoa Shelf Reef	75.04	LT	Well protected
Natal Estuarine Shore	0.49	LT	Well protected
Natal Mixed Sediment Shelf Edge	29.17	LT	Well protected

Priority unconsolidated habitat types include those of small spatial extent that are exposed to pressures over much of their extent such as Agulhas Muddy Inner Shelf and Southern Benguela gravel habitat types. These offshore habitat types should be considered as priority habitat types for inclusion in South Africa's network of MPAs.

Table 19: Critically endangered habitat types with zero protection in South Africa.

Coastal habitat types	Offshore habitat types
Namaqua Sheltered Rocky Coast	Namaqua Inner Shelf Reef
Namaqua Sandy Inshore	Agulhas Canyon
Namaqua Inshore Reef	Southern Benguela Canyon
Namaqua Inshore Hard Grounds	Southern Benguela Hard Shelf Edge
Namaqua Boulder Shore	Agulhas Muddy Inner Shelf
Natal Boulder Shore	Agulhas Mixed Sediment Outer Shelf
	Southern Benguela Gravel Outer Shelf
	Southern Benguela Gravel Shelf Edge
	Southern Benguela Muddy Shelf Edge

Important habitat types for additional protection in no-take zones

Ten habitat types are represented in the current MPA network but have zero protection in no-take zones (Table 20). These habitat types should be considered as priorities when planning to establish additional no-take zones within the current MPA network.

Table 20: Habitat types with zero protection in no-take zones in South Africa.

Agulhas Inshore Gravel
Delagoa Shelf Edge Reef
Delagoa Very Exposed Rocky Coast
Natal Mixed Sediment Shelf
Natal Muddy Inshore
Natal Muddy Shelf Edge
Southern Benguela Dissipative Sandy Coast
Southwestern Cape Boulder Shore
Southwestern Cape Sheltered Rocky Coast
Southwestern Cape Very Exposed Rocky Coast

Twenty habitat types are underrepresented in no-take zones within the current MPA network (Table 21) and these habitat types should also be considered when planning additional MPAs or reviewing existing zonation.

Table 21: Habitat types that need further inclusion in no-take zones in South Africa.

Agulhas Boulder Shore
Agulhas Dissipative-Intermediate Sandy Coast
Agulhas Inshore Reef
Agulhas Mixed Shore
Delagoa Sandy Shelf Edge
Delagoa Canyon
Natal Exposed Rocky Coast
Natal Inshore Reef
Natal Mixed Shore
Natal-Delagoa Dissipative Sandy Coast
Natal-Delagoa Dissipative-Intermediate Sandy Coast
Natal-Delagoa Intermediate Sandy Coast
Natal-Delagoa Reflective Sandy Coast
Southern Benguela Estuarine Shore
Southwestern Cape Exposed Rocky Coast
Southwestern Cape Inshore Hard Grounds
Southwestern Cape Inshore Reef
Southwestern Cape Lagoon
Southwestern Cape Mixed Shore

7.3 Marine Protected Area Management effectiveness

The protection level assessment only considers the representation of different habitat types in South Africa's MPA network. It is acknowledged that actual protection levels depend on the management effectiveness and compliance within protected areas. The state of management of South Africa's Marine Protected Area network has improved since 2003 (Lemm and Attwood 2003, Tunley 2009). Key improvements include the co-ordination and formalisation of MPA management and progress in developing management plans and capacity. Tunley (2009) summarised the key current weaknesses in MPA management in South Africa as:

- a lack of specific gazetted objectives for MPAs
- the absence of a national monitoring program which hinders adaptive management and
- insufficient involvement of stakeholders in MPA design, planning and management.

Poaching, intensive recreational fishing, coastal development and pollution were reported as the main current threats to South Africa's MPA network (Tunley 2009). Increasing political pressure to allow access to no-take zones of MPAs was also noted as a concern. Key recommendations for addressing management deficiencies in South Africa's MPAs include exchange and mentorship programmes to improve management capacity, gazetting of specific MPA objectives, improved management plans and the development of capacity, processes and arrangements to allow stakeholders to participate in MPA design, planning and management (Tunley 2009). Building public awareness of the role of MPAs in marine biodiversity conservation and fisheries management is a key priority.

8 Spatial marine biodiversity priorities

The Offshore Marine Protected Area project (Sink et al. 2011) identified ten focus areas at a National scale for offshore spatial management or MPA establishment (Figure 52, Table 22). Finer-scale investigation and collaboration with stakeholders are needed to determine proposed boundaries within these focal areas. Lombard *et al.* (2010) also recently completed work to identify potential priority areas to support bycatch management in the inshore trawl fishery and Grantham *et al.* (2011) demonstrated the application of systematic planning to identity spatial priorities for pelagic conservation in the southern Benguela.

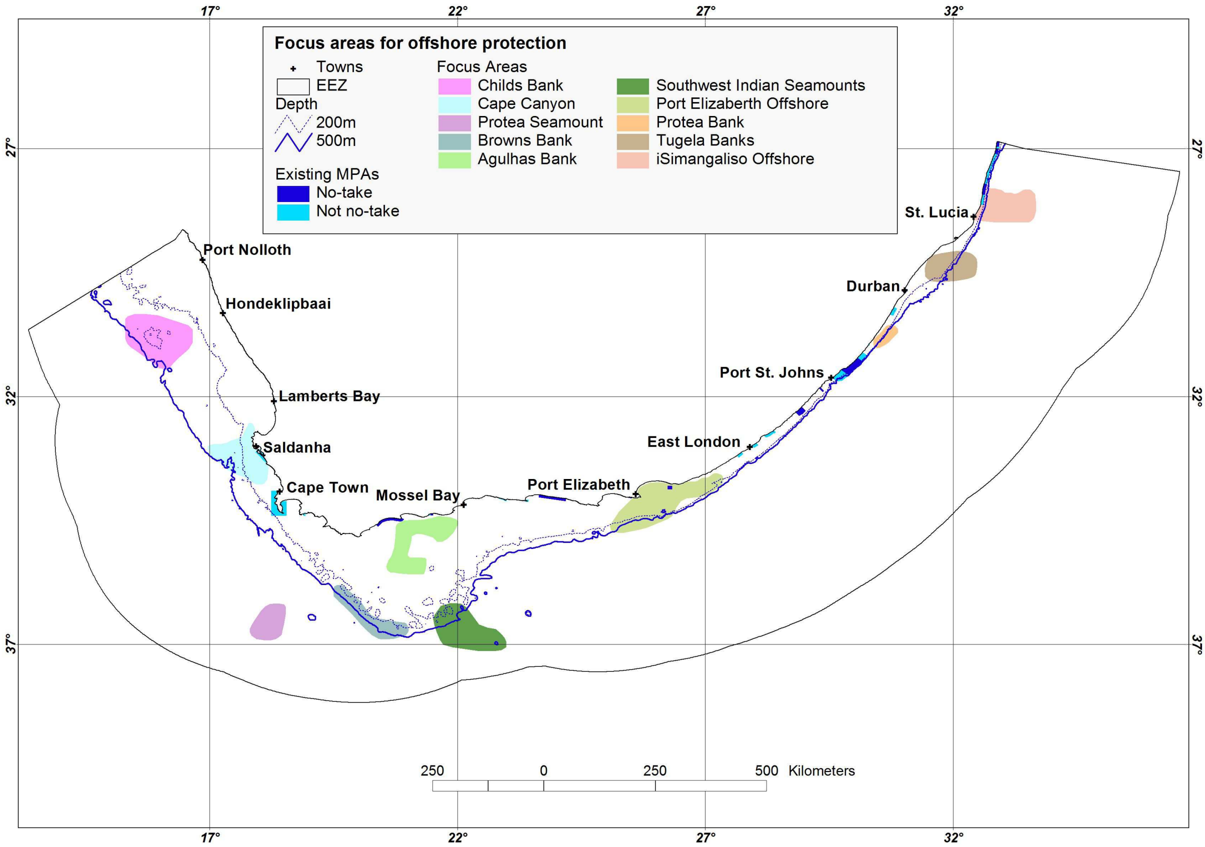


Figure 52: Focus areas for offshore spatial management or Marine Protected Areas (Sink et al. 2011).

Although the Prince Edward Islands were excluded from this assessment it is important to note that a systematic conservation plan was undertaken for the islands and associated EEZ (Lombard *et al.* 2007). Intention to declare an MPA based mostly on this plan was published in 2009. Proclamation of this MPA is an urgent national priority.

A coastal systematic conservation plan for the Agulhas bioregion (extending to the 30 m depth contour) was completed in 2007 (Clark and Lombard 2007). They identified 19 priority areas (Figure 53) for MPA establishment between Cape Point and the Mbashe estuary. These areas would allow for most habitat conservation targets of 20 and/or 30% to be achieved in this region.

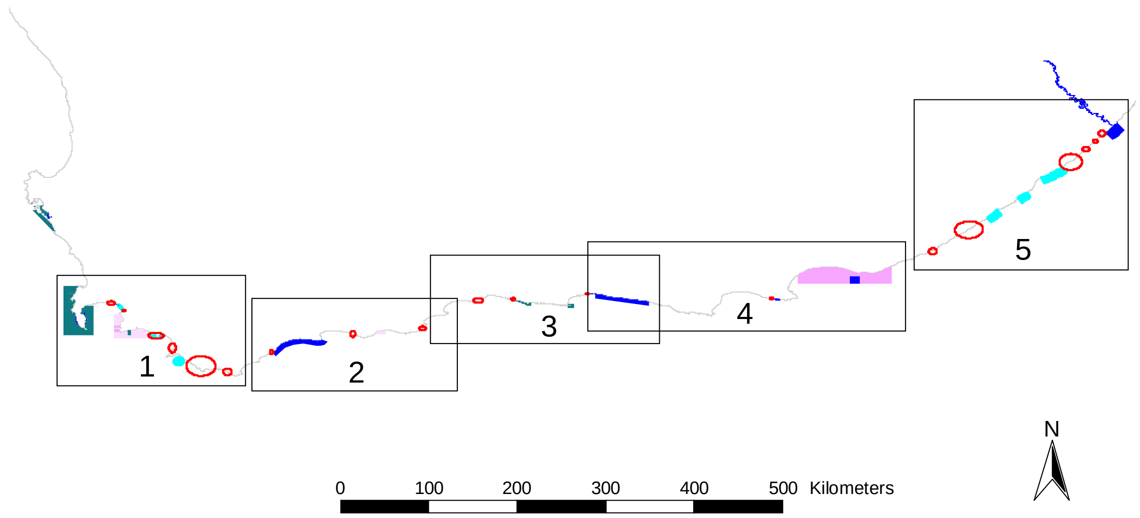


Figure 53: Identified priority areas (red circles) for MPA establishment in the Agulhas region (Clark and Lombard 2007).Existing MPAs are reflected in turquoise and blue (no-take zones), and proposed MPAs in pink.

Ezemvelo KwaZulu-Natal Wildlife has recently developed a fine-scale marine systematic conservation plan (SEAPlan) for the province, extending out to the EEZ boundary. Nineteen focus areas for MPA establishment (Figure 54) have recently been identified in KwaZulu-Natal (Jean Harris, pers. comm.). Note that some of the priorities in KwaZulu-Natal, including the southern and offshore extension of the iSimangaliso Wetland Park (i.e. the Maputland and St Lucia MPAs), the Tugela Banks and Protea Bank on the south coast were also identified as offshore focus areas at a national scale (Sink et al. 2011).

Table 22: Focus areas for offshore protection through MPA establishment and othe types of spatial management in South Africa (Sink *et al.* 2011).

Focal Area Name	Objectives
Childs Bank and adjacent shelf edge	• Offshore habitat representation • Benthic protection (submarine bank, cold water corals, shelf edge, offshore benthic habitat types) • Bycatch management (offshore trawl)
Cape Canyon	• Offshore habitat representation • Pelagic habitat and process representation • Benthic protection (submarine canyon, hard grounds, low oxygen areas) • Threatened species (seabirds) • Fisheries sustainability
Protea Seamount	• Offshore habitat representation • Benthic protection (seamount, ferro-manganese nodules, benthic habitat types) • Pelagic habitat and process representation
Browns Bank	• Offshore habitat representation • Benthic protection (shelf edge, hard grounds) • Bycatch management (offshore trawl) • Fisheries sustainability (offshore trawl)
Agulhas Bank	• Offshore habitat representation • Benthic protection (deep reefs, offshore benthic habitat types) • Bycatch management (inshore trawl) • Supporting fisheries sustainability (linefish, hake) • Threatened species (linefish)
Southwest Indian Seamounts	• Offshore habitat representation • Benthic protection (seamount, shelf edge, offshore benthic habitats) • Fisheries sustainability (small pelagics)
Offshore Port Elizabeth	• Offshore habitat representation • Benthic protection (cold water corals, canyon, shelf edge, deep reefs) • Fisheries sustainability (kingklip, hake, linefish, squid) • Bycatch management (inshore and offshore trawl, large pelagics) • Threatened species (seabirds)
Protea Bank	• Offshore benthic habitat representation • Pelagic habitat and process representation • Benthic protection (canyon, shelf edge, deep reefs) • Fisheries sustainability (linefish) • Threatened species (linefish, sharks)
Tugela Banks	• Offshore habitat representation • Benthic protection (cold water corals, canyon, shelf edge, deep reefs) • Bycatch management (crustacean trawl) • Fisheries sustainability (linefish) • Threatened species (turtles, sharks)
iSimangaliso extension	• Offshore habitat representation • Pelagic habitats and processes • Benthic protection (cold water corals, canyons) • Bycatch management (crustacean trawl,large pelagic) • Fisheries sustainability (linefish) • Threatened species (turtles, seabirds, sharks)

New systematic marine planning projects that are underway include the Benguela Current Commission's project that covers South Africa, Namibia and Angola (led by DEA's Oceans and Coast Department).

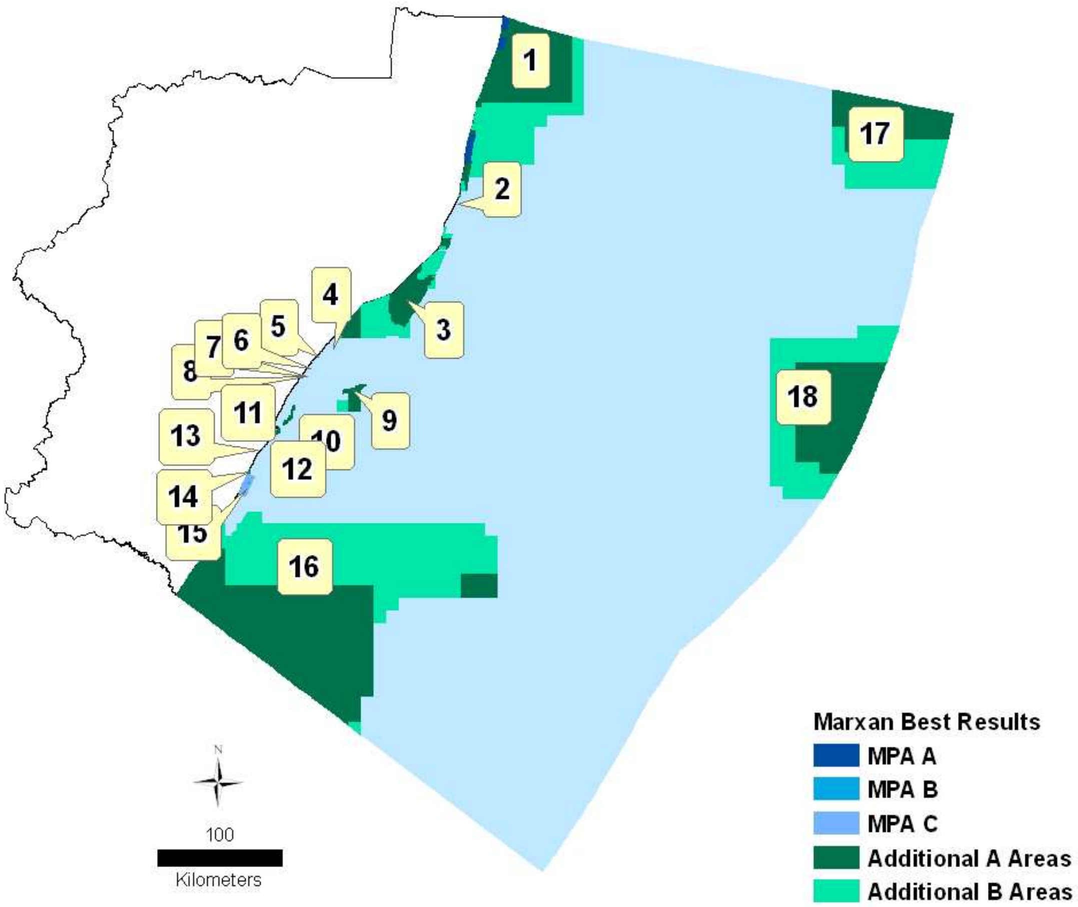


Figure 54: Focus areas for MPA establishment in KwaZulu-Natal as determined by systematic conservation planning (Ezemvelo KZN Wildlife SEAPlan project).

9 Ecosystem services

9.1 Introduction

Recently, and particularly in the last decade, there has been a strong emphasis on the impact of anthropogenic pressures on the environment, primarily linked to global climate change and to rapid human population growth. While this has made humankind aware of the environmentally degrading or destructive practices that have become commonplace in modern times, it has also increased awareness and appreciation of the value of biodiversity and of nature. There are numerous "Go Green" campaigns that encourage people all over the world to alter their perceptions and daily habits to those that are more sustainable and ecocentric. This paradigm shift is also resonating into corporate and government sectors, with a strengthening focus on the "Green Economy" (e.g. UNEP, 2011), and an increasing number of revised policies and laws that seek to work with nature and promote its conservation (e.g. South African Integrated Coastal Management Act, No. 28 of 2008). Central to this paradigm shift is the unfolding understanding of ecosystem services.

9.1.1 Definitions and classification

As defined earlier (section 2), ecosystems are "a dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit" (Millennium Ecosystem Assessment, 2003, 2005); a definition that has been adopted by the South African Biodiversity Act (2004). "[T]he benefits people derive from functioning ecosystems, the ecological characteristics, functions, or processes that directly or indirectly contribute to human well-being" are considered ecosystem services (Costanza *et al.* 2011). In many cases, the ecosystem service itself could be considered synonymous with an ecosystem function, however, the latter should provide a benefit to people to be considered an ecosystem service (Luck *et al.* 2003). Ecosystem services therefore cannot be defined independently of their role in human well-being (Costanza *et al.* 2011), where access to basic necessities (like food and shelter), good health, good social relations, safety and security and freedom of choice and action are the constituents of human well-being (Millennium Ecosystem Assessment, 2005).

There are a number of ecosystem service classification schemes that have been developed in the last few years (e.g. De Groot *et al.* 2002, Boyd and Banzhaf 2007, Wallace 2007; Fisher *et al.* 2009). The scheme presented in this report (Figure 55) is from the Millennium Ecosystem

Assessment (2005) because it is most widely used (Fisher *et al.* 2009). It distinguishes among four types of ecosystem services: provisioning services; regulating services; cultural services; and supporting services, which are each defined in the Millennium Ecosystem Assessment (2005), as follows. Provisioning services are essentially ecosystem goods because they are the products that we obtain from ecosystems, e.g. food, water, fibres, and construction materials. Regulating services are the benefits we get from the regulation of ecosystem processes, e.g. climate regulation, air quality regulation, water purification, and erosion regulation. Cultural services are the benefits society obtains from ecosystems through spiritual experiences, reflection and inspiration, cognitive development and education, and recreation. Supporting services are the ecosystem processes or functions that support the provision of other services, that society consequently benefits from, e.g. pollination, refugia such as nurseries and overwintering grounds, photosynthesis, and sand formation.

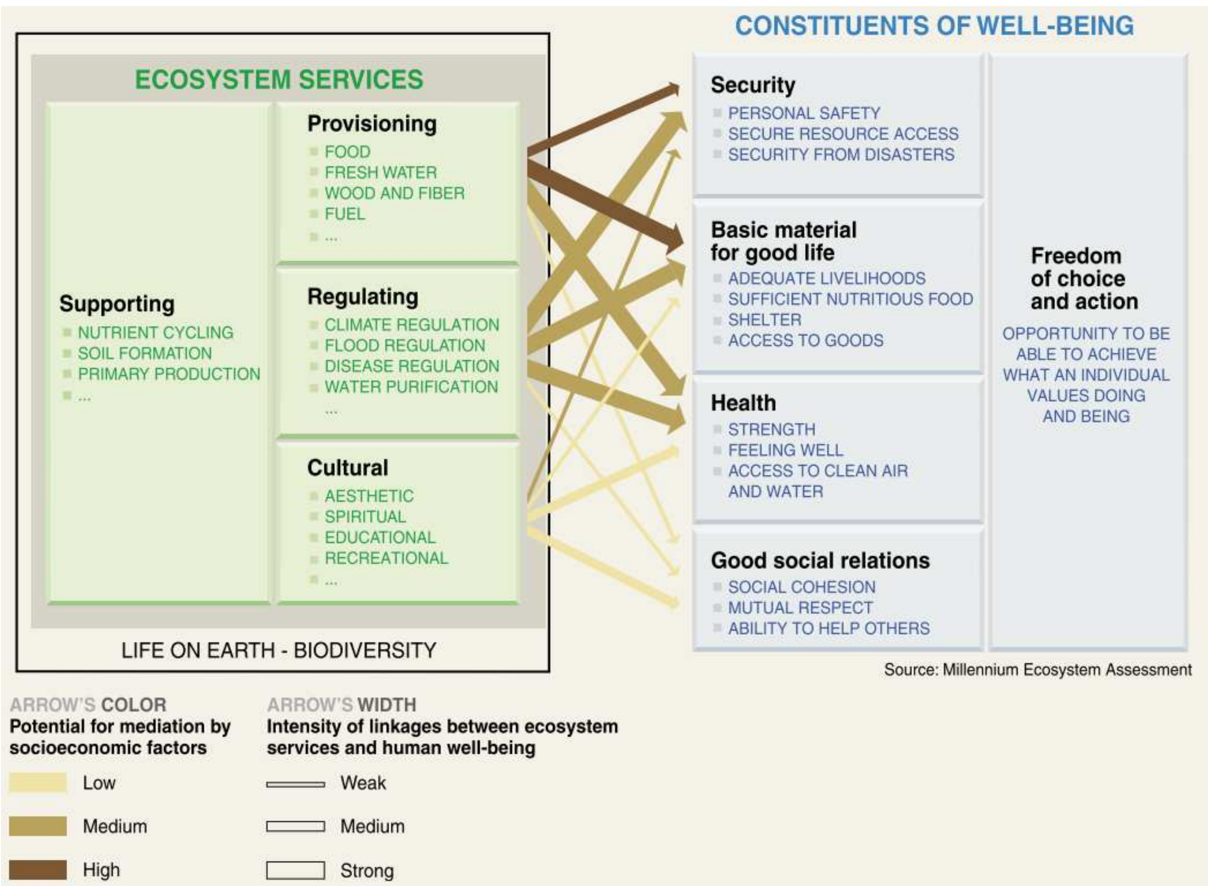


Figure 55: Linkages between ecosystem services and human well-being (adapted from the Millennium Ecosystem Assessment 2005)

9.1.2 The role of biodiversity in ecosystem services

There is compelling evidence from multiple international sources showing that a rich, natural biodiversity underpins ecosystem processes, resilience (including resistance, recovery and reversibility), and thus the sustainability of ecosystem services (e.g. Duarte 2000; Millennium Ecosystem Assessment 2005; Balvanera *et al.* 2006; Worm *et al.* 2006; Palumbi *et al.* 2009, and many others). The (generally) positive relationship between biodiversity, ecosystem processes and services is likely because of increased complementarity of resource use, facilitation among species, probability of key (keystone, or structure-forming) species being present in the community, functional redundancy, and/or the portfolio effect (Palumbi *et al.* 2009). In order to sustain ecosystem processes and thus provision of multiple ecosystem services simultaneously, Palumbi *et al.* (2009) argue for conservation of biodiversity at genetic, species, and habitat levels. Indeed, biodiversity conservation should include more than simply maintaining species richness; genetic diversity may be as important as the number of species present, especially in the context of global change where adaptation to shifting conditions will most likely be necessary for species' persistence. Furthermore, species may need to be present at ecologically effective population densities (Soule *et al.* 2003) in order to provide particular ecosystem services (Luck *et al.* 2003). While biodiversity conservation alone may not solve all problems, it will go a long way to informing the importance of trade-offs among sectors of conflicting use (Palumbi *et al.* 2009).

9.1.3 The variety and value of marine and coastal ecosystem services

Marine and coastal ecosystems are no exception and provide a broad variety of ecosystem services. One of the primary provisioning services is fish for human consumption. Globally, marine fisheries provided more than 99 million tonnes of fish in 2008, of which 17 million tonnes was from aquaculture (FAO 2010). Including fish supply from inland capture fisheries and aquaculture, 1.5 billion people rely on fish for almost 20 % of their average per capita intake of animal protein; 3 billion for 15 %, with an all-time high in the per capita supply of fish (17 kg) recorded in 2008 (FAO, 2010). Furthermore, this industry is estimated to provide nearly 45 million jobs for direct involvement in fisheries activities, and an estimated 180 million jobs if secondary activities are included, which is said to support the livelihoods of about 8 % of the world's population (FAO, 2010). Capture fisheries (nearly 90 % marine) are estimated to be worth \$93.9 billion, and aquaculture (40 % marine) is worth \$98.4 billion; \$106 billion if aquatic plants from aquaculture are included. However, it should be noted that the percentage of fish stocks that are over-exploited, depleted or recovering from depletion (sum of 32 %) is also at an all-time high, and the percentage of stocks that are under-exploited or moderately exploited (sum of 15 %) is at an all time low (FAO, 2010). Fish provide a myriad of ecosystem services other than provision of food, such as regulation of food web dynamics, ecosystem resilience and carbon flux from water to the atmosphere; recycling and transport of nutrients; maintenance of biodiversity and sediment processes; linkages within and between ecosystems; supply of aesthetic values and recreational activities; control of diseases; and production of medicines (Holmlund & Hammer, 1999). Consequently, care should be taken that society does not trade at an overall total economic loss (see section 9.1.4).

Apart from commercial fishing, coastal systems in particular provide a number of food provisioning services for subsistence fishers. Invertebrates, seaweed and kelp are harvested off rocky shores and sandy beaches, for example, and fish are captured in the surf zone by shore-based anglers (e.g. Kyle *et al.* 1997; Clark *et al.* 2002). Coral reef ecosystems also play a vital role in the livelihoods of coastal people, with approximately 30 million people in the poorest and most vulnerable coastal communities depending exclusively on resources from coral reefs for their well-being (Secretariat of the Convention on Biological Diversity, 2010). Another provisioning service that may be important for local communities is the ornamental trade, where shells, corals, and reef fish are sold as curios, jewellery, or in the aquarium trade. In some places, however, selling shells is not a sustainable industry because the animals are harvested live (to obtain pristine shells), which is contributing to declines in species abundance, and impacting subsistence-food fishers' livelihoods (Pilkey *et al.* 2010). The marine aquarium trade has a much greater commercial value, and is said to be worth \$200 - \$330 million per annum, with an estimated 1.5 - 2 million people keeping marine aquaria world-wide (Wabnitz *et al.* 2003). In many instances, the value of reef fish or corals or live rock is worth two orders of magnitude more in the aquarium trade than if the resources are sold as food or construction materials, respectively (Wabnitz *et al.* 2003). In South Africa, marine species are also harvested or collected from other fishing operations for use in the magico-medicinal trade. This is a small but culturally important provisioning service.

Additional provisioning services of commercial importance include the extraction of sand and aggregate for construction, and mining of minerals and oil and gas. Although removal of sand off sandy beaches is currently an unsustainable practice in many parts of the world, and is contributing strongly to erosion of sandy shores (Pilkey *et al.* 2010), this activity does support the construction industry (Baloyi 2006). Sand mining directly on beaches is uncommon in South Africa, but there are a number of sand mining operations in estuaries and dunes (De Lange *et al.* 2009; however, see section 9.1.4). Mining of minerals, oil and gas from dunes, sandy beaches and marine ecosystems is a lucrative industry (see section 3.2.18 and 3.2.19). Provision of water from marine and coastal environments includes groundwater extraction out of coastal aquifers, or desalination of sea water (e.g. Al-Agha & Mortaja, 2005), which may become more important services as rainfall patterns shift in response to global climate change.

Marine and coastal biodiversity is likely to play a key role in the provision of genetic resources for use in the pharmaceutical industry in the future. A recent study indicated that more than 90 % of the novel chemicals from marine animals (of nearly 600 thousand predicted compounds) are undiscovered (Erwin *et al.* 2010). These authors also suggest that anti-cancer drugs of marine origin that are pending discovery are worth $563 billion - $5.69 trillion alone, and that 55 – 214 new anti-cancer drugs sourced primarily from marine animals and bacteria are expected to reach the market (Erwin *et al.* 2010). In addition, it has been estimated that genetic material and bioprospecting opportunities from coral reefs is worth more than US$ 5 million (Secretariat of the Convention on Biological Diversity 2010).

Regulating services are very important in marine and coastal environments. Oceans play a critical role in carbon sequestration and climate regulation. They have absorbed 80 % of the heat that has been added to the climate system in the last 50 years (IPCC 2007), taken up 25 % of fossil-carbon emissions (1.5 – 2.2 Pg $C.yr^{-1}$), and 30 - 50 % of atmospheric NO_2 and 40 % NH_x is continually deposited in the ocean (Reay *et al.* 2008). Similarly, coastal habitats (e.g. mangroves, salt marshes and seagrass beds) sequester an estimated 120-329 million tonnes of carbon annually; the upper limit approximately representing the annual release of greenhouse gases by Japan (Secretariat of the Convention on Biological Diversity 2010). Also, although covering a very small area, wrack piles on sandy beaches have higher CO_2 efflux rates than rainforests (Coupland *et al.* 2007). Marine systems therefore contribute significantly to gas regulation (Chen and Borges 2009), air quality and climate regulation.

Coastal systems, particularly near-shore reefs, mangroves and dune-backed sandy beaches play an important role in storm-impact buffering, and protecting the hinterland from high-energy-wave events (Lucrezi *et al.* 2010; Harris *et al.* 2011), and dune plants play a role in soil retention by preventing erosion (Avis 1995). It has been estimated that natural hazard management and shoreline protection from coral reef and mangrove ecosystems is worth more than US$ 18 million.km^{-2} and US$ 300 000 km^{-1} coastline, respectively (Secretariat of the Convention on Biological Diversity, 2010). Sandy beaches and, to a lesser extent, soft-bottom subtidal benthic habitats play an important role in water filtration and purification (e.g. Riedl *et al.* 1972;

McLachlan 1979; McLachlan *et al.* 1985; McLachlan 1989), and together with the other marine and coastal systems, are important in waste treatment by breaking down xenic nutrients and compounds (de Groot *et al.* 2002). Another important regulating service provided by marine and coastal systems is biological control, pest and disease regulation (Holmlund & Hammer, 1999).

The cultural services provided by coastal and marine systems require little introduction: humans are naturally drawn to the seaside, with coastal population densities approximately three times greater than that of inland populations (Small & Nicholls 2005). Shorelines (particularly sandy beaches) are a popular tourist destination, providing a myriad of recreational opportunities, aesthetically-pleasing and inspirational landscapes, and in a few pristine areas, a strong sense of place. Coastal tourism is consequently a lucrative industry that is important for both local and national economies (Klein *et al.* 2004). Many communities also have strong cultural and spiritual ties to coastal and marine systems (e.g. Charlier & Chaineux, 2009; Ghermandai *et al.* 2009). In addition, there are many opportunities for cognitive development along the coast and in the sea, from environmental education for young school children to scientific research. Given these strong ties between humankind and coastal and marine systems, the bequest value associated with these ecosystems will be relatively very high.

The ecosystem services supporting all the above are numerous. These include: photosynthesis by phytoplankton, microphytobenthos and coastal dune plants (e.g. Campbell & Bate 1988; Serôdio & Catarino 2000; Zehr *et al.* 2009); pollination of coastal dune plants (Correia de Albuquerque *et al.* 2007); connectivity of (meta)populations through larval transport (Cowen & Sponaugle 2009); nutrient cycling and productivity (Jensen *et al.* 1995; Mackey *et al.* 2010); refugia in the form of nurseries and overwintering grounds (e.g. Beck *et al.* 2001; Beck *et al.* 2003); the formation of sand through weathering of rocks and breakdown of biogenic material such as shells (Pilkey *et al.* 2010); and a transport medium that supports shipping, and thus international trade. While many of these may seem intangible, their underlying role in ecosystem service delivery is invaluable, and they consequently play a vital role in human well-being.

Financial gain (or cost avoidance) should not be the primary motivation for biodiversity conservation. However, a monetary value can provide a recognised measure of worth that people outside the conservation-related sectors can relate to more readily, allowing authorities to make more informed trade-offs during decision making. Since many ecosystem services do not have a direct market value, scientists or economists often rely on indirect valuation methods, such as willingness to pay, willingness to accept compensation, contingent valuation or group valuation. Assessments of this nature provide an indication of what intangible ecosystem services are worth to people.

Costanza *et al.* (1997) compiled the first attempt at valuing the global ecosystem services and natural capital. In this review, the marine biome (comprising open ocean and coastal ecosystems) had the greatest total global flow value, at nearly 1994 US$ 21 trillion. This was almost double the value provided by the sum of terrestrial ecosystems. In fact, coastal ecosystems alone were more valuable than the entire terrestrial biome, even though the former comprised just 20 % of the area of the latter (Costanza *et al.* 1997, as per their spatial extent definitions). Undoubtedly, coastal and marine ecosystems are the greatest contributor of ecosystem services (Wilson *et al.* 2005; Martínez *et al.* 2007; Brenner *et al.* 2010; Barbier *et al.* 2011), and thus by definition, are a great contributor to human well-being.

9.1.4 Threats, trends and trade-offs

One of the main findings of the Millennium Ecosystem Assessment (2005) was that more than 60 % of the ecosystem services (15 of the 24 evaluated) are degraded, or being used unsustainably, including 70 % of regulating and cultural services. This is of concern, not only because it suggests breakdowns at an ecosystem process and function level, but also because it implies a potential reduction in human well-being. There are several reasons for impaired ecosystem service delivery, including ill-informed (or poor) trade-off decisions and loss of biodiversity.

The over-utilization of some ecosystem services (particularly provisioning services that have a direct use/market value) can impair the delivery of other ecosystem services (often those with indirect or non-use values). In other words, while we may appear to enjoy the benefits of provisioning services from ecosystems (e.g. fish harvesting), the concomitant costs to regulating services (e.g. diversity, genetic resources, species resilience and biological control through trophic structures and linkages), cultural services (e.g. recreation; education; and research) and supporting services (e.g. nutrient cycling and productivity) may outweigh the benefits. In this way, what was once an ecosystem service, a benefit humans obtain from natural systems, can become a threat to the very ecosystem providing the service. Balmford *et al.* (2002) argue strongly for considering all ecosystem services when evaluating trade-offs, and discuss five international case studies where the perceived benefits of converting natural habitats for aquaculture, agriculture, and forestry came at a far greater total economic cost.

Closer to home, a recent evaluation of sand mining in estuaries in the eThekwini municipality (KwaZulu-Natal), for example, showed that the value of the extracted sand for construction (provisioning service) was less than the summed value of the other ecosystem services this activity compromised (de Lange *et al.* 2009). Certainly, sediments provide a bundle of other supporting, regulating and cultural services, including (among many others) habitat provision, flood control, and water filtration (Apitz 2011 in press). The real problem is that most often, the indirect benefits from services, such as regulating or supporting services, are not realized until they are lost (de Groot *et al.* 2002).

In addition, as much as a rich natural biodiversity can promote ecosystem service delivery, demise in biodiversity can conversely impair ecosystem service delivery. It is also important to note that biodiversity loss should not be evaluated simply as rates of species extinction, but should rather include a range of scales (molecular to landscape), because these all have important implications for ecosystem service delivery and in turn, human well-being (Luck *et al.* 2003). Dobson *et al.* (2006), for example, show that losses in habitat quality and quantity are associated with losses of trophic level diversity. They conclude with the prediction that food webs will thin and then collapse, with a sequential, hierarchical loss of ecosystem services provided by the different trophic levels, starting at the top and cascading down, as habitats become degraded through anthropogenic activities. Losing species may also prove to be more costly than currently realised, since emerging research shows that some ecosystem services are species dependent (Lerdau & Slobodkin 2002). As shown in Figure 56, biodiversity underpins ecosystem processes and functions, which in turn underpins ecosystem services; if biodiversity is lost, the impact is knocked on throughout the system.

Degradation and/or loss of ecosystem services have the potential to negatively affect human well-being substantially, and to cause significant economic losses. For example, tens of thousands of jobs were lost following the collapsed fishery in Newfoundland in the early 1990s; and harmful (and toxic) algal blooms can affect human health (Millennium Ecosystem Assessment 2005). In addition, losing just 20 % of our marine biodiversity could incur a market value loss of $112 billion - $1.14 trillion in anti-cancer drug industry alone (Erwin *et al.* 2010).

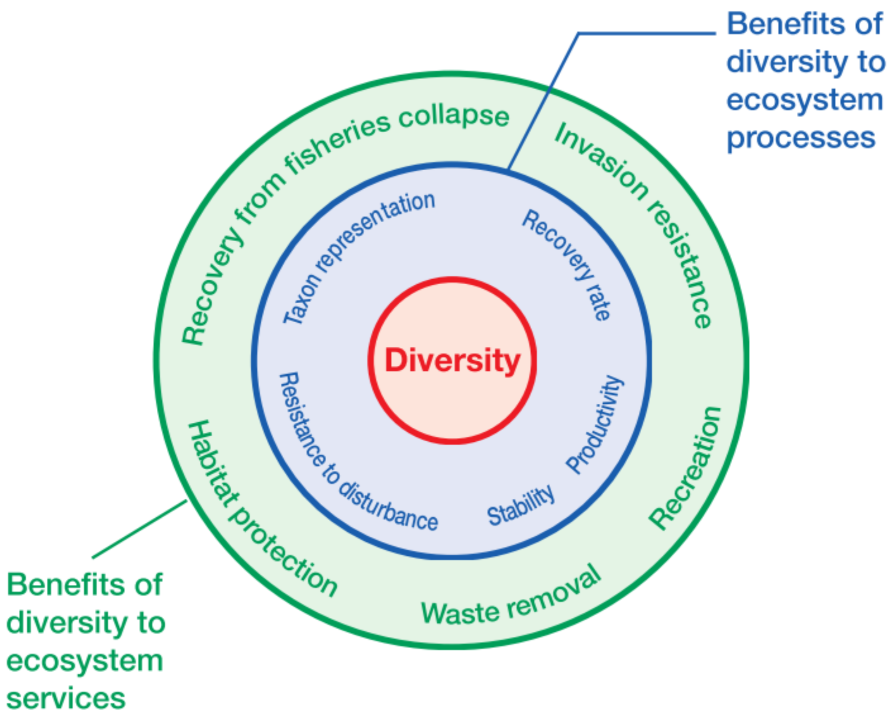


Figure 56: A schematic view of the benefits of biodiversity (Source: Palumbi et al. 2009). Diversity (red ring) enhances a variety of ecological processes (blue ring). These enhanced processes accelerate benefits that ecosystems provide in terms of recovery, resistance, protection, recycling, recreation, etc (green ring). Results are summarized from Loreau et al. (2001); Stachowicz et al. (2002); Duffy et al. (2003); Hilborn et al. (2003); Allison (2004); Hughes and Stachowicz (2004); Wall et al. (2004); Reusch et al. (2005); Byrnes et al. (2006); and Worm et al. (2006).

The reality is that there will always be humanus use of marine and coastal systems, and so "one of the outstanding challenges is to relate the nature and magnitude of services to the extent of habitats and communities, the biodiversity that they contain, and the types and levels of disturbance they can endure" (Palumbi *et al.* 2009). Although biodiversity loss is increasingly retarding the ability of ocean systems to provide ecosystem services, the trends still appear to be reversible (Worm *et al.* 2006). If we continue with business as usual, however, there could be serious consequences for food security, coastal water quality and ecosystem stability, globally, that will affect both current and future generations (Worm *et al.* 2006). Thus, while society stands to gain a great deal from ecosystem services, both directly and indirectly, careful management is necessary to ensure sustainability.

9.2 A South African perspective

9.2.1. Knowledge and gaps

Little research has been done on marine and coastal ecosystem services in South Africa specifically. There is comparatively more information for the terrestrial, freshwater and estuarine systems, for example, with the Working for Water programme (Turpie *et al.* 2007) being a prime South African example that is frequently cited in the international literature (e.g. TEEB 2010). It is currently beyond the scope of this report to calculate the summed value of South African marine and coastal ecosystem services accurately, given that there are still many research gaps. However, Table 23 summarises some of the work that has been done on the South African marine and coastal ecosystem services, with the majority (virtually all) seeking to understand aspects of the ecosystem process or function, rather than quantify the ecosystem service value. Although efforts were made to find as many South African papers as possible, this is by no means a comprehensive or exhaustive list. Note that coastal ecosystem services include those provided by estuaries, but these are dealt with in a separate component report (see van Niekerk & Turpie 2011) and are not included here.

It is worth mentioning that coastal resources make a significant contribution to the South African national Gross Domestic Product (GDP) with nearly R2.5 billion derived from fishing alone (Statistics SA 2011). In terms of ecosystem services, coastal tourism is probably the second largest direct contributor to the GDP. There is a steady increase in the number of tourists visiting South Africa (25 - 28 million people annually since 2006, peaking in 2010 at nearly 32 million because of the soccer world cup), of which about 94 % was for holiday purposes (Statistics SA 2010). Tourism contributed R68 billion to the GDP in 2009 (South African Tourism 2011). Since beach visiting is ranked highly as a preferred activity in South Africa (seventh by international tourists and third by domestic tourists; South African Tourism 2011), it is likely that coast-related tourism comprises a substantial portion of this sector’s contribution to the national GDP.

Table 23: Ecosystem services provided by marine and coastal ecosystems in South African. Examples of references to South African case studies of these ecosystem services are indicated.

	Service	**References**
Provisioning	Fish	Brouwer *et al.* 1997; McGrath *et al.* 1997; Griffiths 2000; Myeza *et al.* 2010
	Invertebrates	Griffiths & Branch 1997; Kyle *et al.* 1997; Clark *et al.* 2002; Cockcroft *et al.* 2002; Turpie *et al.* 2003
	Aquaculture / mariculture	Safriel & Bruton 1984; Anderson *et al.* 1996; Troell *et al.* 2006
	Macrophytes (seaweed & kelp)	Griffiths & Branch 1997; Clark *et al.* 2002
	Minerals (including diamonds), oil & gas	Statistics SA 2011 (not marine specific)
	Construction materials (sand and aggregate)	Baloyi 2006; de Lange *et al.* 2009
	Water supply	
	Biodiversity / genetic resources	Von der Heyden 2009
	Pharmaceuticals	Davies-Coleman & Beukes 2004; Davies-Coleman 2010; Cwala *et al.* 2011
	Ornamental Resources (Shells / curios / Aquarium trade)	
Regulating	Carbon sequestration	Hietkamp *et al.* 2008; Waldron *et al.* 2009
	Climate regulation	Midgley *et al.* 2010 (and references therein)
	Disturbance regulation (Storm buffering & coastal protection)	Harris *et al.* 2011
	Gas regulation & air quality	
	Soil (sand) retention (roots of dune plants preventing erosion)	Avis 1995
	Water filtration & purification	McLachlan 1979
	Waste treatment (regulating water quality – including breakdown of xenic nutrients and compounds)	
	Biological Control / Pest & disease regulation	
Cultural	Spiritual and cultural	
	Bequest value	Turpie 2003
	Sense of place / aesthetic and inspirational value	
	Education / Research / Knowledge Systems	
	Recreation	De Ryk *et al.* 1995
	Tourism / ecotourism	Findlay 1997; Turpie & Ryan 1998; Hara *et al.* 2003; Turpie *et al.* 2003; Dicken & Hosking 2009
Supporting	Photosynthesis	Campbell & Bate 1988
	Nutrient cycling and Productivity	McLachlan *et al.* 1981; McLachlan & Illenberger 1986
	Pollination on coastal dunes	
	Dispersal of larvae (connectivity of (meta)populations)	McQuaid & Phillips 2006; Teske *et al.* 2007
	Refugia (nurseries, overwintering grounds etc)	Whitfield 1989; Pattrick & Strydom 2008
	Sand formation	
	Transportation (shipping)	

9.2.2. Turtle conservation: an ecosystem services success story

One salient success story in the marine and coastal systems has been the paradigm shift in local communities towards sea turtles in the Isimangaliso Wetland Park World Heritage Site. More than 50 years ago, poaching of turtles was rife on the sandy shores in northern KwaZulu-Natal. A community-based turtle monitoring programme was initiated by Ezemvelo KZN Wildlife (then Natal Parks Board) in the early 1960s, which has been running annually since. Today, there is a strong sense of ownership of both the programme and the turtles by the local people. Instead of poaching the endangered (loggerhead, *Caretta caretta*) and critically endangered (leatherback, *Dermochelys coriacea*) turtles for food (provisioning service), the communities now enjoy a more sustainable income through eco-tourism and conservation (both cultural services; conservation has an associated bequest value). In addition, the turtle populations are benefitting from the conservation efforts (Nel 2010).

9.2.3. Opportunities for maintaining ecosystem services in South Africa

The people of South Africa are in a strong position to benefit greatly from the many ecosystem services that are available from our rich marine and coastal ecosystems. This is mainly because many of our coastal and marine habitats are still in a good condition, or can be restored, and we are poised to expand and strengthen our marine protected area (MPA) network that in turn will enhance ecosystem service provision, with long-term sustainability. South Africa's strong position is of particular importance as a developing nation, since the attainment of human well-being is considered the opposite of poverty (Millennium Ecosystem Assessment, 2003). Not only is poverty eradication a Millennium Development Goal and a top government priority, but the defining constituents of human well-being, as described above, are all echoed in the Constitution of the Republic of South Africa (No. 108 of 1996) as rights for every individual. It is therefore imperative to note that properly planned, science-based management and conservation of biodiversity and intact, functional ecosystems is not a separate agenda to poverty eradication and socio-economic development; rather, it is a powerful tool that can contribute to achieving social, economic and environmental goals simultaneously, with long-term sustainability (see Tallis *et al.* 2008 and Nahman *et al.* 2009).

Empowered by strong and progressive environmental legislation, such as the Integrated Coastal Zone Management Act, 2008 (No. 28 of 2008), National Environmental Management Act (NEMA, No. 107 of 1998), and associated regulations such as Regulations in terms of NEMA: Vehicles in the coastal zone (Government notice 1399, 21 December 2001), National Environmental Management: Biodiversity Act (No. 10 of 2004), National Environmental Management: Protected Areas Act (No. 57 of 2003), and Marine Living Resources Act (No. 18

of 1998), South Africa has the potential to lead the way globally, and show that by simply regarding and respecting our rich biodiversity as a national asset, there can be equitable social and economic benefits for all people, including the generations to come.

10 Species of special concern

10.1 Fisheries species

The provision of marine resources can be considered as a key ecosystem service from the marine environment. Sustainable use of marine resources is important for long term food and job security in South Africa. About 630 marine and estuarine species are caught (deliberately or incidentally) in South Africa with current estimates reflecting a total of 11 algae, 81 invertebrate and 546 fish species impacted by commercial, recreational and subsistence sectors (unpublished data, DAFF). Many species are also impacted by multiple sectors. There are a few additional species harvested or purchased and sold in the magico-medicinal trade and collected and by the aquarium trade that are not reflected in these estimates.

Approximately 53% of the 638 species caught by fisheries are targeted species (Lombard *et al.* 2004, Appendix 3) and many of the others are considered as bycatch, several of which are not regularly caught. Target species are those that are primarily sought in a fishery such as hake, sole, rock lobsters, squid and prawns. Bycatch can be defined in many ways and includes those species caught incidentally that are retained and those discarded at sea because of economic, legal or personal considerations (Alverson *et al.* 1996). Davies *et al.* (2009) define bycatch as any catch that is unmanaged or unused and this simple definition will allow for the reduction of bycatch in South African fisheries through management of more species that are caught (Attwood *et al.* 2011). Changing markets can alter which species are primarily targeted, retained or discarded and many bycatch species can be considered as secondarily targeted species or joint products. Concern has been expressed about the diversity and volume of the bycatch in several of South Africa's fisheries (Japp *et al.* 1994, Fennessy and Groeneveld 1997, Nel *et al.* 2007, Attwood *et al.* 2011), particularly the trawl fisheries. To assess the sustainability of bycatch, catch volumes should be examined in the context of total stock sizes and fishing mortality (Alverson *et al.* 1996). Further information about bycatch is detailed in the review of each fishery sector in section 3.

South Africa has a long history of fishery management grounded in excellent scientific research. Several stock assessment techniques are applied in the management of the most important resource species (Table 24). Of the total number of caught species, stock status is reported for 41 (6%) of the caught species (Table 25) although other assessments and abundance trends exist and could provide information for additional species. Recently, DAFF has started to examine species abundance trends for 111 nominal taxa using the demersal trawl research database. These data can be used to infer whether the trend over time is positive, negative or stable.

About 14 speices are managed through a full stock assessement cycle (Table 24). These include South Africa's most important species in terms of catch and value. Rigorous modelled stock assessments require substantial amounts of data and are not feasible for every species caught. Per recruit models are less data hungry than production models but also less robust. They have been used extensively in the management of linefish in South Africa. Trends in CPUE, size structure and catch composition support fisheries management decisions in the linefish and netfish sectors. A standardised time series of CPUE, covering a substantial period (typically longer than 20 years) may be used as the basis for preliminary stock assessment in the absence of fitted production models. CPUE provides a relative measure of fish abundance, but care should be taken to interpret spatial components of the data. The best application of CPUE, in conjunction with total catch, is for the fitting of production or age-structured production models where the necessary age and size structure data are available.

Stock assessment models are most successful when abundance and catch data contain sufficient contrast to estimate stock dynamics. Contrast is usually achieved by having historical data from a time at or near the beginning of the fishery as well as the fully or overexploited period. Re-establishing historical baselines can significantly improve the understanding of stock dynamics which can support better management and resource recovery in the long term. For linefish, it is recommended that species are assessed at intervals equivalent to half their maximum lifespan (DAFF 2010). Many species are due for update.

Where historical data are unavailable, contrast can be found in the comparison of data between exploited and protected areas. This is a major reason for the recommendation to maintain no-take MPAs to support fisheries management (Attwood 2003).

Table 24: Methods of assessing stock status or trends in support of managing marine resources in South Africa. Assessment methods are listed in order of decreasing data requirements (and certainty). Species managed by regional fishery management organisations (RFMOs) are excluded.

Type of assessment	Data needs	Species currently assessed by this method
Age structured production model	Index of abundance (often CPUE), total catch, catch at size and age-length key	Hake, *West coast rock lobster, *South coast rock lobster, *Abalone, Cape horse mackerel, Pilchard, Anchovy and Redeye, Kingklip, Patagonian toothfish
Production model	Index of abundance and total catch	Monk, Chokka Squid, East Coast Sole, Smoothhound shark
Per recruit models	Catch at size data, age-length key, an estimate of natural mortality	Silver kob, Dusky kob, Geelbek, Dageraad, Seventy four, Red steenbras, White steenbras, Yellowbelly rockcod, Scotsman, Englishman, Carpenter, Elf, Soupfin shark
Standardised CPUE time series	CPUE over time	Snoek, red stumpnose, roman and other linefish also monitored by spawner biomass per recruit, Netfish, Shallow and deep water prawns, langoustines, deep water rock lobster and crabs

**Models for these species are sex and area disaggregated. West coast rock lobster assessments also incorporate standardised growth indices and fisheries independent survey data.*

The 2010 Status of the South African Marine Fishery Resources Report (DAFF 2010) reflects the poor confidence or unknown stock status for several resources, as well as the overexploited status for many species (Table 25). The status of several important resources, including shallow water hake, small pelagic fish, several tuna, south coast rock lobster, squid, prawns, some oysters and kelps, are considered optimal. The south coast rock lobster fishery provides a good example of how effective fishery management can lead to resource recovery. The decline of south coast rock lobster was arrested in the early 2000s, through co-ordinated catch and effort reductions, a 30% reduction in the number of active vessels and by a reduction in the illegal catch (DAFF 2010).

Of the resources for which stock status was reported in 2010 (DAFF), 25 of 41 (61%) are overexploited, collapsed or threatened (Table 24). There is a trend of deteriorating status of the more accessible inshore resources (DAFF 2010). Overexploited resources include abalone, deep water hake, west coast rock lobster and several shark and linefish species (Table 25). Deep water hake is however showing signs of recovery in response to management action and it is anticipated that the resource will reach the target level (maximum sustainable yield level) by 2014. (DAFF 2010). Key elements involved in the recovery of the hake resource include an improved understanding of the stock dynamics, extended data sets to monitor trends and a more conservative (less risky) fishing strategy i.e. the implementation of lower quotas and more stringent effort limitation (Rademeyer *et al.* 2008a, 2008b).

Linefish data have not yet clearly reflected an improvement in stock status since this fishery was declared in a “state of emergency” in 2000 (DAFF 2010) but many assessments are outdated and there is current research effort to assess whether resources are recovering. The linefishery has the potential to become a much more ecologically sustainable and economically viable fishery in South Africa. This is due to the selectivity of the fishing method, low ecosystem impacts associated with linefishing and the opportunities that follow from more labour intensive and less capital intensive fisheries. Linefishing can be highly selective, by-catch of undersized fish and unwanted species can be avoided and linefishing inflicts minimal physical damage to habitats. The labour-intensive, low-technology, low-investment method maximizes employment opportunities and the product is potentially of high quality and many species command a high price on local and international markets. To achieve a more sustainable and economically viable linefisher, this sector should be returned to sustainable levels by reducing over-capacity, initiatives to encourage voluntary compliance by commercial and recreational fishers, improving effectiveness of monitoring and compliance, and by managing linefish by-catch in other sectors, such as the inshore trawl fishery. Open access for inshore resources will compromise the potential of this fishery to deliver long term benefits into the future.

There has been recent progress in the assessment of some sharks although this indicates that several species are overexploited (DAFF 2010). Soupfin shark is reported as both overexploited (under sharks) and optimally exploited (under linefish) (DAFF 2010). The National Plan of Action: Sharks is currently under revision and the implementation of priorities for sharks, as detailed in the plan, should be taken forward.

Table 25: Stock status of main fishery resources as reported by DAFF (2010).

Uncertain status	Overexploited, collapsed or threatened	Optimally exploited	Underexploited
Cape horse mackerel	Abalone	Albacore tuna	Round herring
East Coast sole	Carpenter	Anchovy	Seaweeds
Patagonian toothfish	Dageraad	Bigeye tuna	Swordfish
White stumpnose	Deep-water hake	Kelps	
Several linefish	Dusky kob	Oysters (KZN)	
Several sharks	Elf (shad)	Prawns	
White mussel	Englishman	Sardines	
Other invertebrates	Geelbek	Shallow-water hake	
	Great hammerhead	Snoek	
	Harders	Squid	
	Longfin mako	South coast rock lobster	
	Oceanic whitetip	Yellowfin tuna	
	Red steenbras	Yellowtail	
	Roman		
	Scotsman		
	Seventy four		
	Silver kob		
	Smoothhound shark		
	South Coast oysters		
	Southern bluefin tuna		
	Spiny dogfish		
	Stumpnose		
	West coast rock lobster		
	White steenbras		
	Yellowbelly rockcod		

Of the 111 nominal taxa (species and entire families) for which linear abundance trends were recently calculated using the demersal trawl database (DAFF unpublished data), 70 (63%) show no significant abundance trends. Commonly caught bycatch in this category included the ribbonfish *Lepidopus caudatus* and Cape gurnard *Chelidonichthys capensis.* The remainder reflect significant decline, significant increase, significant trends on one coast but not on the other or opposing responses on the west and south coast.

Species that appear to have declined include piked dogfish *Squalus acanthias,* the pyjama shark *Poroderma africanum,* electric ray *Narke capensis,* shyshark *Haploblepharus edwardsii,* guitarshark R*hinobatos annulatus* and twineye skate *Raja miraletus.* A decline in piked dogshark over the last 23 years was also reported by Atkinson et al (2011b) who examined long term changes in demersal fish assemblages using multivariate analyses of the same dataset. Declines of relatively slow growing chondrichthyan species could be expected as these taxa are considered vulnerable to fishing pressure (Stevens *et al.* 2000). Abundance trends from the demersal research database (DAFF unpublished data) also reflected a decline in the crab *Gonaplax angulata*. Species with a significant rate of increase included the spiny eel *Notacanthus sexpinis*, angelfish *Brama brama*, and hairy conger *Bassanago albescens*. The lesser gurnard *Chelidonichthys queckettі* consistently increased on both the west and south coast although the rate of increase was slower than the previously mentioned species. Of the invertebrates, several cephalopods seemed to increase over time on the west coast with the lesser flying squid *Todaropsis eblanae* showing the greatest rate of increase. Based on the same dataset, Atkinson *et al.* (2011b) also reported a significant increase in the eels *Notacanthus sexpinis* and *Bassanango albescens* and noted that these taxa are likely to be relatively fast growing and early maturing.

Several species (such as the slime skate *Dipturus pullopunctata* and the legskate *Cruriraja hulleyi*) increased significantly on the west coast but showed no significant trend on the south coast. The spiny horse fish *Congiopodus spinifer* and the St Joseph shark *Callorhinchus capensis* declined and increased respectively on the south coast but trends for these species were not significant on the west coast. Atkinson *et al.* (2011b) noted a decline in *Callorhinchus capensis* on the west coast over time when comparing fish assemblages over the past 23 years. Only one species showed opposing trends in the demersal research database; the biscuit skate *Raja straeleni* declined on the south coast but increased on the west coast. This species has commercial value and is caught mostly on the south coast where much more trawling effort overlaps with the core habitat for this species, suggesting that fishing pressure is driving this decline.

These linear abundance trends represent a significant step forward in monitoring the status of non-target species but standardisation of CPUE trends and further exploration is required. These data reflect complex patterns that should be interpreted with caution. Atkinson *et al.* (2011b) attributed change in demersal fish assemblages to long-term indirect effects of fishing in concert with environmental change. A key limitation of this dataset includes the limited time series (1986 – 2010) for these taxa. For many of the more vulnerable species, the most significant changes may have taken place in the early stages of the fisheries (Jennings and Kaiser 1998, Atkinson *et al.* 2011b). The demersal research database now includes a number of invertebrate species and a more comprehensive long-term monitoring initiative for benthic invertebrates is under development.

Potential impacts on other species caught incidentally and species that are impacted but remain out of sight also warrant consideration. These aspects of fishing operations should also be reported along with the state of resources. Further detail on the incidental mortality of seabirds, turtles and sharks is included in the sector specific reviews in section 3. Atkinson *et al.* (2011b) is one of few studies to examine fishing effects on benthic invertebrate assemblages in South Africa. Results suggest that intense trawling is at least partly responsible for significant differences in benthic infauna and epifauna. The abundance, biomass, diversity and community composition differed significantly at heavily versus lightly trawled sites, with epifauna (particularly larger, slower growing epifauna) showing a stronger response than infauna. Two urchin species appear to be vulnerable to heavy trawling, *Brissopsiis lifer capensis* and *Spatangus capensis*, yielding lower densities at heavily trawled sites. The burrowing anemone *Actinauge granulata*, (previously misidentified as *Actinage richardii*) and the brittlestars *Ophiura* sp. were more common at lightly trawled sites. The anemones may survive trawling by burrowing and the brittlestars may colonise disturbed areas. The lack of an untrawled reference site, limited this study and the most significant changes in benthic invertebrate fisheries in relation to trawling may have taken place at the onset of the fishery (Jennings and Kaiser 1998). The potential impact of trawling on species that inhabit hard ground habitats in South Africa has never been examined. This led to challenges in the eco-certification of South Africa's hake trawl fishery which requires consideration of rare species, species vulnerable to trawl impacts and species that may been significantly impacted by trawling.

Dedicated sector-specific studies based on observer data can improve bycatch estimates and help to advance the understanding of non-target species that may be significantly affected by fishing (see Attwood *et al.* 2011). Observer data also plays a key role in monitoring other species (such as seabirds and turtles) that are killed incidentally during fishing operations and South Africa has the opportunity to strengthen the collection of observer data to support the mapping of vulnerable benthic species. More work is needed to support monitoring of bycatch species and species that are caught or damaged incidentally in South Africa fishing operations.

All primary fisheries target species as well as regularly and abundantly caught bycatch species should require stock assessments. Bycatch with high economic value should be carefully managed to prevent overexploitation. The catch of non-retained (discarded) species should be minimised and monitored to determine whether fishing may be having a significant adverse impact on these species.

Illegal fishing or poaching is a major concern in South Africa. DAFF (2010) reports that illegal abalone, linefish and rock lobster fishing is of particular concern (DAFF 2010). Poaching threatens marine biodiversity, resource sustainability and the livelihoods of legitimate fishers and their dependent communities.

Research priorities to support improved stock assessment and resource management include

- Assessment of whether kingklip on the west coast and south coast are separate stocks
- Aging studies are needed for many species to improve stock assessment. Priority species include hake species, East coast sole, kingklip and monk and (Colin).
- Linefish – longer time series to achieve sufficient contrast in the data – good historical estimates or MPA surveys
- Updated and more reliable information is needed to reflect effort and catch for squid including the spatial distribution of catch
- Improved data for sharks, caught by multiple sectors, is needed to support better assessments and management. Detailed priorities for sharks have been identified through the current revision of the South African National Plan of Action for sharks.
- Increased and improved data collection and systematic research is needed to support stock assessment and management in the prawn trawl fishery. Better biological information is needed for the various prawn species (DAFF 2010).
- Scientific observer priorities include work to support resource management and the Ecosystem Approach to Fisheries management. Estimates of pre-discard catch by area are a priority for trawl fisheries. In the case of longlining, losses from the line need to be estimated. Estimates of seabird mortality and interactions between fisheries and large marine predators should be documented. Observers can also perform many specialised functions such as the collection of genetic samples, and size structure data.

10.2 Threatened species

Species conservation assessments are used by policy makers to guide developments of protected species lists and other laws and policies aimed at conserving threatened species. Conservation assessments underpin species management and the identification of priority taxa and areas for conservation as well as playing a key role in sustainable development. They are needed to guide monitoring efforts and assist in the identification of research priorities. The International Union for Conservation of Nature (IUCN) has developed standard criteria for assessing species conservation status. The IUCN Species Programme produces, maintains and manages the IUCN Red List of Threatened Species. Red Listed species are regarded as important international indicators of the state of biodiversity and offer significant opportunities for attracting attention and funding to biodiversity conservation (Foden 2005). Marine species assessments have also been used to support other conservation initiatives such as fisheries eco-certification assessments and the listing of seafood for the Southern African Sustainable Seafood Initiative (SASSI).

In total, 93 species that occur in South Africa are currently listed on the IUCN global redlist of threatened species (Table 26). This total includes 13 Critically Endangered, 21 Endangered and 59 Vulnerable species. The list includes marine mammals, seabirds, several elasmobranchs fish and coal species. The main threats underlying the poor conservation status of these species are fishing, including over-fishing of target species, poor bycatch management and incidental mortality of seabirds; freshwater flow reduction and estuarine degradation; invasive alien coastal development and climate change including ocean acidification (particularly for corals).

Few regional or national conservation assessments have been undertaken but South Africa has adopted global assessment results for regional endemics (those species found only in South Africa and our neighbouring countries), and a few national assessments have been completed (Table 27).

Table 26: List of threatened species occurring in South Africa, as listed on the by IUCN global redlist. Species endemic to southern Africa (South Africa and Mozambique or Namibia) are indicated with an asterisk.

Species	Common name	Status	Criteria	Year Assessed	Population trend
Balaenoptera musculus ssp. Intermedia	Antarctic Blue Whale	CR	A1abd	2008	increasing
Dermochelys coriacea	Leatherback turtle	CR	A1abd	2000	decreasing
Diomedea dabbenena	Tristan albatross	CR	A4ade	2010	decreasing
**Electrolux addisoni*	Ornate sleeper ray	CR	B2ab(ii)	2008	unknown
Eretmochelys imbricata	Hawksbill turtle	CR	A2bd	2008	decreasing
**Haploblepharus kistnasamyi*	Natal Shyshark	CR	B1ab(iii)	2008	unknown
Latimeria chalumnae	Coelacanth	CR	A2cd, C2b	2000	unknown
Pristis microdon	Largetooth sawfish	CR	A2abcd+3cd+4bcd	2006	decreasing
Pristis pectinata	Smalltooth sawfish	CR	A2bcd+3cd+4bcd	2006	decreasing
Pristis zijsron	Narrowsnout sawfish	CR	A2bcd+3cd+4bcd	2006	decreasing
**Siphonaria compressa*	Compressed false limpet	CR	B1+2c	1996	
Thunnus maccoyii	Southern bluefin tuna	CR	A1bd	1996	
**Tomichia tristis*	Mollusc	CR	B1ab(ii,iii)+2ab(ii,iii)	2007	unknown
**Chelonia mydas*	Green turtle	EN	A2bd	2004	decreasing
Balaenoptera borealis	Sei Whale	EN	A1ad	2008	unknown
Balaenoptera musculus	Pygmy Blue Whale	EN	A1abd	2008	increasing
Balaenoptera physalus	Fin Whale	EN	A1d	2008	unknown
Caretta caretta	Loggerhead	EN	A1abd	1996	
Diomedea sanfordi	Northern royal albatross	EN	A4bc; B2ab(iii,v)	2010	stable
Epinephelus marginatus	Dusky grouper	EN	A2d	2004	decreasing
**Hippocampus capensis*	Knysna seahorse	EN	B1+2c+3d	2000	
**Holohalaelurus favus*	Honeycomb izak, Natal izak	EN	A2abcd+3bcd+4abcd	2008	decreasing
**Holohalaelurus punctatus*	Whitespotted izak, African spotted catshark	EN	A2abcd+3bcd+4abcd	2008	decreasing
**Liza luciae*	Saint Lucia mullet	EN	B1+2ab+3a	1996	
**Phalacrocorax neglectus*	Bank cormorant	EN	A2ace+3ce+4ace	2010	decreasing
Rhinobatos cemiculus	Blackchin guitarfish	EN	A4bd	2007	decreasing

Species	**Common name**	**Status**	**Criteria**	**Year Assessed**	**Population trend**
Rhinobatos rhinobatos	Common guitarfish, violinfish	EN	A4cd	2007	decreasing
Rostroraja alba	Spearnose skate	EN	A2cd+4cd	2006	decreasing
Spheniscus demersus	African penguin	EN	A2ace+3ce+4ace	2010	decreasing
Sphyrna lewini	Scalloped hammerhead	EN	A2bd+4bd	2007	unknown
Sphyrna mokarran	Great hammerhead shark	EN	A2bd+4bd	2007	decreasing
Thalassarche carteri	Indian yellow-nosed albatross	EN	A4bde	2010	decreasing
Thalassarche chlororhynchos	Atlantic yellow-nosed albatross	EN	A4bd; B2ab(v)	2010	decreasing
Thalassarche melanophrys	Black-browed albatross	EN	A4bd	2010	decreasing
Acropora anthocercis	(coral)	VU	A4ce	2008	decreasing
Acropora horrida	(coral)	VU	A4cde	2008	decreasing
Acropora retusa	(coral)	VU	A4ce	2008	decreasing
Acropora verweyi	(coral)	VU	A4ce	2008	decreasing
Acropora willisae	(coral)	VU	A4ce	2008	decreasing
Alopias pelagicus	Pelagic thresher, thresher shark, whiptail shark	VU	A2d+4d	2004	decreasing
Alopias superciliosus	Bigeye thresher shark	VU	A2bd	2007	decreasing
Alopias vulpinus	Common thresher shark	VU	A2bd+3bd+4bd	2007	decreasing
Alveopora allingi	(coral)	VU	A4cd	2008	unknown
Anomastraea irregularis	(coral)	VU	A4ce	2008	decreasing
Carcharhinus longimanus	Whitetip shark	VU	A2ad+3d+4ad	2006	decreasing
Carcharhinus obscurus	Dusky shark	VU	A2bd	2007	decreasing
Carcharhinus plumbeus	Sandbar shark	VU	A2bd+4bd	2007	decreasing
Carcharias taurus	Spotted Ragged-tooth Shark	VU	A2ab+3d	2005	unknown
Carcharodon carcharias	Great white shark	VU	A2cd+3cd	2005	unknown
Centrophorus granulosus	Gulper shark	VU	A2abd+3d+4d	2006	decreasing
Centrophorus squamosus	Deepwater spiny dogfish	VU	A2bd+3bd+4bd	2003	decreasing
Cetorhinus maximus	Basking shark	VU	A2ad+3d	2005	decreasing
Diomedea epomophora	Southern royal albatross	VU	D2	2010	stable
Diomedea exulans	Wandering albatross	VU	A4bd	2010	decreasing
**Epinephelus albomarginatus*	White-edged Rockcod	VU	A2d	2004	decreasing

Species	Common name	Status	Criteria	Year Assessed	Population trend
Epinephelus lanceolatus	Brindle bass	VU	A2d	2006	decreasing
Eudyptes chrysocome	Rockhopper penguin	VU	A2abcde+3bcde+4abcde	2010	decreasing
Eudyptes chrysolophus	Macaroni penguin	VU	A2bc+3bc+4bc	2010	decreasing
Galeorhinus galeus	Soupfin	VU	A2bd+3d+4bd	2006	decreasing
Haploblepharus fuscus	Brown shyshark	VU	B2ab(iii)	2008	unknown
Heliopora coerulea	Blue coral	VU	A4cde	2008	decreasing
Hemipristis elongatus	Snaggletooth shark	VU	A2bd+3bd+4bd	2003	decreasing
Heteronarce garmani	Natal electric ray	VU	A2d+4d	2007	unknown
Himantura uarnak	Honeycomb stingray, leopard stingray, marbled stingray	VU	A2bd+3bd+4bd	2004	decreasing
Isurus oxyrinchus	Shortfin mako	VU	A2abd+3bd+4abd	2004	decreasing
Isurus paucus	Longfin mako	VU	A2bd+3d+4bd	2010	decreasing
Lamna nasus	Porbeagle shark	VU	A2bd+3d+4bd	2006	decreasing
Lepidochelys olivacea	Olive Ridley turtle	VU	A2bd	2008	decreasing
**Morus capensis*	Cape gannet	VU	A2acde+3cde+4acde; B2ab(iii,iv,v)	2008	decreasing
Mustelus mustelus	Common smoothhound	VU	A2bd+3bd+4bd	2004	decreasing
Nebrius ferrugineus	Tawny nurse shark	VU	A2abcd+3cd+4abcd	2003	decreasing
Negaprion acutidens	Sharptooth lemon shark	VU	A2abcd+3bcd+4abcd	2003	decreasing
Odontaspis ferox	Small-tooth Sand Tiger Shark	VU	A2bd+4bd	2007	decreasing
Oxynotus centrina	Angular rough shark	VU	A2bcd+4bd	2007	unknown
Physeter macrocephalus	Sperm whale	VU	A1d	2008	unknown
Procellaria aequinoctialis	White-chinned petrel	VU	A4bcde	2010	rapid decrease imminent
Procellaria conspicillata	Spectacled petrel	VU	D2	2010	increasing
Rhina ancylostoma	Bowmouth guitarfish, mud skate, shark ray	VU	A2bd+3bd+4bd	2003	decreasing
Rhincodon typus	Whale shark	VU	A2bd+3d	2005	decreasing
Rhinoptera javanica	Flapnose ray, javanese cownose ray	VU	A2d+3cd+4cd	2006	unknown
Rhynchobatus djiddensis	Giant guitarfish, whitespotted wedgefish	VU	A2d+3d+4d	2006	decreasing
Scylliogaleus quecketti	Flapnose houndshark	VU	B1ab(iii);C2a(ii)	2005	unknown

Species	**Common name**	**Status**	**Criteria**	**Year Assessed**	**Population trend**
Sphyrna zygaena	Smooth hammerhead	VU	A2bd+3bd+4bd	2005	decreasing
Squalus acanthias	Piked dogfish	VU	A2bd+3bd+4bd	2006	decreasing
Stegostoma fasciatum	Leopard shark	VU	A2abcd+3cd+4abcd	2003	decreasing
Taeniura meyeni	Round ribbontail ray	VU	A2ad+3d+4ad	2006	unknown
Thalassarche chrysostoma	Grey-headed albatross	VU	A4bd	2010	decreasing
Thunnus obesus	Bigeye tuna	VU	A1bd	1996	
Turbinaria mesenterina	Pagoda coral	VU	A4cd	2008	unknown
Urogymnus asperrimus	Porcupine ray	VU	A2bd	2005	unknown

Regional assessments were undertaken for marine mammals with several species that are globally data deficient recognised as threatened in South Africa (Table 27, Endangered Wildlife Trust 2004). Turtles were recently assessed through regional assessments as reported in Table 27. For seabirds, national assessments have not been undertaken or are not considered appropriate for the wide ranging species. Global assessments are considered appropriate for non-endemic or non-near-endemic seabirds that have large distributions and therefore Table 26 is the best reference for these seabirds. Several seabirds are threatened by prey availability, incidental mortality, pollution and invasive species (Crawford 1999, Pichegru *et al.* 2007, Wanless *et al.* 2007, Crawford *et al.* 2008, Gremillet *et al.* 2008, Wanless *et al.* 2009). There is concern about the Damara tern *Sterna baleanarum*, which has not been recently assessed in the region but expert opinion suggests has a worse threat status in South Africa than the global assessment (Near threatened) indicates. This species has a very small fragmented distribution in South Africa and a decreasing population (Simmons 2005). Some linefish have recently been assessed in South Africa and through global initiatives revealing that several iconic and important linefish are threatened. This should be communicated to the public, including recreational fishers, who target some of these species.

Very few South African marine invertebrates have been assessed. Currently the most threatened invertebrate is the pulmonate limpet *Siphonaria compressa*. This limpet is endemic to only two known localities and is threatened by its extremely narrow habitat range (Angel *et al.* 2006). Loss of seagrass habitat in Langebaan lagoon further threatens this species (Pillay *et al.* 2010). Abalone, *Haliotis midae* was recognised as a threatened species in the 2005 NSBA (Lombard *et al.* 2004) and remains a key species of concern although this species has not been assessed using IUCN criteria.

Table 27: Marine species that are threatened in South Africa as identified through national assessments or global assessments for endemic species. Species endemic to southern Africa (South Africa and Mozambique or Namibia) are indicated with an asterisk.

Species	Common name	South African Status	IUCN Global Status
**Argyrosomous japonicus*	Dusky kob	Vulnerable (2011)	Under assessment
Balaenoptera edeni	Bryde's whale	Vulnerable (2004)	Data Deficient (2008)
Balaenoptera musculus ssp. intermedia	Antarctic Blue Whale	Endangered (2004)	Endangered (2008)
Caretta caretta	Loggerhead Turtle	Vulnerable (in press)	Endangered (1996)
**Chrysoblephus cristiceps*	Dageraad	Endangered (2010)	In review
**Chrysoblephus gibbiceps*	Red stumpnose	Vulnerable (2010)	In review
**Cymatoceps nasutus*	Black musselcracker	Endangered (2010)	In review
Dermochelys coriacea	Leatherback Turtle	Endangered	Critically Endangered (2000)
**Electrolux addisoni*	Ornate sleeper ray	Critically Endangered (2008)	Critically Endangered (2008)
**Hippocampus capensis*	Knysna seahorse	Endangered (2000)	Endangered (2000)
**Holohalaelurus favus*	Honeycomb izak, Natal izak	Endangered (2008)	Endangered (2008)
**Holohalaelurus punctatus*	Whitespotted izak, African spotted catshark	Endangered (2008)	Endangered (2008)
**Lithognathus lithognathus*	White steenbras	Endangered (2011)	In review
**Liza luciae*	Saint Lucia mullet	Endangered (1996)	Endangered (1996)
Mirounga leonina	Southern elephant seal	Endangered (2004)	Least Concern (2008)
**Petrus rupestris*	Red steenbras	Endangered (2010)	In review
**Phalacrocorax neglectus*	Bank cormorant	Endangered (2010)	Endangered (2010)
**Polysteganus undolosus*	Seventy four	Critically Endangered	In review
**Siphonaria compressa*	Compressed false limpet	Critically Endangered (1996)	Critically Endangered (1996)
Sousa chinensis	Indo-pacific humpbacked dolphin	Vulnerable (2004)	Near Threatened (2008)
**Tomichia tristis*	Mollusc	Critically Endangered (2007)	Critically Endangered (2007)
Tursiops aduncus	Indian ocean bottlenose dolphin (migratory subpopulation)	Endangered (2004)	Data Deficient (2008)
Tursiops aduncus	Indian ocean bottlenose dolphin	Vulnerable (2004)	Data Deficient (2008)

Much more work is needed to support South African assessments and it is recommended that a strategy is developed and implemented to prioritise and catalyse conservation assessments where appropriate. Resources will need to be secured to implement a marine species assessment strategy. Red Listing Assessments should be undertaken only when the resulting products will be of sufficient benefit to conservation to justify the resources used and when it has been determined that a species-based approach is appropriate (Foden 2005). In 2008, SANBI held a workshop attended by 26 experts from 11 institutes to review existing initiatives and criteria for listing threatened marine taxa, to agree on the approach for assessing threat status of marine species in South Africa and to identify gaps, opportunities and potential priority taxa (SANBI, 2008).

Linefish were identified as a priority group as there are several taxa under threat (due to overexploitation and inherent vulnerability) and many endemic species. The lack of internationally recognised conservation status for several key species protected in existing MPAs was considered an obstacle when decisions were being made about the re-introduction of fishing in no-take zones. No other priority groups were identified although key characteristics for further prioritization of marine taxa were identified. These are:

- Harvested taxa – As direct exploitation is the primary driver of marine biodiversity loss, harvested taxa should be a key focus for assessment. In addition, monitoring data (or catch data series) exist for many species and there is adequate taxonomic knowledge for most harvested species. Many assessments of harvested taxa assessments could benefit from improved distribution data. The need for a National Fish Atlas was first identified in the 2005 National Spatial Biodiversity Assessment (Lombard *et al.* 2004) and remains a priority.
- Endemic and highly range-restricted taxa – South Africa should take responsibility for assessing endemic taxa. These national assessments would also constitute global assessments. Before this can be achieved, lists need to be produced, first for marine fishes, algae and then for priority invertebrate groups. A key step is to identify range restricted species. It is estimated that approximately 20% of known marine invertebrates in South Africa are known only from the type locality (Charles Griffiths, pers. comm.). Lists of these taxa need to be produced and investigated to identify priority groups for further taxonomic and other research and possibly conservation assessment. Atlassing projects could be considered for selected groups with many such species.
- Near-endemic taxa - Focus on taxa for which the majority of the distribution range is within South Africa or the southern African Region.

- Species that may be threatened by alien species or by farming of indigenous taxa in open systems (in-situ mariculture) should also be considered for assessments. Further work is needed to identify such taxa.
- Where research identifies species sensitive to any pressure on marine biodiversity those species should be considered for conservation assessment using the IUCN criteria.

Consensus was reached at the workshop to use the IUCN Red Listing criteria for assessing marine taxa although there was a great deal of discussion about the focus on extinction risk when marine taxa are generally considered at lower risk of extinction than terrestrial taxa. There was a clear recognition that in many cases, economic extinction (for fished taxa) or loss of role in the ecosystem could be concerning before taxa are at risk of extinction. Nevertheless, it was agreed that there were many benefits from using an internationally agreed approach for species assessment and trial Red Listing for several invertebrate and fish taxa yielded assessments that were considered realistic. Dulvy *et al.* (2005) effectively applied the IUCN criteria to 76 fished stocks and found that extinction risk outcomes were consistent with population viability analyses when applied to exploited marine fish and invertebrates. In no cases were sustainably managed stocks categorized as threatened. The results suggested that scientists with different backgrounds and objectives should usually be able to agree on species requiring the most urgent management action.

National conservation assessments are needed as a first step in listing species under the Threatened and Protected Species (TOPS) as per current revision of these lists. It is important to note that the purpose of the TOPS regulations is to control restricted activities defined by NEMBA and therefore supports permitting rather than reporting on actual conservation status of species. A national list of threatened marine species is a priority and this is distinct from the TOPS list. Threatened species whose conservation status could be improved by additional regulation through listing on the TOPS list should be considered for inclusion. At present, most threatened marine species are considered to be regulated through other legislation, particularly the Marine Living Resources Act and the Seals and Seabirds Protection Act.

Species that are threatened by trade are listed by the CITES convention. The current CITES database cites a total of 243 species that occur in South Africa, 23 on appendix 1 and 221 on Appendix 2.

11 Alien and invasive alien species

On a global scale the rate of human-mediated introductions of marine species is increasing (Mack *et al.* 2000). In developed countries, non-indigenous species have long been the focus of dedicated research and monitoring programmes and the serious threat posed to marine biodiversity by invasive species is well recognised (Olenin *et al.* 2007). In contrast, research focused on marine bioinvasions has only come to the fore in South Africa in the last decade (Griffiths *et al.* 2009a). While 2009 saw only 22 known alien species recorded from the region (Griffiths *et al.* 2009b), recent work has extended this list to include 84 known introduced species and 34 cryptogenic species (Sink *et al.* 2010, Mead *et al.* 2011a,b). Eight of the alien species are considered invasive, supporting large populations that have or are spreading and negatively impacting indigenous species (Table 28). While the discovery rate of marine introductions along the South African coast is increasing through time (Mead *et al.* 2011a,b), the recent dramatic increase in numbers resulted mainly from detailed review of historic literature, although field surveys of previously unconsidered and under-sampled environments and taxonomic resolution of a number of species also elevated the number of recognised introductions.

Table 28: Marine alien invasive species recorded in South Africa.

Species	Common Name	Year of first record	Reference
Balanus glandula	Pacific barnacle	1992	Laird and Griffiths 2008, Mead *et al.* 2011a,b
Carcinus maenas	European green crab	1983	Robinson *et al.* 2005, Hampton and Griffiths 2007
Ciona intestinalis	Sea vase ascidian	1955	Monniot *et al.* 2001, Robinson *et al.* 2005, Mead *et al.* 2011a,b
Crassostrea gigas	Pacific oyster	2001	Robinson *et al.* 2005, Mead *et al.* 2011a,b
Metridium senile	Feather-duster anemone	1995	Robinson *et al.* 2005, Sink *et al.* 2010
Mytilus galloprovincialis	Mediterranean mussel	1979	Robinson *et al.* 2005, Sink *et al.* 2010
Sagartia ornata	Brooding anemone	2002	Robinson *et al.* 2005, Sink *et al.* 2010
Semimytilus algosus	Bisexual mussel	2010	Mead et al. 2011

The diversity of alien marine species known from South Africa is notable, with species recorded from four kingdoms and 14 phyla. Cnidarians, polychaetes, crustaceans, molluscs, and ascidians account for 77% of all alien species, with two anemones, two crustaceans, three molluscs and one ascidian being invasive. The low number or absence of inconspicuous species such as protists, dinoflagellates, nematodes and bacteria as alien species is unlikely to be real, and future research is expected to recognise significant numbers of these species as alien.

Spatially, a clear pattern exists with most invasive alien marine species occurring on the west coast (Figure 57). Additionally, harbours around South Africa form hotspots, with few invasive species able to withstand the wave exposed nature of the open coast (Robinson *et al.* 2005, Hampton and Griffiths 2007, Branch *et al.* 2010). It is important to note that the high invasion rate observed on the west coast may reflect uneven sampling effort and taxonomic expertise around the coast. When considering the origin of alien species a significant spatial pattern is also evident. Temperate species originating from the northern hemisphere predominate on the west and south coasts, while species from the southern hemisphere occur largely on the east coast (Mead *et al.* 2011a, b).

The most important pathways of South African marine introductions are related to shipping, with hull fouling and ballast water contributing to 50% and 37% of introductions respectively. The next most important pathways of modern introductions are mariculture and then petroleum infrastructure, while historically ship boring and solid ballast (both associated with wooden ships) were more prevalent pathways.

The spread of alien species is altering the composition of marine communities on a global scale, with ecological and evolutionary consequences acting at the level of individuals through to habitats (Mack *et al.* 2000, Grosholz 2002). As such, alien introductions have been identified as a major threat to biodiversity (Occhipinti-Ambrogi & Savini 2003, Molnar *et al.* 2008) and have been identified as the second most important cause of loss of biodiversity after habitat destruction (Wilcove *et al.* 1998). Invasive alien species have been shown to displace native species and alter community structure, foodwebs, ecological processes and ecosystem functioning, compromise biodiversity services and result in serious environmental, economic and health impacts (Molnar *et al.* 2008).

Invasive alien species can also have impacts on commercial fisheries, including mariculture and other natural-resource-based industries, with serious economic implications for the communities dependent on them. In addition, fouling of infrastructure by alien species can have major impacts on shipping and other coastal industries by, for example, decreasing the speed of vessels, clogging water intake pipes and driving up management costs (GISP 2008). On a global scale it has been estimated that the control of fouling of water intakes, piping systems and heat exchangers of just desalinization and power plants costs $ 15 billion per year (GISP 2008).

Despite 84 alien species having been recorded in the marine environment, only eight of these have become invasive (Table 28). The most ecologically important of these species is the Mediterranean mussel *Mytilus galloprovincialis*. This aggressive invader is currently the most dominant invertebrate on west and south coast rocky shores, and occupies over 2000 km of coastline (Robinson *et al.* 2005). The ecological impacts of this mussel include partial displacement of indigenous mussels along the west coast (Hockey & van Erkom Schurink 1992), competitive interactions with local limpets (Steffani and Branch 2005) and the induction of significant changes in rocky shore communities (Robinson *et al.* 2007).

The mussel *Semimytilus algosus* is the other invasive mollusc. Although abundant on central and northern Namibian shores for at least two decades (Van Erkom Schurink and Griffiths 1990), this mussel was recorded in South Africa for the first time in 2010 (Mead *et al.* 2011a, b). This mussel currently supports extensive populations at Elandsbaai along the west coast, and research on its impacts is underway (Charlie Griffiths, pers. com.). After being cultured for 30 years, wild populations of the oyster *Crassostrea gigas* were first reported along the South African coast in 2005 (Robinson *et al.* 2005). This species remains restricted to the Breed, Goukou and Knysna estuaries and is absent from the open coast. This pattern of spreading from aquaculture facilities is common for this oyster, and is reflected in the fact that *C. gigas* has established naturalised populations along all major coastlines in the northern hemisphere.

The European shore-crab *Carcinus maenas* was first detected in Table Bay Harbour and is thought to have arrived via fouling of international oil exploration vessels (Le Roux *et al.* 1990). This invasive crab supports extensive populations in Table Bay and Hout Bay Harbour (Robinson *et al.* 2005) while small intertidal populations are known between these points and at Bloubergstrand. It is thought that the spread of this species has been restricted by the wave exposed nature of the coast (Hampton and Griffiths 2007) but it could easily be unintentionally translocated to other harbours by rock lobster fishing boats. Of special concern is the Saldanha Bay system on the west coast. An invasion of this area could be disastrous for local biota of the West Coast National Park which has been predicted to be highly vulnerable to predation by *C. maenas* (Le Roux *et al.* 1990). Additionally, this area is the focus of the shellfish mariculture industry in South Africa and an invasion by this crab species could have significant economic implications for both mussel and oyster operations. The previous National Spatial Biodiversity Assessment reported that this species can and should be eradicated (Lombard *et al.* 2004). Despite raised awareness about the risks of this invasion, no action has been taken.

The barnacle *Balanus glandula* was first documented in 2007 (Simon-Blecher *et al.* 2008), although it has since been identified in photographs from as early as 1992 (Laird and Griffiths 2008). This barnacle has a range of approximately 400 km, occurring between Elands Bay and Misty Cliffs (Scarborough, Cape Point) on the west coast. Early research indicates that this species is a dominant space occupier which may displace indigenous barnacles. However, it appears to benefit the small gastropod *Afrolittorina knysnaensis* that occurs at higher densities and lower down the shore at invaded sites, by providing it with shelter (Laird and Griffiths 2008).

The ascidian *Ciona intestinalis* occurs in harbours along the entire coast where it is an important fouling organism (Monniot *et al.* 2001). Despite this species having significant negative economic impacts on the mussel industry by smothering target mussels (Robinson *et al.* 2005) and its recognised dominance of hard substrata communities in harbours, the ecological impacts of this invader remain unquantified.

When the anemones *Metridium senile* and *Sagartia ornata* were first recorded in Table Bay Harbour and Langebaan Lagoon respectively (Robinson *et al.* 2005), they appeared to be restricted to small areas and were thought to pose limited threat to indigenous populations. However, in 2009 both these species were recorded at exceptionally high densities on petroleum infrastructure on the Agulhas Bank and are now recognised as invasive (Sink *et al.* 2010). While it remains unclear if these species have spread extensively into natural habitat offshore, they have invaded large areas of petroleum infrastructure. As such a dedicated survey of these species is required in order to gain a full understanding of their current range and potential impacts. Risk assessments should be undertaken to ascertain the risk of further invasion in adjacent habitats. The black sea urchin *Tetrapygus niger* (a potential invasive species with serious ecological consequences where it has invaded elsewhere) has been reported in mariculture facilities and should be eradicated.

Recently, molecular tools have been successfully employed to better understand the colonisation and invasion dynamics of non-indigenous marine species (Geller *et al.* 2010). By using a comparative population genetic approach, the structure of native populations can be determined, from which it is possible to ascertain the origin of alien populations (Reusch *et al.* 2010). Notably, comparisons of genetic diversity in native versus alien populations usually differ significantly, with alien populations having reduced genetic diversity (Rius *et al.* 2008, Lejeusne *et al.* 2011). This is because only a small sub-sample of the native population usually becomes established, which carries only a proportion of the total genetic diversity of a species; this is known as a 'founder effect'. However, examples exist where invasive populations are genetically as diverse as or even more diverse than their source populations, which confirms broad-scale and persistent transportation (Gillis *et al.* 2009; Chang *et al.* 2011). Established invasive populations can also become secondary sources of introduction to other non-native areas, especially with human-mitigated transport, which can be reliably confirmed with several DNA markers (Blakeslee *et al.* 2010).

In South Africa there have only been a few studies focussed on understanding genetic aspects of invasive alien marine species, but these show a great diversity of geographical locations from which marine invaders arrive. The majority have focused on the Mediterranean mussel, *Mytilus galloprovincialis* for which little population genetic structure has been observed in animals sampled, which is an expected pattern for recently alien populations and confirms a recent arrival in the region (Zardi *et al.* 2007).

For *Carcinus maenas* it is likely that some crabs have their native population in the Netherlands, whereas the origin of some of the genetic lineages found by Darling *et al.* (2008) remains unknown. Interestingly, some of the green crabs sampled in South Africa appear to be a mixture of *C. maenas* and *C. aestuarii* (Darling *et al.* 2008). The barnacle *Balanus glandula*, a fierce intertidal competitor, probably originated from the north-western Pacific shores of Oregon (Simon-Blecher *et al.* 2008). For the introduced ascidian, *Microcosmus squamiger,* it is likely that Australia (Rius *et al.* 2008) and specifically south-western Australia (Rius *et al.*, in review) is a probable source for this species in South Africa. A study by Rius *et al.* (in review) examined the regional population structure of four alien ascidian species, *Microcosmus squamiger, Ciona intestinalis, Styela plicata* and *Clavelina lepadiformis* along the South African coastline. They recovered shallow genetic structure between populations with a number of genetic lineages found in two or more biogeographic regions. However, analyses showed different pathways of introductions; all species except *C. lepadiformis* were originally introduced to the north-east coast around Durban and then spread to other localities. *Clavelina lepadiformis* most probably had an introduction on the south-west coast. This study also showed that some lineages are more widespread than others, which could potentially indicate differences in the physiological adaptability of ascidians. Importantly, because all four species can be found from the west to the north-east coasts, it is likely that they are able to colonise other regions globally, with South Africa acting as a stepping stone in new colonisations.

While the rate of discovery of alien species from South African waters is increasing through time (Mead *et al.* 2011a, b), the number of species recognised from the region (i.e. 84 species) is still much lower than other parts of the world (e.g. 99, 150 and 180 species are known from San Francisco Bay (USA), Chesapeake Bay (USA), and Port Phillip Bay (Australia) respectively (Cohen and Carlton 1998, Ruiz *et al.* 1999, Hewitt *et al.* 2004). A wide variety of factors including uneven sampling coverage around the coast and among habitat types (especially offshore habitat types), a scarcity of taxonomic expertise and limited financial and logistic support for marine invasion biology research are likely to be obscuring the true pervasiveness of invasions in South Africa. Surveys are required along the south and east coasts and dedicated surveys of mariculture operations are urgently needed. More research attention needs to be focussed on understanding the historical and contemporary processes shaping marine invasive alien populations in the region, to better understand not only their local, but also global invasion potential. Molecular tools are well placed to examine such processes and resulting patterns, and can help bridge the gap in understanding colonisation pathways that has until recently been lacking.

A study of genetic sequences from local and foreign populations of the harmful algal bloom (HAB) species *Aureococcus anophagefferens* (brown tide) was coupled with a review of historical shipping records to demonstrate the species was recently introduced to South African waters from the coastal waters of eastern North America through ships' ballast water (Botes and Awad 2004). Dinoflagellates and other HAB forming phytoplankton species are easily transported through ships ballast water and recreational vessels (Hallegraeff and Bolch 1992, Doblin *et al.* 2004, Drake *et al.* 2005). Due to wide-spread distributions and lack of historical data, these species are often considered cosmopolitan or cryptogenic, and not necessarily categorized as alien or invasive. The consequences of an algal blooming event can be severe, and include impacts to human health, fisheries resources and the mariculture industry (Sellner *et al.* 2003, Anderson *et al.* 2000). New records of such species in South African waters (Awad *et al.* 2003, Botes 2003), where historical records are insufficient for conclusive status determinations, have highlighted the need for increased attention and research in this area. Compliance with international legislation and associated developing management measures should focus on preventing both the importation and exportation of HABs (IMO 2004), which implies a need for increased monitoring associated with port areas.

The prevention of future marine invasions is an important focus area that was highlighted in the previous National Spatial Biodiversity Assessment (Lombard *et al.* 2004), but has still received little attention in South Africa. As shipping is the major introduction pathway, strengthening of legislation and enforcement to prevent the release of ballast water in all South African ports and to control the cleaning of ships hulls in harbours is needed. Presently, mid-oceanic ballast exchange prior to port entry is enforced at some ports (e.g. Saldanha Bay) but not all. In addition, cleaning of hulls sometimes happens when ships are anchored near shore and debris is simply allowed to fall to the sea bottom (e.g. Table Bay) (Charlie Griffiths, pers. comm.).

Improved import and operational permits for mariculture operations are needed to prevent future invasions. The Code of Practice of the International Council for the Exploration of the Sea (ICES) is commonly applied internationally to prevent introductions associated with mariculture. Basic principles which are incorporated within the code include the periodic inspection (including microscopic examination) of material prior to importation and the disinfection and quarantine of imported organisms in the receiving country (ICES 2005). While South Africa is not a member of ICES it is affiliated to the organization. Nonetheless, the Code of Practice has not been rigorously applied in this country, and a recent study found four aliens species introduced to just one oyster farm (Haupt *et al.* 2010). Also of concern, is the fact that inter-regional translocation of imported mariculture species within South Africa is not controlled. As such, invasive alien species introduced by mariculture operations (target species and associated biota) are often subsequently moved to multiple locations along the South African coast (Haupt 2009).

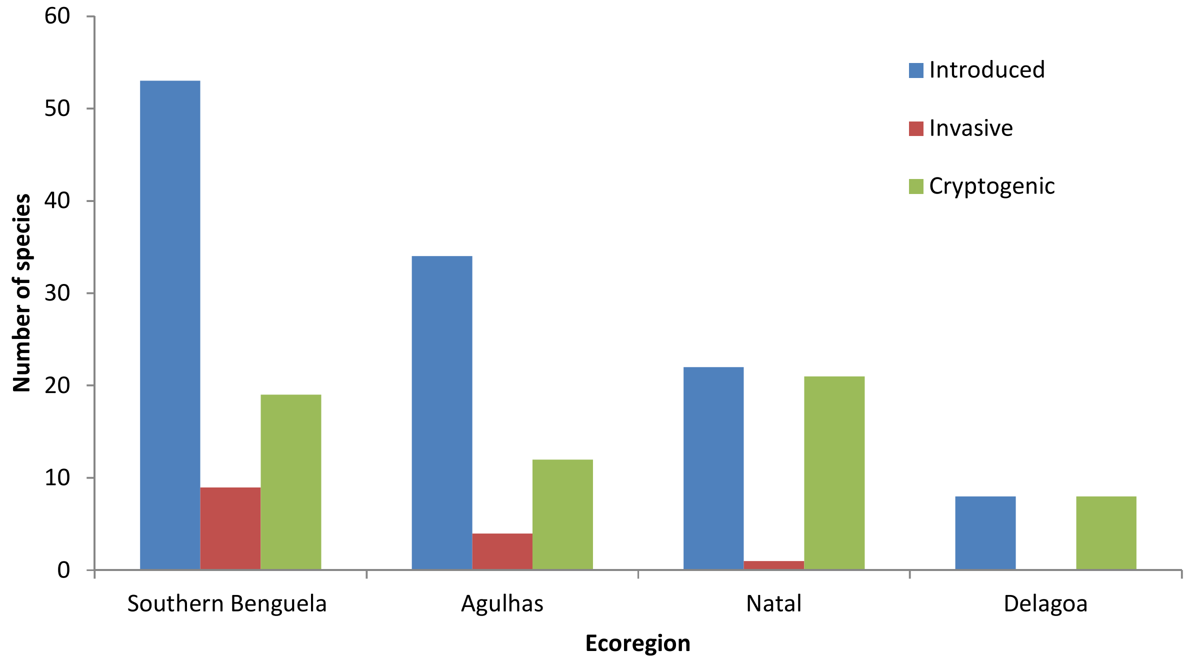


Figure 57: The number of alien, invasive and cryptogenic marine species occurring in the various ecoregions of South Africa. Data extracted from Sink et al. 2010 and Mead et al. 2011a, b.

South Africa's Biodiversity Act provides for the listing and regulation of invasive alien species in order to support the prevention and management of these species. A draft national list of invasive alien species was published for comment in 2009 and includes only four marine species: the Pacific seastar *Asterias amurensis*, the Asian mitten crab *Eriocheir sinensis*, the Asian kelp *Undaria pinnatifida* and the museum weed *Caulerpa taxifolia*. None of these species has yet been recorded in the South African marine environment to our knowledge but they are invasive elsewhere and have had significant biodiversity and economic impacts in other countries (Lowe *et al.* 2000, Casas *et al.* 2004, Anderson 2005). Research effort and the participation of appropriate researchers are needed to support revision of the national list of invasive species to ensure all appropriate species are included.

In addition to prevention measures, there is a dire need for the establishment of a dedicated monitoring program to enable the early detection of alien marine species. While control or eradication of invasive alien species is very challenging, especially in the marine environment, successful eradications have taken place (Culver and Kuris 2000, Miller *et al.* 2004, Hewitt *et al.* 2005). These have relied on early detection (often through routine monitoring programmes) and a quick response by authorities. Essential to the long-term success of these projects have been six underlying principles: (1) eradication efforts should take place while the invasion is spatially contained (normally reliant on early detection); (2) sufficient resources (economic, logistical support & skills) should be available; (3) clear lines of authority / responsibility should be in place; (4) the target organism should be susceptible to control; (5) reintroduction should be prevented; (6) follow-up monitoring should be able to detect the alien species at relatively low densities (Myers *et al.* 2000, Miller *et al.* 2004, Wotton *et al.* 2004). Internationally, this proactive approach to the management of invasive alien species is well developed and widely applied (Anderson 2005, Ashton *et al.* 2006, Coutts and Forrest 2007, Forrest *et al.* 2009) and should be applied to safeguard South Africa's rich marine biodiversity.

12 Climate variability and change

Climate variability and change has complex cascading effects in the marine environment and South Africa's diverse and dynamic oceanographic environment is particularly complex. Broad-scale variability is driven by the three major current systems that dominate this region, the cold Benguela Current on the west coast, the warm Agulhas Current on the east coast and the West Wind Drift, the circumpolar flow that circulates in the Southern Ocean. The different climatic drivers of these systems, together with variability in local oceanographic conditions, coastal topography and habitat types are expected to result in variable climate change effects around the coast (Rouault *et al.* 2010, DEA 2011). Changes in wind fields and pressure systems affect upwelling and current systems which can lead to changes in productivity and rainfall patterns. Currents influence South Africa's coastal climate and even global climate through large-scale ocean circulation patterns. Anthropogenic change, in concert with climate variability and change, results in complex responses that pose additional challenges to scientists and managers. Existing South African research, together with international work, enables discussion of some general effects and potential impacts of climate change on South African marine biodiversity.

Changes in sea temperature and species distributions

While the overall warming trend in the oceans and atmosphere are clear on a global scale, unambiguous localised effects are not evident. There are several inshore areas in South Africa on the south and west coasts where sea surface temperature (SST) is actually decreasing, Mixed warming and cooling effects appear to be occurring, with some areas warming offshore and cooling inshore (Rouault *et al.* 2010). SST has declined in the southern Benguela and along the south coast, mainly due to changes in wind patterns and resultant intensification of upwelling (Rouault *et al.* 2009, Rouault *et al.* 2010). There is also pronounced seasonal, inter-annual, decadal and multi-decadal variability superimposed on the very small overall trend and these signals are difficult to disentangle with only a few decades of data available, a situation typical for much of the southern hemisphere. There are, however, considerable risks of significant biophysical changes to marine ecosystems, leading to important ecological shifts. It is not only the absolute trends that are important, but also the level of variability in the system. Although climate change can negatively affect ecosystems and the services they provide, some changes may be positive in some areas. For example, increased upwelling and productivity could benefit fisheries.

Changes in species distributions

Shifts in the ranges of intertidal species driven by changes in sea temperature have been recorded internationally (Helmuth *et al.* 2002, Mieszkowska *et al.* 2006) and in South Africa (Griffiths *et al.* 2010). Declining sea temperatures linked to changes in wind patterns and increased upwelling (Rouault *et al.* 2009, Rouault *et al.* 2010) has resulted in shifts in the proportions of cold-water and warm-water species within rocky shore communities in False Bay (Mead 2011). Changing sea temperatures in the southern Benguela ecosystem have also been linked to the eastward movement of the West Coast rock lobster along the south coast and shifting distributions of pelagic fish (Roy *et al.* 2007, Cockcroft *et al.* 2008, Coetzee *et al.* 2008). However, these changes reflect the period 1982-2005 when south east winds showed a general increase, which appears to have reversed recently, and may be part of longer-scale cycles (Agenbach 2011).

Two significant changes in the distribution and resource availability of West Coast rock lobster have been observed (Cockcroft *et al.* 2008, Hutchings *et al.* 2009). Changing catches on the west coast reflect declining rock lobster numbers in the north from 1988 to 1996 and a sudden short movement to the east of Cape Hangklip in the early 1990s. On the west coast, the shifting resource has coincided with reduced somatic growth and increased lobster walkouts, suggesting that environmental changes may play a key role in driving distributional change (Cockcroft *et al.* 2008). Dissolved oxygen changes in the near-shore zone on the west coast in St Helena Bay may also affect rock lobster distribution and productivity and appears to follow multi-decadal variability. An increase in oxygen content in the mid-1970s was followed by a prolonged decrease from 1978 to 2005. The latter is commensurate with a slight increase in the southerly winds that enhance upwelling and primary production, leading to greater organic loading in sub-thermocline waters in St Helena Bay (Larry Hutchings, Oceans and Coasts, Department of Environmental Affairs unpublished data), that may have contributed to the decreased lobster catches on the northern section of the west coast. Heavy fishing pressure on the slow-growing rock lobster may also have contributed to the observed changes in distribution from the west coast to the Cape Point grounds (Hutchings *et al.* 2009). The increase in abundance of lobsters east of Cape Hangklip may be related to an onshore movement of lobsters from deeper water (Cockcroft *et al.* 2008, Cockcroft 2011). Heavy fishing pressure is not considered to have contributed to the movement of lobster into the area east of Cape Hangklip.

The changing distribution of rock lobsters has had serious ecological, fisheries and resource management implications. Ecological impacts include reduced densities of urchins and winkles *Turbo cidaris* and increased algal cover (Tarr *et al.* 1992, Mayfield and Branch 2000). Reduced urchin densities are believed to have impacted on abalone recruitment as juvenile abalone shelter under urchins (Mayfield and Branch 2000, Blamey 2010, Bamey and Branch 2011). Reduced numbers of breeding bank cormorants which have a high proportion of lobster in their diet is a key conservation concern for this endangered species (Crawford *et al.* 2008). Social and economic impacts include reduced numbers of long term rights on the west coast and job losses at processing facilities (Cockcroft 2011). Further challenges in the management of both lobster and abalone are anticipated in the future.

Abrupt shifts in anchovy distribution are reported to be linked to improved feeding conditions for this species east of Cape Agulhas linked to cooling through increased upwelling and improved productivity (Roy *et al.* 2007). The distribution of sardines has shifted more gradually, with changes in adult sardine distributions accompanied by changes in location of their principal spawning grounds (Van der Lingen *et al.* 2005 in Hutchings 2009). This more gradual shift in sardine distribution may be linked to environmental change and the effect of intense fishing (Coetzee *et al.* 2008). These shifting distributions have led to a spatial mismatch between fishing infrastructure (such as canneries) and effort, with serious socio-economic implications (Roy *et al.* 2007). In addition, this shifting distribution affects ecosystems, with reported negative effects on predators such as gannets and penguins (Pichegru *et al.* 2007, Crawford *et al.* 2008, Gremillet *et al.* 2008). An improved understanding of the response of small pelagic fish to environmental variation is a research priority.

In contrast to the west coast, SST has risen along the east coast (Rouault *et al.* 2009, Rouault *et al.* 2010) and is expected to result in the southward expansion of the ranges of tropical intertidal species, as has been recorded for some fish species (DEA 2011). A slightly increased flow of the Agulhas Current (Rouault *et al.* 2009) may aid in the transport of juvenile stages southwards on the east coast, but when the organisms reach the shoreline, cooler waters may limit successful colonisation. In particular, the divergence of the Agulhas Current from the coast in the Port Alfred-Port Elizabeth region is topographically fixed and may represent a barrier to further coastward expansion of either cool or warm water biota.

Coral bleaching

The rise in sea temperatures on the east coast has had impacts on coral encrusted reefs in the Delagoa ecoregion. Insignificant coral bleaching was recorded in South Africa in 1998 (Schleyer *et al.* 2008) during the largest mass coral bleaching and mortality event that affected much of the western Indian Ocean (Goreau *et al.* 2000). Quantifiable coral bleaching was recorded during an extended period of warming in 2000 (Schleyer *et al.* 2008). Recent publications report higher bleaching levels in South African coral communities in 2005 (McClanahan *et al.* 2007a, b, Ruiz Sebastián *et al.* 2009) during the warm-water anomaly in the southern Indian Ocean. South African coral communities experienced less bleaching than those in southern Mozambique, but the emerging trend is one of increasing frequency and intensity of bleaching or episodic bleaching. Elevated temperatures are also reported to have negatively affected coral recruitment and community structure at the single long term monitoring site in the Maputaland Marine Protected Area, with a decline in soft corals and an increasing dominance of hard corals (Schleyer *et al.* 2008, DEA 2011). South African corals host algal symbionts that are predominantly putatively thermal sensitive, which may reflect limited bleaching experience (Ruiz Sebastián *et al.* 2009). This highlights the vulnerability of our coral communities to moderate levels of thermal stress. The long-term response of South African coral communities to global change is difficult to predict because of their complex response and our limited understanding. Localised upwelling in South Africa may play a dual role in affecting coral bleaching. The cooler water may provide a refuge from coral bleaching, but when water temperatures rise rapidly after an upwelling event this may result in higher levels of bleaching (Ruiz Sebastian *et al.* 2009).

Ocean Acidification

The sea plays an important role in the global carbon cycle through the absorption of carbon dioxide. Increased emissions have increased the acidity of the oceans leading to impacts on calcareous organisms and the species that rely on them for food (Caldeira and Wickett 2003, Orr *et al.* 2005, World Meteorological Organization 2010). Coral reef and polar ecosystems are likely to experience the greatest impacts related to ocean acidification. Ocean acidification reduces the ability of coral reefs to grow and maintain their structure and function. In the Benguela ecosystem, calcareous phytoplankton is a small component of the plankton community but in the Southern Ocean, impacts on key components of the pelagic foodweb are anticipated (Bernard 2011). Pteropods, shell-forming snails that live in the open ocean, are considered keystone species in the pelagic ecosystems of the Southern Ocean and will be vulnerable to acidification as their shells dissolve under conditions of reduced pH. Similarly, corals in the shallow waters of the Delagoa ecoregion and cold water corals from deep water in all ecoregions could be at risk (Feely *et al.* 2004, Orr *et al.* 2005, Kleypas *et al.* 2006). South Africa should initiate research in this field. Some of the current observed changes in coral communities at Sodwana Bay (such as die off of *Acropora* staghorn coral beds) could be related to ocean acidification.

Sea level rise

Following global trends, sea level has been shown to be rising by approximately 1.5-2.7 mm per year along the South African coast (Mather *et al.* 2009). This is not expected to significantly impact most coastal species as they are anticipated to move higher up the shore. Exceptions may occur on sandy beaches which are constrained by hard infrastructure like seawalls, and on rocky shores on the east coast where many take the form of flattened rock platforms in the lower shore that are bounded by sandy beach above. In such instances rising sea levels will result in greater periods of inundation and the loss of habitat for high-shore species (Harris 2008, Griffiths *et al.* 2010). Great uncertainty exists about the predictions of future sea level changes, dependent on the melting of the Greenland and Polar Ice caps. Further information about the role of coastal development in concert with sea level rise is provided in Section 3.1.6 (Coastal development).

Increased frequency of storm related wave action

Storms are well recognised as important physical forces in shaping beaches, as they erode large quantities of sand from the upper shore, suspending it in the surf zone. Under calm conditions this sand is then reworked back onto the beach. An increase in storm frequency and intensity due to climate change has been predicted for the South African coast (Theron and Rossouw 2008). Such an increase is expected to negatively alter sandy beaches as erosion will increase and insufficient time between storms will prevent re-deposition of sand. This process, coupled with sea level rise could erode large quantities of sand from beaches, and is expected to deplete sandy beach fauna. In addition, the suspension of large amounts of sediment in near-shore waters may negatively affect rocky shore, coral reef, temperate reef and kelp bed communities due to abrasion and reduced light penetration (Schleyer and Celliers 2003, DEA 2011).

Current climate change priorities are reported by Pauw (2011) including the need for an improved understanding of impacts, improved predictive capacity through long-term environmental observation and research , improved communication about climate change and strengthened policies and institutes, including all sectors of society, to support adaptation and mitigation. More specific research priorities are reported by DEA (2010).

The trends and variability associated with climate change are difficult to predict, particularly at a local level, and are likely to lead to additional complexity, uncertainty and variability for decision-makers and marine and coastal managers. At a strategic level, management should be aimed at optimising the inherent ecological buffering capacity of ecosystems against uncertainty and change. Adaptation strategies should centre on sound integrated ecosystem-based management approaches including Integrated Coastal Management and the Ecosystem Approach to Fisheries Management (to complement the current single species approach). A representative Marine Protected Area (MPA) network is a key element in South Africa's climate change response strategy. The maintenance of genetic variability to secure genetic potential to adapt to change can be supported by sustainable fishing practices and MPAs. Operationally, marine and coastal management should also include tactics such as: improving the speed of adaptive learning cycles, decentralisation and diversification, and enhancing management flexibility to adapt to a changing environment (Jones 2011).

13 The status of marine taxonomy

South Africa currently boasts more than a dozen institutions with a strong focus in marine science and globally South Africa has an average state-of-knowledge index for marine biodiversity (Costello *et al.* 2010). As in many other developing countries, marine taxonomic expertise in South Africa is, however, very limited. Costello *et al.* (2010) reported that of 26 regions included in their Census of Marine Life reports, South Africa had the lowest number of taxonomic experts per taxonomic group. A list of currently active taxonomists and their fields of expertise was published by Griffiths *et al.* (2010). A total of 31 local marine scientists are active in the field of taxonomy in South Africa, but it is important to note that many of these are graduate students undertaking taxonomic studies, university staff with a part-time interest in taxonomy, or are retired academics who are still involved in publishing taxonomic work. Presently only one expert is employed as a full-time taxonomist (Michelle Hamer, pers. comm.). While groups such as Mollusca, Cnidaria, Crustacea, Bryozoa and Porifera currently receive the majority of taxonomic focus, local expertise is completely lacking for a number of important taxa. These include those with small body size and little economic significance, such as Hydrozoa, Nematoda, and most Platyhelminthes. Currently there is one marine taxonomist for approximately every 1700 species known from our waters (Michelle Hamer, pers. comm.) and marine invertebrates have the highest number of species / taxonomist ratio of any South African group of organisms (i.e. they are the most neglected group in terms of capacity) (Figure 58).

In terms of marine animal priorities for taxonomy, several taxa can be prioritised based on the work of Griffiths *et al.* (2010). Taxa with more than 30 species, that score 3 or less in the “state of knowledge” category South Africa include:

- Ascidiacea*
- Appendicularia
- Platyhelminthes (specifically Cestoda, Digenia and Monogenia – i.e. Parasites)
- Nematoda
- Pycnogonida
- Crustacea (Copepoda, Ostracoda, Stomatopoda, Cumacea, Mysida*, Euphasiacea, Thecostraca*)
- Cnidaria (Actinaria*, Scleratina, Octocorallia, Hydrozoa*)
- Echinodermata (Ophiuroidea*)
- Siphonophora
- Porifera*.

Groups marked with an asterisk indicate current research on this group in South Africa.

Despite the limitations of South African taxonomic expertise, a number of major taxonomic reference works and guides to the regional marine biota exist (Griffiths *et al.* 2010) although some of these are now severely outdated. In the global context, South Africa has few identification guides (Costello *et al.* 2010) despite their critical role in supporting research. Costello *et al.* (2010) emphasize the importance of citing these guides in research outputs, a key point for South Africa. There is considerable scope to increase taxonomic output in South Africa if resources can be secured (Griffiths *et al.* 2010). In the last six years only ten papers have been published by South African-based authors describing new marine species (Michelle Hamer, pers. comm.), this despite the fact that it has been estimated that there are over 7500 undescribed marine species from South Africa (Griffiths *et al.* 2010). Costello *et al.* (2010) reported that an estimated 38% of South African marine species are undescribed.

Taxonomic knowledge is particularly limited for deep water taxa and groups. This limits our capacity to understand deep water ecosystems, assess potential impacts and plan for effective protection of deep water ecosystems. This lack of expertise for deep water species is a global phenomenon (Costello *et al.* 2010) and reflects poor sampling effort in deep water. In South Africa, Griffiths *et al.* (2010) report that 83% of all samples are from water shallower than 100 m and only 2% are from water deeper than 1000 m despite the vast extent of habitats in deeper water. The abyssal zone has not been sampled even though it constitutes approximately half of South Africa's EEZ (Griffiths *et al.* 2010). Other key sampling gaps for marine taxonomic work include consolidated or hard ground habitat types from below 30 m depth and the north-east coast and offshore area of South Africa. Genetic approaches and barcoding also have much to offer marine taxonomic efforts (see following section).

South Africa needs to engage more widely in global biodiversity programs such as the Census of Marine Life. Costello *et al.* (2010) reflect on the value of international collaboration in addressing global marine taxonomic challenges. Globally, improved co-ordination between institutions including museums, fisheries institutes, government departments and universities is recommended and formally agreed priorities are needed to focus taxonomic efforts.

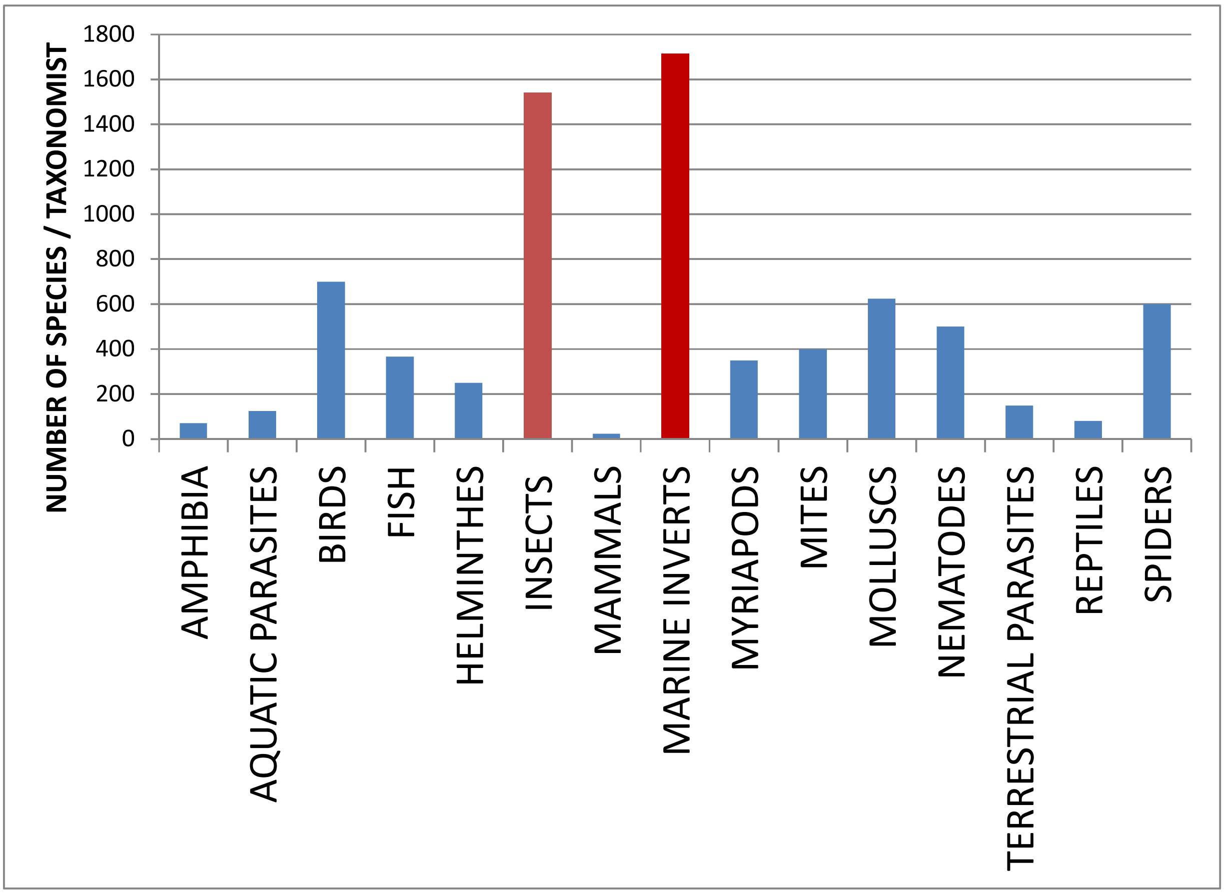


Figure 58: The ratio of species relative to number of taxonomists for different groups of animals in South Africa. This graph shows that marine invertebrates have the lowest number of taxonomists relative to the high diversity of this group (graph by Michelle Hamer, SANBI).

The primary South African marine invertebrate collections are housed at the Iziko South African Museum in Cape Town and comprise some 129 000 records, offering significant coverage of all major marine taxonomic groups in the southern African region. In addition, a number of specialised collections are housed at several smaller museums around the coast, notably the national fish collection at the South African Institute for Aquatic Biodiversity in Grahamstown (56 000 records) and the collection of molluscs at the Natal Museum (63 000 records) (Griffiths *et al.* 2010). Large collections of algae are also held by the Bolus Herbarium at the University of Cape Town (11 000 records) and the Schoenland Herbarium at Rhodes University (32 000 records).

14 The status of genetic knowledge

Understanding the biological and evolutionary processes that affect marine species distributions is crucial for understanding the high and variable biodiversity found along the southern African coastline and to support the effective management and conservation of marine and coastal resources and ecosystems. Current distributional data do not take into account metapopulation structure, cryptic speciation, historical population structures, vicariance effects and potential range expansions, i.e. the processes driving biodiversity. For example, many commercially exploited species are treated as discrete stocks for management purposes, the boundaries between which have been arbitrarily chosen based on geopolitical grounds (von der Heyden *et al.* 2007a), without examining the underlying structure.

Genetic methodologies allow researchers to trace historical change through genes, rather than organisms. As genes direct life and are fundamental in natural selection (on species and their genes), genetic methodologies can be used to provide quantitative data where conventional biological applications fail. Moreover, population genetic data are important for any commercially exploited species because genetic differentiation might represent recent local ecological adaptation necessary for population persistence (Crandall *et al.* 2000). Such local adaptations can decrease the chances of successfully repopulating an area once it has been over-exploited or otherwise impacted, due to non-exchangeability of individuals among populations. The main aim of management agencies should therefore be to maximise genetic variability of the species under consideration, while recognising the importance of local ecological adaptations.

In South Africa, there is mounting evidence for distinct evolutionary lineages within recognised species that are predominantly separated by oceanographic barriers (see below for more detail). Conserving such evolutionary and genetically significant units is highly important in the face of an uncertain climatic future (Fraser and Bernatchez 2001) and evolutionary significant units have been suggested to be the minimal unit of conservation (Ryder 1986). However, the number of species analysed thus far are few and there are a number of research gaps that should be addressed before genetic approaches can be effectively applied to South African marine biodiversity assessment and planning.

14.1 The application of molecular tools in biodiversity and resource management

The application of molecular tools to investigate evolutionary patterns, phylogeography (the distribution of genes across marine systems), as well as in conservation and fisheries management has been a relatively recent field, with the last ten years seeing an increase in published papers and reports dealing with genetics of marine species. In South Africa, it has only been since 2005 that a determined effort has been made to apply genetic tools in the study of marine ecosystems and only since 2007 that genetic data has been highlighted in conservation (von der Heyden *et al.* 2008; von der Heyden 2009) and fisheries management (Matthee *et al.* 2007; von der Heyden *et al.* 2007a; von der Heyden *et al.* 2007b; Teske *et al.* 2010).

Globally, the application of molecular tools to the conservation and management of marine resources and ecosystems is well established and research has focused on a wide range of marine taxa and habitat types, including sandy beaches (Laudien *et al.* 2003, Ketmaier *et al.* 2010), rocky shores (von der Heyden *et al.* 2008, Marko *et al.* 2010), coral reefs (Ridgeway *et al.* 2008, Almany *et al.* 2009), estuaries (Teske *et al.* 2006, Earl *et al.* 2010) and seamounts (Miller *et al.* 2010). Molecular tools are also extensively used in aquaculture (Roodt-Wilding 2007), population recruitment studies (Planes *et al.* 2009), research to uncover evolutionary histories of marine species and the historical effects of climate change (von der Heyden *et al.* 2010a), to track marine invasive alien species (Darling *et al.* 2008, Rius *et al.* 2008) and to identify disputed or falsely labelled seafood (von der Heyden *et al.* 2010b). Additionally, genetic techniques have the power to discriminate between cryptic species, thus extending knowledge of existing biodiversity and associated distribution patterns. Without accurate data on species diversity, it is not possible to fully assess or manage marine biodiversity if species are overlooked or remain undiscovered (von der Heyden 2011). When enough data from long-term (ideally multi-species) data sets are available, then it also becomes possible to use genetics (in conjunction with other parameters) to more accurately model the influence of fishing and MPAs on fisheries mortality (Dunlop *et al.* 2009).

Importantly, genetic research can also facilitate the estimation of the effective population size (N_e) of species. In many marine species N_e is magnitudes smaller than the census population size (N). Palstra and Ruzzante (2008) and Hauser *et al.* (2002) state "that millions of individuals may therefore be equivalent to an N_e *of* only hundreds or thousands". This means that decreases in genetic diversity could potentially occur over short periods of time where stocks or populations experience high mortality. Unfortunately few examples exist that document such changes, as well-preserved tissue of pre- and post-exploitation individuals are required for analysis. Hauser *et al.* (2002) and Hoarau *et al.* (2005) show significant decreases in genetic diversity for New Zealand snapper, *Pagrus auratus* and plaice, *Pleuronectes platessa* respectively which are attributed to the unsustainable exploitation of the species. The rate of loss of genetic diversity is probably also explained by life-history characteristics of exploited species; in the exploited Atlantic Herring, *Clupea harengus* there was no significant reduction in N_e even though census population size had declined between 30-50% (Larsson *et al.* 2010).

Molecular tools are important in a marine conservation and MPA framework because geographic range, abundance and morphology of a species, or its larvae, seldom reveal the processes that have shaped a species distribution and population patterning, or are of less importance to contemporary conservation planning than historical demographic history. Further, it is often impractical to tag many individuals of a large number of species and then to recapture enough individuals to understand dispersal patterns, as applied in linefish population research. Most marine taxa have a dispersive larval stage, which is probably more important in determining species dispersal than adult movement, especially in species that have sedentary or sessile adult stages. Yet larval research is often hampered by a lack of basic taxonomic identification tools and expertise and the vast numbers of larvae from a single field sample (Grantham *et al.* 2003). This makes it exceedingly difficult to study larval dynamics of multiple species across the entire South African coastline. By applying molecular techniques it is possible to screen large numbers of individuals for several marker systems (see for example Barluenga & Meyer 2010 (over 2000 fishes analysed) or von der Heyden *et al.* 2010a (over 1000 fishes analysed). Such data can show historical and contemporary population dynamics of marine species, as well as guide marine conservation and management practices. It is therefore important to consider molecular data in the management of marine species to support the effective conservation of the genetic populations and species of the future (Rocha *et al.* 2007).

14.2 Population genetic structuring in South Africa

Prior to the last National Spatial Biodiversity Assessment in 2004 (Lombard *et al.* 2004) the majority of studies carried out on South African marine species (including hake *Merluccius capensis* and *M. paradoxus*, monk *Lophius vomerinus*, and kob *Argyrosomus* spp.) used Restriction Fragment Length Polymorphisms (RFLPs), or Random Amplified Polymorphic DNAs (RAPDs), but given their limited technical and analytical value these were not reviewed here. Since 2003, most studies of South African marine species have focussed on mitochondrial DNA (mtDNA) genes, some in conjunction with nuclear DNA (nDNA) genes and a limited number on microsatellite DNA genotyping. These three marker systems have different evolutionary and mutational trajectories and as such a combination of either mtDNA and nDNA or mtDNA and nuclear microsatellites are able to give a more complete view of the historical and contemporary processes influencing marine species (Zhang & Hewitt 2003, Lukoscheck *et al.* 2008, André *et al.* 2011; Grobler *et al.* 2011).

Between 2003 and the beginning of 2011, 34 papers have been published that examine population genetic structuring of marine species in South or southern Africa. Nineteen of these deal with coastal taxa and seven with commercially exploited fishes (hake *Merluccius* spp. and red roman *Chrysoblephus laticeps*) and lobster (*Jasus* spp. and *Palinurus* spp.). Five unpublished MSc or PhD theses were not included in the above count. These papers can be evaluated from two differing management perspectives; 1) coastal marine protected areas and 2) management of shallow-water and demersal commercially exploited species. Unfortunately few data are available for offshore species, and as such genetic data cannot as yet be used to guide offshore conservation planning.

A comparison of all published studies to date reveal that there are several areas along the South African coastline that appear to limit or decrease the exchange of genes amongst adjacent areas (Figure 59). This has led to the establishment of independently evolving lineages and genetically structured populations within recognised species. Therefore the assumption that there is free genetic exchange supported by the local oceanography for South African marine species is clearly false. Thus, it is a minority of species that appear to have no population genetic structuring along the South African coastline (e.g. the barehead goby, *Caffrogobius caffer* (Neethling *et al.* 2008) and the red roman, *Chrysoblephus laticeps* (Teske *et al.* 2010). Such patterns of population genetic homogeneity probably arise from a long-lived pelagic larval stage that allows effective dispersal in the goby, and a combination of mobile adult and pelagic larval stages for red roman. It should be emphasised that the length of time that pelagic larvae spend in the plankton does not directly relate to the population genetic structuring of the adult population, i.e. one cannot predict population structure from pelagic larval duration. Numerous examples exist in the international literature that show contrasting results where species with long pelagic larval durations have highly structured adult populations or where marine species with differing life histories show similar genetic patterns (see for example Ayre *et al.* 2009; Shanks 2009). There are also several MSc and PhD projects currently being completed that show very similar patterns to the ones described above, but which were not included in this review.

The majority of South African coastal species studied show significant levels of population genetic structuring (and thus reduced gene flow), which often coincide with recognised marine biogeographic boundaries. On the south-west coast, Cape Point and Cape Agulhas appear to play major roles in limiting gene flow between species (Figure 59). The former coincides with the recognised biogeogeographic boundary separating the south-west and west coasts. Several species have phylogeographic breaks at both sites, with distinct lineages that are endemic to this transition zone (Teske *et al.* 2006, 2007). There also appears to be some genetic discontinuity on the south coast (Figure 59). On the south-east and east coasts, biogeographic breaks have been harder to define; this area is often considered as a transition zone between the warm-temperate and sub-tropical biota. One profound genetic break is recovered for some species in the vicinity of Algoa Bay between Port Elizabeth and Port Alfred, whereas a second break is found on the Central Wild coast (Figure 59). The third locality across which genetic exchange is limited, coincides with the biogeographic transition zone between the sub-tropical and tropical biotas. Genetic breaks can be found in the north-east of the country on the border with Mozambique, whereas some appear to lie in southern Mozambique (Figure 59). It is important to note that not all marine species that have distributional ranges across several biogeographic provinces necessarily show the same genetic patterns. Further fine-scale data are required to understand regional patterns. For example, a study on the brown mussel, *Perna perna*, showed distinct genetic differences between mussels sampled from bays compared to mussels sampled on the open coast, with genetic differences at the scale of tens of kilometres (Nicastro *et al.* 2008).

Interestingly, it appears that genetically isolated lineages within species also correspond to physiologically adapted lineages. For example, the larvae of the subtropical lineage of the mudprawn, *Upogebia africana*, are unable to establish themselves in the temperate south coast, as they cannot survive colder water temperatures prevailing in this region in winter (Teske *et al.* 2008). Similar results have been shown for the sandprawn, *Callianassa kraussi* and for the brown mussel, *Perna perna*, with explanations including not only that genetically different lineages are adapted to different temperatures, but also salinity levels (Teske *et al.* 2009; Zardi *et al.* in press).

There have also been several studies focusing on the effect of oceanography on gene flow patterns in order to determine whether dispersal and recruitment are driven by regional current systems. These are of great interest as they measure connectivity between areas and thus provide significant insights into dispersal of marine species. Interestingly, there appears to be a correlation between the direction of dispersal and life-history. Results suggest that for the live-bearing (and thus a very short-lived pelagic larval duration) clinid fish, *Clinus cottoides*, gene flow is predominantly asymmetric and strongly influenced by the Benguela Current, as well as an inshore counter-current on the south and south-east coasts (von der Heyden *et al.* 2008). For the goby, *Caffrogobius caffer*, which has a long pelagic larval duration, gene flow is in the direction of the Agulhas Current (Neethling *et al.* 2008). Many more data are required to validate these early results, but it is likely that in the next few years with better computational power and models, data for many more species will become available.

Offshore demersal and pelagic fisheries, as well as non-commercially exploited species have to date received little attention. This is primarily a result of the difficulties of obtaining sufficient samples, e.g. not being able to cover the entire geographical range of a species, the relative expense compared to coastal sampling and the lack of cross-border collaboration and funding programmes. There is considerable scope for offshore molecular studies, especially of commercially exploited species that are caught by two or more nations in southern Africa. Therefore recent phylogeographic attention has focused on commercially valuable species, in particular the Cape hakes, *M. paradoxus* and *M. capensis* (von der Heyden *et al.* 2007a, 2007c, 2010a), as well as three lobster species, *Jasus lalandii* (Matthee *et al.* 2007), *Palinurus gilchristi* (Tolley *et al.* 2005) and *P. delagoae* (Gopal *et al.* 2006).

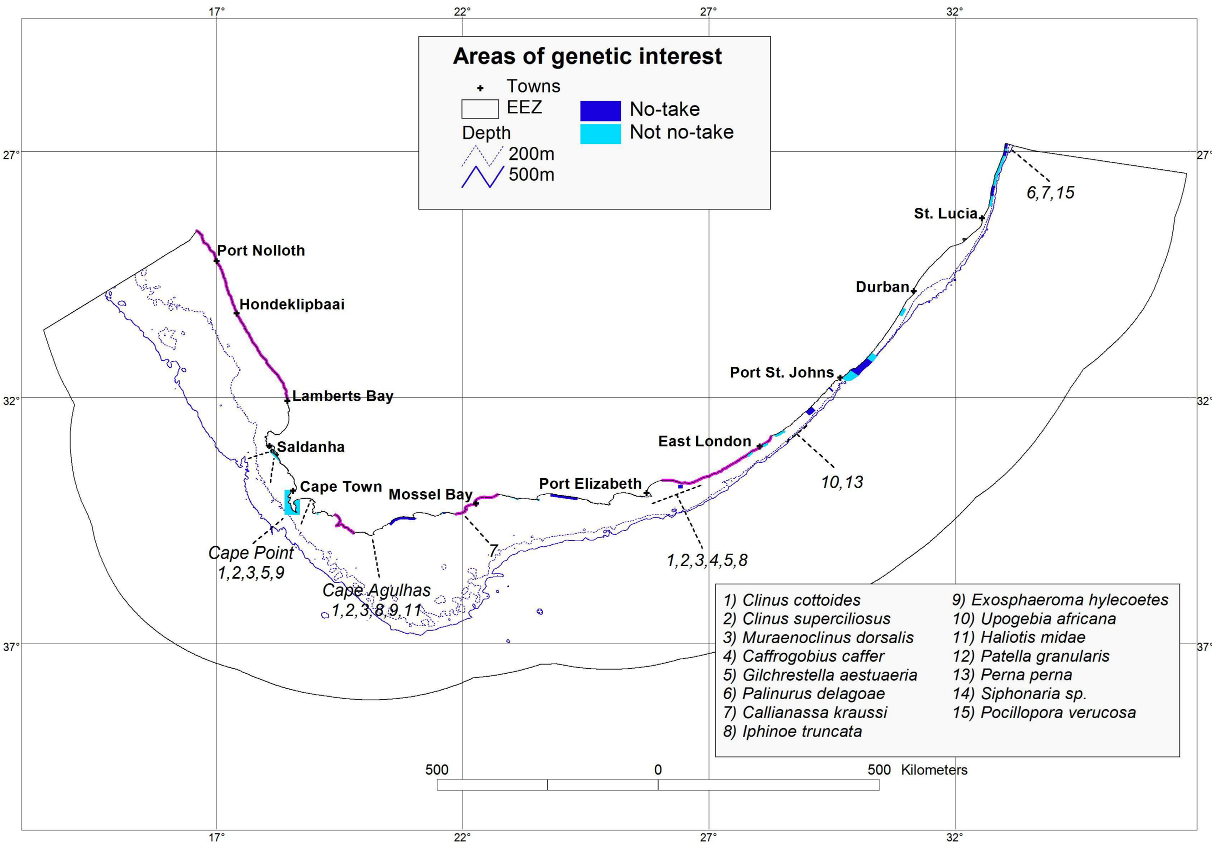


Figure 59: Summary of key areas of interest in terms of patterns in genetic biodiversity for marine and estuarine species. Dashed lines represent breaks in gene flow or significant population structuring for the species listed. Current MPAs are shown. Areas of genetic interest, either as areas of genetic breaks or high diversity, are shown in green. Figure adapted from von der Heyden (2009) and only includes published or thesis information, excepting work on clinids by SvdH and co-workers).

The largest study to date has been on the Cape hakes, *M. capensis* and *M. paradoxus*. In total, over 1300 fishes were caught and analysed in two studies (von der Heyden *et al.* 2007a, von der Heyden *et al.* 2010a). These showed that for *M. capensis* (the shallow-water hake), there was no detectable population genetic structuring among any of the areas sampled, including between South Africa and Namibia. For *M. paradoxus* (the deep-water hake), significant population structuring was recovered between Namibian and South African sampling areas, as well as between west-coast populations of *M. paradoxus*. Interestingly, it appears that adult hake mostly contribute to a signal of population structuring, as juvenile fishes under 30 cm length have genetic homogeneity over the same geographical area. A third study analysed hake eggs and larvae, and showed significant spawning differences (both in depth and geographical area) between the two species (von der Heyden *et al.* 2007).

Lobsters have long pelagic larval stages (usually between two and 24 months), but interestingly *Palinurus delagoae* shows shallow, but significantly structured populations between Mozambique and South Africa (Gopal *et al.* 2006). For the west-coast rock lobster*, Jasus lalandii*, no population genetic analyses were carried out, but a comparison of genetic diversity revealed populations on the south-west coast of South Africa to be more diverse than populations at the edges of the geographic distribution of *J. lalandii* (Matthee *et al.* 2007). The south-coast rock lobster, *Palinurus gilchristi*, shows no evidence of structured populations (even though mark-recapture suggested the existence of two populations), which is probably due to larval dispersal in the Agulhas Current (Tolley *et al.* 2005).

14.3 Genetic knowledge in the context of conservation planning

It is well recognised that in order for a Marine Protected Area (MPA) network to be effective, individual components of a MPA network should be connected, either by adult or larval dispersal (Planes *et al.* 2009). Most marine taxa have a dispersive larval stage, which is probably more important in the dispersal of a species than adult movement, especially in species that have sedentary or sessile adult stages. However, the biology of marine species also differs widely. Given the difficulties in sampling across large numbers of individuals for differing life-stages (as highlighted above) across multiple species, genetic information of multi-species data sets is a critical component in assessing marine connectivity at regional scales.

An initial attempt was made by von der Heyden (2009) to evaluate the current Marine Protected Area network in South Africa in a genetic framework. Isolation-by-distance (IBD) models that plot geographic distance against measurements of genetic differentiation (such as F_{ST}), have shown that for a number of different marine species, actual dispersal distance may only be between 25 and 150 km (Palumbi 2004). This is further supported by the work of Nicastro *et al.* (2008), that showed brown mussel, *Perna perna*, connectivity to be limited to the scale of tenss, rather than hundreds of kilometres. Notably, the mean distance between South African MPAs is ~110 km. This, in addition to the numerous barriers that limit genetic exchange between adjacent areas, strongly suggests that the current MPA network in South Africa is not effectively connected via gene flow. As such, the current MPA network cannot safeguard against the loss of genetic diversity in the future. Further research, linked to the specific objectives of individual MPAs is needed to guide the appropriate spacing of MPAs in South Africa.

The conservation of genetic diversity is one of the three components of the 'International Convention on Biodiversity'. Worryingly, genetic diversity has been overlooked by many of the signatory states of the convention (Laikre 2010) and it is only recently that in South Africa there is increasing awareness of the importance of including genetic data in marine conservation assessment and planning. Genetically distinct populations warrant protection, not only to protect the genetic diversity and the contemporary processes shaping diversity and populations today but also 'to conserve the populations and species of tomorrow' (Rocha *et al.* 2007). This is especially important considering that many genetically distinct lineages probably also have unique physiological adaptations whose future is uncertain with the changes that human-induced climate change could lead to in marine ecosystems. The maintenance of genetic marine biodiversity should be an important objective within South Africa's climate change adaptation strategy.

14.4 Gaps in molecular knowledge in South Africa

Molecular tools have only been recently applied in the marine environment, but have already led to a much better understanding of the processes leading to the marine biodiversity patterns evident today. For example, the effect of the last glacial maximum on extant biodiversity and genetic diversity of South African fish species is better understood using a molecular approach (von der Heyden *et al.* 2010a). However, molecular marine sciences in South Africa still lag greatly behind biodiversity pattern research at a species level (see biogeographic references in Table 1), and there are several research gaps that require urgent attention to not only understand the marine systems better from a genetic perspective, but also to have data that are applicable for the management of marine species. Briefly, these include 1) more studies in the least examined areas in the Delagoa ecoregion, 2) a greater focus on the west coast, which experiences the highest levels of pressure on marine ecosystems and where two studies have shown high levels of population differentiation along the coast (for the Cape urchin, *Parenchinus angulosus* and the clinid fish, *Clinus superciliosus*; unpublished data), 3) population genetic dynamics of sandy shore organisms, 3) genetics in coral reef habitats require further research effort, 4) there has been surprisingly little published data on commercially exploited fishes, including linefish, 5) the South African offshore areas require further study, and 6) where samples are available then temporal genetic diversity in species before and after exploitation should be assessed.

The research gaps identified above will need to be contextualised in a conservation and sustainable utilisation framework. Therefore, the more data become available, the more it should become possible to integrate genetic data sets into, for example, MPA planning. In order for this to be achieved, comparisons across multiple species that represent different life-histories and that have different ecological requirements, are needed. Further, considerable effort will have to be made to generate multi-locus data sets that span across different markers in order to understand the historical and contemporary processes that have led to and maintain the extant patterns of marine genetic diversity. However, of utmost importance is that molecular tools and answers are integrated with other approaches, which include biodiversity assessments, oceanographic and socio-economic research. This approach of 'seascape genetics' spanning research disciplines (Selkoe *et al.* 2008) will ultimately be 'first prize' in supporting systematic marine biodiversity assessment and planning and the sustainable use and conservation of our valuable marine resources and ecosystems.

15 Key findings

The key findings of the marine and coastal component of the National Biodiversity Assessment 2011 are highlighted below, including some of their implications. These findings form the basis for the key messages and priority actions that follow.

47% of marine and coastal habitat types are threatened

- Sixty-four of 136 (47%) marine and coastal habitat types are threatened, with 17% of all habitat types critically endangered, 7% endangered and 23% vulnerable.
- Many threatened habitat types have limited spatial extent, so more than 70% of South Africa's total marine and coastal area is least threatened.
- A higher proportion of coastal than offshore habitat types are threatened. In the offshore environment, there are more threatened benthic habitat types than threatened pelagic habitat types.
- All rocky shelf edge and island-associated habitat types are threatened.
- Along the coast, many habitat types in Namaqualand and the southwestern Cape are threatened. Offshore, the Southern Benguela and Agulhas ecoregions have the most threatened habitat types, including productive habitats that support important commercial fisheries.

40% of marine and coastal habitat types have no protection

- Fifty-four (40%) marine and coastal habitat types are not represented at all in South Africa's MPA network.
- Most of these unprotected habitat types are offshore, reflecting the fact that almost all of South Africa's existing MPAs extend only a short distance from the shore.
- Along the coast and inshore, habitat types with no protection include five in Namaqualand and two in the Natal ecoregion.
- A total of 13 habitat types are both critically endangered and have no protection, suggesting that these habitat types are priorities for improved management as well as representation in the MPA network, to reduce human impacts.

Only 6% of marine and coastal habitats are well protected

- Only 9% of coastal and inshore habitat types are well protected.

- Most coastal habitat types are moderately protected, reflecting the fact that in many MPAs there is insufficient protection from fishing (i.e. insufficient representation in no-take zones).
- Only 4% of offshore habitat types are well protected.
- There is poor awareness of the role of MPAs in biodiversity conservation, fisheries management, climate change adaptation and delivery of socio-economic benefits.

Fishing remains the greatest pressure on marine biodiversity

- Fishing is a key driver of change in marine and coastal ecosystems and has the highest impact score in 10 of 13 broad ecosystem groups.
- Key challenges include overexploited resources, substantial and unmanaged bycatch in some sectors, incidental seabird mortalities, habitat damage, concerns around food supply for other species and other ecosystem impacts of fishing.
- Poaching continues to threaten marine biodiversity, resource sustainability and the livelihoods of legitimate fishers.
- The division of the former Marine and Coastal Management branch in the Department of Environmental Affairs into a fisheries branch within the Department of Agriculture, Forestry and Fisheries and the Oceans and Coasts Branch within the Department of Environmental Affairs in 2009 makes the implementation of the Ecosystem Approach to Fisheries management more difficult and costly.

Coastal development is the greatest pressure on coastal biodiversity

- 17% of South Africa's coastline has some form of development within 100 m of the shoreline.
- Coastal ecosystems provide key ecosystem services including:
    - protection from large waves associated with extreme weather events
    - provision of a reserve supply of sand in the dunes to maintain beaches
    - water filtration and nutrient cycling
    - provision of critical nursery areas for important fish species
    - valuable tourism asset.
- The interacting pressures of coastal development and climate change (coastal squeeze) threaten beaches, dunes, other coastal habitats and their underlying processes. This can disrupt critical ecosystem services.

- Inappropriate coastal development compromises ecosystem services and hampers our ability to adapt to climate change.

Freshwater flow reduction impacts marine, coastal and estuarine ecosystems

- Approximately 40% the flow from South Africa’s 20 largest catchments no longer reaches the estuaries concerned.
- Freshwater flow reduction can uncouple critical ecological linkages between terrestrial and marine environments and disrupt ecological processes needed to maintain marine habitats, resources and ecosystem services.
- The impacts of reduced freshwater input on marine biodiversity and resources include those on physical habitat, reduced nutrient inputs and alterations to important ecological processes such as nursery functions, foodwebs and energy flow.
- Impacts have occurred along the entire South African coast but are expected to be more severe in the oligotrophic marine environment of the east coast.
- Freshwater input has been linked to marine resource abundance including linefish such as slinger and kob more than 40 km offshore on the Thukela banks in KwaZulu-Natal.

The majority of marine resources are overexploited and several marine and coastal species are threatened

- More than 630 species are caught by commercial, subsistence and recreational fisheries in South Africa.
- Stock status is reported for approximately 6% (41) of these species.
- Of these, 61% (25 of 41) are overexploited.
- Overexploitation and fishing impacts, freshwater flow reduction and the poor state of South Africa’s estuaries, pollution and climate change are key threats at the species level.
- South Africa has at least 23 threatened marine species but needs to invest in conservation assessments (such as Red Lists) to systematically and comprehensively assess the status of marine species and prioritises conservation action.
- Several elasmobranchs and linefish are threatened.

Marine alien and invasive species are an emerging pressure

- New research has shown a large increase in the number of known introduced marine species.

- Introduced microbes, parasites and pathogens are an emerging concern that threatens biodiversity, the developing mariculture industry and human health.
- Some harmful algal blooms (HABs) are caused by alien species and these can have severe consequences for human health, fisheries resources and the mariculture industry. Proper ballast water management can reduce the risks associated with HABs.
- There are eight known marine invasive species that are impacting marine and coastal biodiversity and driving up management costs in mariculture facilities.
- The main pathways of introduction include shipping, mariculture and petroleum activities.

Climate change has ecological, fisheries, resource management and socio-economic implications

- Clear climate change trends are difficult to detect and predict, particularly at a local scale, but it is recognised that climate change adds uncertainty and variability, which in turn increases the complexity of research and management in the marine and coastal environment.
- The following changes have been observed in South Africa:
  - Changes in sea temperature
  - Shifting distributions of rock lobster and small pelagic fish have led to social, ecological and economic impacts. These impacts complicate resource management.
  - Increased frequency and extent of coral bleaching
  - Sea-level rise
  - Increased coastal erosion linked to increased frequency and severity of storms
- The 17% of South Africa’s coastline with some development within 100 m of the shoreline is particularly vulnerable to climate change impacts.

Products from this assessment

Box or table: The following data layers and information was developed to support this assessment.

- National marine and coastal habitat classification and map
  Includes National beach classification, digital coastline and dune map (Harris *et al.* 2010, Harris 2011b) and offshore pelagic habitat map and classification (Lagabrielle 2009)
- Scaled national marine and coastal pressure maps for
  - Inshore demersal trawl fishing
  - Offshore demersal trawl fishing
  - Offshore demersal longline fishing
  - Small pelagic fishing
  - Midwater trawl fishing
  - Crustacean trawl fishing
  - South coast rock lobster fishing
  - West coast rock lobster fishing
  - Squid jig fishing
  - Commercial linefishing
  - Tuna pole fishing
  - Shark fishing
  - Large pelagic longline fishing
  - Kelp harvesting
  - Shark control program
  - Mariculture
  - Invasive alien species
  - Diamond and other mining
  - Petroleum exploration and mining
  - Shipping
  - Coastal development
  - Waste water discharge
  - Freshwater flow reduction
  - Recreational shore fishing
  - Recreational boat fishing and National launch site map
  - Subsistence harvesting
  - Coastal disturbance
- Ecosystem threat status map
- Ecosystem protection levels map

16 Knowledge gaps, research priorities and future assessments

16.1 Knowledge gaps and limitations

Several knowledge gaps that limit our ability to assess marine biodiversity emerged from the work undertaken as part of this study. These comprise gaps in many research areas including taxonomic, molecular and species research, population assessment and conservation status, habitat classification and distribution, ecology, impact assessment and management fields.

- The current state of marine taxonomic knowledge limits the understanding of biodiversity pattern and process, ecosystem function, impact assessment & detection of introduced species.
- South Africa lacks basic national marine biodiversity databases and species lists that are available for public dissemination. Inventories and checklists of species recorded in South Africa (along with distribution information) are needed as well as accessible specimen databases with locality, date of collection, collection method and habitat information.
- Poor species level data inhibit conservation assessments for marine species and assessment of the effectiveness of South Africa's MPA network. The poverty of knowledge about offshore ecosystems limits the assessment of the status of offshore biodiversity and planning for effective protection of offshore species and habitats.
- The limitations of the habitat maps are reflected in Section 2.1.7 - *Limitations of the habitat classification*.
- Further research is needed to improve our understanding of the drivers of biodiversity pattern and change and refine ecosystem classification and mapping efforts.
- The absence of in-situ measurements of habitat state across for different habitat types or broad ecosystem groups weakens the assessment of habitat condition and hinders the identification of key drivers of change in different habitat types.
- There is insufficient information to support good understanding of the impacts of key emerging pressures, including mariculture, desalination plants and petroleum activities.
- Accurate flow volume data are needed for all discharge points to improve mapping of the effect of discharge into the wider marine environment.
- The limited long term monitoring for marine ecosystems in South Africa hampers the understanding of climate variability and change in marine ecosystems and undermines the important ability to separate complex interacting variables driving change in marine ecosystems.
- Improved spatial data that reflect the direction of change and information to weight climate change effects in all broad ecosystem groups are needed to incorporate climate change in future spatial assessments of ecosystem threat status.
- South Africa does not have ecosystem-based biodiversity targets that account for the differences in species richness and turnover, extent or vulnerability of different habitat

types. This as a limitation in the current assessment of ecosystem condition and protection levels.

- Limited genetic data restrict spatial analyses to the species and ecosystem level. Several gaps in molecular knowledge were identified and these research gaps should be addressed before genetic approaches can be effectively applied in marine biodiversity assessment and planning in South Africa.

16.2 Research priorities

16.2.1 Species and Genetic Research

- Taxonomic priorities should align with priority biodiversity knowledge needs as well as address key gaps reported in section 13 The status of marine taxonomy. Groups that are poorly known and suitably diverse are priorities for the revision of existing species and description of new species, using natural science collections and through additional surveys (systematic where possible).
  Groups that are priorities for marine biodiversity management include
  - Groups with high levels of endemism and many range restricted species;
  - Groups with high potential for invasion and introduction,
  - Harvested groups (for food, aquaculture, and trade)
  - Groups that will be useful in monitoring impacts of global change
  - Groups that are important in major ecosystem processes.
- DNA barcoding of priority groups to enable identification of traded, harvested, threatened and invasive species, and the development of mechanisms to carry out analyses of bulk ecological / monitoring samples. Note that improved co-ordination is needed in this area to ensure wise use of resources and avoid repetition of work done.
- More effort is needed in the inventory of marine species and comprehensive national species databases should be compiled and expanded, maintained and disseminated by SANBI. Resources will need to be secured if this is to be achieved. Two types of databases are needed; verified species lists (checklists / inventories that include basic information such as endemism and threat status for each species, as well as invalid names and up to date classification) and co-ordinated species databases (such as a South African version of the Encyclopaedia of Life) that link to collection and spatial information through the Global Biodiversity Information Facility or the Ocean Biogeographic Information System and the literature. More systematic surveys are needed to support improved species distribution data for South Africa.
- A national fish atlas remains a research priority as identified in the 2004 National Spatial Biodiversity Assessment. This atlas could be focused on priority species including threatened, protected and other species of concern, indicator species, key resources and species that can contribute to current research efforts.
- Endemic and species with very restricted ranges need to be identified. Many marine invertebrates are known only from the type locality. Lists of these taxa need to be produced and investigated to identify priority groups for further taxonomic and other research and possibly conservation assessment. Atlassing projects could be considered for selected groups with many such species.

- Civil society can and should contribute to improved coastal and marine biodiversity information for South Africa. New initiatives that can harness citizen science collaboration from divers, fishers and other user groups are needed.
- Scientists need to support the identification of potential invasive species and the development of appropriate lists to enable effective regulation.
- Systematic surveys and monitoring is needed to identify potential invasive species. Research effort is needed on the east and south coasts, in offshore habitats and in mariculture facilities.
- There are opportunities to use genetic tools to better understand the colonisation and invasion dynamics of non-indigenous marine species.
- Improved species data are needed for Marine Protected Areas. Such data will underpin the assessment of the effectiveness of current MPAs in meeting biodiversity protection and resource management objectives. Research to guide appropriate spacing of MPAs is required and model-based approaches should be used to determine targets for key species identified using clear criteria.
- Research priorities to support improved stock assessment and resource management include
    - Assessment of whether kingklip on the west coast and south coast are separate stocks
    - Aging studies for sole to improve stock assessment
    - Updated and more reliable information is needed for squid effort and catch data
    - Many linefish assessments need updating
    - Improved data collection and research are needed to support management in the prawn trawl fisheries (DAFF 2010)
    - Improve data to support stock assessments and management of sharks are required.
- Conservation assessments are needed to support the identification of threatened marine and coastal species. (See Section 10.2 – Threatened species).
- Genetic biodiversity requires further research attention to facilitate the incorporation of this component of biodiversity into future assessments & MPA planning. More detailed research priorities are presented in Section 14.4 - Gaps in molecular knowledge in South Africa and include the need for more research in the Delagoa and Southern Benguela ecoregions, research in sandy beach and coral reef habitats, more genetic data for linefish and studies to assess genetic differences prior to and after exploitation.

16.2.2 Habitat classification, mapping and research to support ecological understanding and impact assessment

- Existing datasets and new sampling opportunities should be used to test the validity of the current habitat classification.
- Research to support the ecological definition of coastal habitat types including appropriate seaward and landward boundaries is needed.
- Research is required to support the delineation and classification of island and associated habitat types. Further research is needed to assess whether habitats such as

sandy beaches and reefs that are associated with islands are distinct from those along the mainland coastline.

- Priority habitat types that require improved mapping and distribution data include muds, gravels and other coarse sediment types, hard grounds, submarine canyons and reefs. Mapping of submarine features such as banks, paleo-shorelines, seamounts and canyons is needed to support the development of appropriate spatial management measures to protect seabed features.
- Existing data do not adequately reflect fluvial inputs. Maps of unconsolidated sediment habitat types that are linked to riverine or estuarine systems are needed. An example of such habitat types includes the fluvial fans on the south coast which constitute spawning habitat for white steenbras. Mud banks require improved delineation.
- A systematic bathymetric (depth contours) and geological mapping programme is needed for the South African seabed. Systematic biodiversity surveys are needed to assess the influence of physico-chemical drivers and other proposed determinants of biodiversity pattern. These programmes should underpin improved ecosystem classification, mapping and assessment.
- Key research priorities for broad ecosystem groups and habitat types were identified and reported in Section 2.3 - Overview of habitat types.
    - Long term experiments and monitoring could improve our understanding of all habitat types.
    - For sandy beaches, improved information of the smaller components of beach biodiversity and an improved understanding of connectivity and key ecological processes are needed.
    - Inshore and offshore unconsolidated sediment types are poorly understood with a need further research to improve our understanding of the biodiversity associated with different sediment types (particularly muds and gravels), the key drivers of biodiversity pattern and the impacts of human activities on these habitats. There are 16 different unconsolidated offshore habitat types, many of which have never been sampled. The productive shelf edge habitat types that support valuable fisheries are key research priorities.
    - Inshore reefs and hard grounds are poorly studied in the Agulhas and southern Benguela shelf ecoregions. Improved information of reef biodiversity, ecosystem functioning and the effects of anthropogenic impacts is needed in these regions.
    - There is very limited knowledge about offshore rocky habitat types on the shelf and shelf edge and the biodiversity associated with these habitat types. South Africa has deep water reef building corals although nothing is known about the extent, associated biodiversity and ecological role of these habitat types. Submarine canyons in the Natal, Agulhas and southern Benguela shelf ecoregions have not been researched.
    - Pelagic biodiversity is poorly understood and the pelagic “habitat types” used in the NBA 2011 should be tested and refined. Comparison of these habitat types with the distribution of pelagic species, known foraging areas for pelagic feeders and key movement pathways of pelagic species would be a useful first step. More information on vertical stratification within the ocean is needed to support improved classification and the high levels of variability associated with pelagic

habitat types need to be better incorporated into future classification, mapping and assessments of pelagic habitats.

16.2.3 Pressures, changes and assessment of marine and coastal biodiversity

- An improved understanding of emerging pressures on marine and coastal ecosystems is needed. Research should be directed at assessing the actual and potential impact of key emerging pressures including desalination plants, freshwater flow reductions, dredge mining and petroleum activities.
- Research to support the understanding of climate variability and change in marine and coastal ecosystems is a national priority. More detailed research priorities are reflected in Section 12 including further research on shifting species distributions and the potential impact of ocean acidification in South Africa. Research needs to develop predictive capacity in South Africa, support early detection of change and contribute to the development of mitigation and adaptation measures.
- A standardised national survey of recreational fishing effort is a key research priority.
- Estimates of subsistence fishing effort and the effort and catch data for the emerging small scale fisheries sector is a national priority.
- Finer-scale and spatially referenced fishing effort and catch data is needed to support more accurate assessments of habitat impacts, more refined mitigation measures for habitat protection and bycatch management
- The impacts and risks of mariculture in South Africa, particularly finfish culture need to be understood. Research should help to identify risks and threats to indigenous species (including the effects of disease and parasites as well as population and genetic impacts) and habitats. New farms offer research opportunities using a robust experimental approach to understand impacts and support science-based management advice.
- Research effort to support the mitigation of human impacts on marine and coastal biodiversity is required. There are opportunities and incentives for research that helps to mitigate incidental mortality and bycatch associated with fishing. Key areas for further research innovation include mitigation of mining and petroleum impacts, mariculture impacts, and in managing ballast water.
- The feasibility of removing the invasive crab *Carcinus maenas* warrants assessment.
- Long term in-situ monitoring of habitat condition is needed to calibrate the assessment of habitat condition and ecosystem threat status. This type of research is important in understanding complex changes in marine ecosystems and is a key element in research to understand, predict and respond to climate variability and change.
- Further examination of historical data and patterns is needed to assess ecosystem changes over a longer time period. Funding should be directed at the acquisition, archiving and analysis of historical data sets.
- Improved data are needed to support the assessment and review of Marine Protected Areas (MPAs) in South Africa. Species and habitat data is needed for all MPAs and a central data archive is needed to support MPA assessment. A more co-ordinated

National MPA research program could contribute to assessment of the achievement of MPA objectives and the understanding of change in marine ecosystems.

- Ecosystem-based biodiversity targets should to be established for marine and coastal habitats. Porter *et al.* (2011) provide more detailed research priorities to support target setting.
- Research to improve our understanding and evaluation of marine and coastal ecosystem and biodiversity services is needed. Spatial assessment of ecosystem services could facilitate better integration of ecosystem services into marine biodiversity assessment and planning at multiple scales.

16.2.4 Systematic planning and the identification of priority areas

- Research to support the identification and mapping of critical habitats for key resource species (such as nursery, spawning and feeding areas) is needed.
- Sensitive coastal and offshore areas should be identified to support the prevention of significant adverse impacts and the loss of biodiversity and ecosystem services.
- Achievement of the biodiversity and resource management objectives of South Africa's Marine Protected Area (MPA) network need to be reviewed. Comprehensive species and habitat data is needed to support the assessment of South Africa's MPAs.
- Marine ecosystem priority areas and ecological support areas should be identified through systematic biodiversity plans.
- Systematic biodiversity planning is required for the northern section of the Natal bioregion and the west coast of South Africa.

16.3 Recommendations for next NBA

The following checklist of key considerations and potential products for the next National Biodiversity Assessment emerged from the work undertaken during the 2011 process.

- The assessment of ecosystem threat status would be strengthened if the assessment of condition could be calibrated through to in-situ measurements of ecosystem state across broad ecosystem groups. Future assessments should be based on an updated habitat maps until more refined and stable habitat maps are finalised.
- The marine ecosystems of the Prince Edward Islands should be included in future assessments. Funding should be secured to facilitate this addition.
- The pelagic classification needs to account for the three dimensional nature of the open ocean and better incorporate vertical stratification. Pelagic "habitat types" require verification.
- Harbours should be assigned to their original habitat type.
- Islands and associated habitats should be reclassified and mapped based on an improved understanding of island ecology and determinants of biological community structure.
- Fine scale coastal analyses should be undertaken with consideration of products needed to implement the Integrated Coastal Management Act. Integrated assessment that includes relevant data from terrestrial, freshwater, estuarine, and marine ecosystems should be included in future assessments. New work should draw from

research to support the inclusion of ecological criteria in implementing Integrated Coastal Management.

- Climate change maps and GIS layers should be developed, reviewed and considered for inclusion in future assessments. The direction of change should be adequately reflected in these maps and layers.
- Recreational fishing effort needs to be assessed and mapped at a national scale as a priority.
- Net fisheries, including the available spatially referenced effort data, should be included in future assessments.
- Accurate and up-to-date subsistence and small scale fishing data layers and maps should be included.
- Develop maps and include key emerging threats including discharge areas for desalination plants, sandwinning and climate change.
- The results of international reviews on target setting for marine habitats and recommendations from the discussions around that work should be considered during planning for future assessments.
- The conservation of genetic biodiversity and population structure should feed into MPA planning.
- Strengthened information and improved valuation data on ecosystem services should be incorporated into the assessment.

17 Key messages and priority actions

These messages and recommendations follow from the key findings of the 2011 National Biodiversity Assessment.

Key messages and priority actions

The messages and recommendations below follow from the key findings of the National Biodiversity Assessment 2011. Strategic objectives and priority actions for managing and conserving South Africa's biodiversity are set out in the National Biodiversity Strategy and Action Plan (NBSAP) and the National Biodiversity Framework, both of which are due to be reviewed shortly. Priority actions suggested by the results of the National Biodiversity Assessment 2011 should feed into the review process. They are intended not to pre-empt the process of revising the NBSAP and National Biodiversity Framework but rather to provide science-based input to strengthen the process.

Many opportunities exist to secure South Africa's marine and coastal habitats

Although 47% of South Africa's marine and coastal habitats are threatened, there are still opportunities to restore impacted habitats, secure remaining healthy habitats, prevent further damage and improve marine biodiversity management. South Africa can constrain key emerging pressures through pro-active integrated spatial planning and effective regulation that accounts for sensitive and threatened ecosystems. Sensitive areas and critical habitats for the recovery of key marine and coastal resources should be identified and secured. Marine and Estuarine Protected Areas, Integrated Coastal Management, Fishery Management Areas and other types of ecosystem-based spatial management measures (such as seabed protection zones) are key tools for securing marine and coastal habitats. Collaborative mainstreaming initiatives in the fisheries and mining sectors offer opportunities for improved marine biodiversity management.

South Africa is poised to expand its Marine Protected Area network

South Africa is a global leader in systematic biodiversity planning and has identified several strategic geographic priority areas for the establishment of new Marine Protected Areas and other types of spatial management measures. These include priority areas in KwaZulu-Natal and the Agulhas ecoregion as determined from fine-scale plans and focus areas for offshore protection based on a national analysis. Many of South Africa's most productive offshore habitats that support fisheries are not included in the current MPA network. The Prince Edward Islands MPA is ready for declaration and a coastal MPA in Namaqualand is an urgent priority.

MPAs are valuable national assets that deliver ecosystem services and socio-economic benefits

South Africa's Marine Protected Area (MPA) network plays a key role in protecting marine and coastal habitats and sustaining fisheries. Coastal protected areas can support rural livelihoods and local economic development through providing jobs and opportunities for ecotourism and conservation-related industries. Protected areas attract foreign and domestic tourists, provide ecosystem services, and safeguard the environment for future generations. Fully protected MPAs help sustain fisheries by protecting breeding resources and by seeding adjacent areas with eggs, larvae or young and adults. South Africa has the opportunity to improve the delivery of ecosystem services from the existing MPA network by implementing new no-take zones, increasing benefits through diversified non-consumptive tourism activities and improving monitoring and management effectiveness. The strengthening of South Africa's MPAs will depend on resolving current resource-use conflicts, reducing current impacts inside existing MPAs (especially fishing) and strengthening management capacity. Building public awareness of the role of MPAs in protecting biodiversity and sustaining fisheries is a priority. Capacity, processes and arrangements are needed to allow stakeholders to participate in MPA design, planning and management.

Overexploited fish stocks can recover and provide long-term food and job security

Although many resources are overexploited, management action can lead to stock recovery. Key elements in securing resource sustainability in the long term include robust stock assessments, effective data management and science-based management action grounded in the realities of resource abundance. The implementation of the Ecosystem Approach to Fisheries management can contribute to resource recovery through protection of spawning and nursery areas and the maintenance of other essential fish habitats. Improved bycatch management offers opportunities to reduce waste and derive benefits from non-target species, through value adding activities that support job creation. Credible third party eco-certification provides an incentive for responsible fisheries and can deliver additional socio-economic benefits through improved market access and security. Current levels of poaching should be reduced to ensure recovery of key resources and to secure livelihoods of legitimate fishers and their dependent communities.

Integrated coastal management supports key ecosystem services and climate change adaptation

Integrated coastal management (ICM) is the process by which multiple uses of the marine and coastal environment are managed so that a wide range of needs are catered for, including both biodiversity protection and sustainable use, allowing all stakeholders to participate and benefit. The relatively high proportion of threatened coastal habitat types (62%) highlights the need for integrated management of the coastal environment, reinforcing the importance of the ICM Act and the tools it has introduced for coastal management. The implementation of ICM can constrain impacts in the sensitive coastal zone and ensure continued delivery of key coastal ecosystem services. These services include protection and buffering from sea-level rise, severe storms and tsunamis. ICM is essential in the wise development and optimal use of South Africa's coastline, including our beautiful beaches, an important investment that is critical to successful coastal tourism.

Healthy natural ecosystems increase society's resilience to the impacts of climate change and ICM is therefore a key element in South Africa's climate change adaptation strategy. Coastal Management Programmes, coastal set-back lines, extending coastal public property, and refining the delineation of the coastal protection zone are required in terms of the Act and will support resilience to climate change. Other tools such as demarcating coastal hazard areas, use of coastal vulnerability indices and coastal land-use planning will further support climate change adaptation. Further coastal ribbon development should be avoided in favour of nodal development, appropriately placed behind scientifically determined set-back lines. This will ensure that coastal impacts are mitigated and managed and allow sections of the coast to remain natural, supporting long term delivery of key ecosystem services and buffering human settlements and activities from climate change impacts.

Fresh water flowing into the sea is not wasted and is critical for ecosystem functioning

Fresh water (including groundwater) flowing into the estuaries and the sea maintains important ecological processes that keep marine resources healthy. Catchments, rivers, estuaries, groundwater and the ocean are linked through freshwater flow and this essential connectivity depends on maintaining these links. Freshwater flow provides nutrients, sediments that form important habitats, and underlies critical ecological processes. These processes include 1) the nursery function of estuaries and areas offshore of rivers and 2) natural environmental cues needed for spawning, migration and recruitment of key resource species. Freshwater inputs have been shown to affect linefish resources more than 40 km offshore in South Africa. A certain amount of water is needed to scour the mouth of most estuaries – without this scouring effect, sediments build up at the mouth increasing the risk of back-flooding during storms. Artificial breaching of an estuary mouth to minimise this risk is expensive and damages estuarine ecosystems. Water running out to sea should not be considered wasted but instead is essential for maintaining a range of coastal and marine ecosystem services.

Early detection, risk assessment and quick management action can prevent future invasions by alien species

South Africa can avoid the ecosystem damage and economic impacts associated with new invasive species through finalisation and effective implementation of the Alien and Invasive Species regulations in terms of the National Environmental Management: Biodiversity Act (Act 10 of 2004), a dedicated monitoring programme to enable early detection, and effective management. Effective management will depend on adequate planning, co-ordination and resources to support preventative management action and early response mechanisms. The developing mariculture industry should be supported to ensure that further invasive species are not introduced and that the management of existing invasive species reduces their economic impacts in this sector. Increased awareness of the risks, impacts and management options for invasive species is needed within the mariculture sector. Co-ordinated cross-sectoral management for ballast water and biofouling vectors is critical to prevent further introductions of alien and invasive species.

Priority actions

Priority actions suggested by the key findings and messages above include the following. As explained earlier, these priority actions should support the upcoming revision of the National Biodiversity Strategy and Action Plan and the National Biodiversity Framework.

Priority Action: Minimise impacts on priority ecosystems

- Prevent further degradation of critically endangered and endangered marine and coastal habitat types.
- Ensure that the refinement of boundaries of the coastal protection zone and coastal public property takes ecological factors into account, in support of the implementation of the ICM Act.

- Develop a map of coastal ecosystem priority areas based on a systematic biodiversity plan that integrates terrestrial, freshwater, estuarine, and marine aspects. This national coastal biodiversity plan should cover the whole coastal protection zone as well as the terrestrial and near-shore areas of coastal public property. The coastal biodiversity plan should identify coastal areas where it is critical to keep natural habitat intact to assist with adapting to the impacts of climate change.
- Identify marine ecosystem priority areas including sensitive habitats and key areas for resource recovery.
- Support the use of coastal and marine ecosystem priority areas in integrated planning, management and decision making across all sectors that impact on marine and coastal ecosystems and their relevant government departments. These include fisheries and mariculture, mining and alternative energy, coastal development, and water resource management.
- Determine and implement the most appropriate tools to manage and conserve coastal ecosystem priority areas. Mandatory tools include Coastal Management Programmes, coastal set-back lines, the extension of coastal public property and refining the delineation of the coastal protection zone. Other potential tools include MPAs, Special Management Areas, demarcating coastal hazard areas, the use of coastal vulnerability indices, coastal land-use planning, and listing of threatened or protected coastal ecosystems in terms of the Biodiversity Act.
- Determine and implement the most appropriate tools to manage and conserve marine ecosystem priority areas. Potential tools include MPAs, Fishery Management Areas, listing of marine ecosystems and collaborative management with offshore industries.
- Explore alternative management mechanisms for biodiversity conservation other than direct regulation (e.g. MPAs), such as incentive-based mechanisms, market-based mechanisms (e.g. eco-certification), awareness initiatives and payment for ecosystem services.

Priority Action: Expand and strengthen the Marine Protected Area Network

- Expand South Africa's MPA network to include currently unprotected habitat types, including proclamation of Offshore MPAs and an MPA in Namaqualand.
- Increase the delivery of the existing MPA network by
  - implementing more no-take zones to contribute to the sustainability of fisheries
  - increasing benefits through diversified non-consumptive tourism activities and
  - improving monitoring and management effectiveness.
- Improve the science base for South Africa's MPAs through species inventories, fine-scale habitat mapping, and coordinated monitoring initiatives. MPAs provide significant research opportunities for scientists, including potential to strengthen stock assessments for linefish.
- Transboundary MPAs between South Africa, Namibia, Mozambique and our neighbours in the Southern Ocean should be pursued and would need clear management agreements.
- Build public awareness of the role of MPAs in marine biodiversity conservation and fisheries management through targeted awareness initiatives, collaborative research and co-management.

Priority Action: Support the recovery of overexploited resources and threatened species

- Ensure that fishing quotas and fishing effort allocations (e.g. number of fishers or vessels) are grounded in the realities of resource abundance.
- Invest in the management of critical data sets (e.g. fisheries research and commercial catch and effort data and observer data) to support fisheries management. Dedicated data managers, better electronic systems for capturing, storing, validating and disseminating data and improved fisheries data with finer spatial resolution will improve place-based resource and ecosystem management. Advanced data policies and adequate resources will need to be developed and secured to achieve this priority.
- Develop and implement resource recovery plans for overexploited species.
- Cap effort on shark fishing and protect shark nursery grounds.
- Identify critical habitats for the recovery of key resources (e.g. spawning and nursery areas, key foraging areas).
- Secure critical habitats through the implementation of spatial management measures including Fishery Management Areas and Marine Protected Areas.
- Manage incidental mortality of seabirds and secure important offshore bird areas.
- Fortify compliance efforts and reduce poaching especially for rock lobster, abalone and linefish.

- Develop and implement a strategy to prioritise and catalyse southern African or national conservation assessments (Red Lists) for marine species.
- Build public awareness about threatened species, with a focus on linefish such as white steenbras and dusky kob.

Priority Action: Prevent further introduction and spread of invasive species

- Prevent future introductions of invasive species introductions through finalising and implementing the Alien and Invasive Species Regulations, including ensuring that all relevant marine species are listed.
- Review South Africa's adherence to international protocols, capability to deal with existing and emerging invasive species and enforcement of law to prevent new invasions.
- Build scientific and management capacity to support the identification of potential marine invasive species, assess risks and develop and implement appropriate management action. Additional capacity will also be needed to enforce regulations.
- Develop capacity and resources to make use of DNA barcoding to identify invasive species.
- Publish and publicise existing lists of known marine invasive species found in the South African marine environments.
- Establish co-ordinated monitoring initiatives to allow early detection of potential invasive species. Such monitoring initiatives need to include a focus on mariculture facilities, offshore oil and gas infrastructure, ports and harbours.
- Secure resources and develop capacity to enable rapid management action to prevent potential invasive species from becoming established when detected through monitoring programmes.
- Explore methods and potential for eradicating the European shore crab *Carcinus meanus* (currently confined to two harbours) and the black sea urchin *Tetrapygus niger* (currently confined to maricuture facilities).
- Ensure that the national strategy for invasive species that is currently being initiated addresses the marine environment comprehensively.
- Support the Department of Transport in the co-ordinated implementation of the conditions of the International Maritime Organisation Ballast Water Management Convention to ensure South Africa's readiness when the convention comes into force.
- Develop technical and management capacity to support the implementation of the conditions of the Ballast Water Management Convention.

- Promote South Africa's work in support of the International Maritime Organization as related to management of ballast water and biofouling. Develop case studies to report on port surveys and management of marine invasive organisms.

Priority Action: Support good environmental practice and effective regulation of the emerging mariculture sector

- Apply global lessons and good practice guidelines in avoiding and mitigating the environmental impacts of mariculture to ensure that wild fish populations and marine ecosystems are not further threatened by this emerging sector.
- Locate mariculture on land, or in ocean areas that have sufficient depth and flushing rates to minimise habitat impacts. Mariculture should be avoided in biodiversity priority areas including Critical Biodiversity Areas, Marine Protected Areas, Estuaries, Fresh Water Ecosystem Priority Areas (including estuaries), critically endangered and endangered ecosystems and other sensitive biodiversity areas.
- Select species for mariculture with full consideration of potential impacts on indigenous species, ecosystems and fisheries. In keeping with the Biodiversity Act, a comprehensive risk assessment and contingency plan should be conducted for all mariculture operations proposing to farm alien or translocated species. For improved cooperative governance, the biodiversity sector should be represented in the mariculture working group.
- Ensure effective management and husbandry of stock, food and feeding, disease control, effluent, waste and interactions with wild stocks and predators to minimise impacts on indigenous species and ecosystems and prevent negative impacts on existing fisheries and other activities (e.g. ecotourism).
- Control incidental introductions with stock or spat of introduced species.
- In order to prevent the introduction of microbes, parasites and pathogens to wild populations, effluent from land-based farms should be filtered and sterilised and sea-farmed stock should be certified disease free prior to stocking. This should also apply to the transport medium for mariculture species, irrespective of whether animals are moved within or imported from outside South Africa's borders.
- To avoid potentially damaging genetic impacts, ensure that the genetic variability of broodstock resembles the genetic profile of the surrounding wild populations.
- Raise awareness about the potential impacts of mariculture and develop management capacity within the mariculture industry sector through increased training in responsible aquaculture methods and best practices.

- Develop capacity for effective regulation of the mariculture sector and to ensure compliance with environmental management plans developed for mariculture enterpises. Regular, inspections of all mariculture enterprises by suitably qualified biodiversity and animal health experts are needed to minimise the risks of the introduction of disease and invasive species into marine and coastal ecosystems.

Priority Action: Strengthen climate change resilience

- Conserve, manage and where appropriate rehabilitate natural ecosystems that play a critical role in climate change adaptation. For example, beaches, dunes, estuaries, mangroves and kelp forests should be maintained in an ecologically healthy and functioning state as they play a critical role in helping humans cope with the impacts of climate change.
- Implement integrated ecosystem-based management including Integrated Coastal Management and the Ecosystem Approach to Fisheries management.
- Ensure MPAs support resilience to climate change through adequate representivity and connectivity by expanding and consolidating the MPA network.
- Improve the knowledge base to support the understanding of climate change in South Africa. Long-term monitoring is a key element in research to understand climate variability and change.
- Further develop scientific capacity to detect and predict changes and provide science-based advice to support climate change adaptation and mitigation.
- Develop adaptive management capacity including enhanced management flexibility to adapt to a changing environment.
- Ensure policies encourage diversification of resource use and income generation to enhance social resilience in the face of uncertainty and variability. This is especially important for the most vulnerable coastal and fisher communities.

Priority Action: Ensure sufficient freshwater flow to the coastal and marine environment

- The needs of coastal and marine ecosystems (water quantity, water quality & sediment) should be taken into account in determining and implementing ecological water requirements for estuaries.

Priority Action: Strengthen institutional arrangements to facilitate integrated ecosystem-based management

- Develop effective institutional arrangements to underpin co-operative governance to support ecosystem based management (including the Ecosystem Approach to Fisheries management) and integrated strategic planning and management (including Integrated Coastal Management).
- Consider the development of an Inter-Departmental Liaison Committee for Marine Ecosystems, similar to the recently established Inter-Departmental Liaison Committee for Freshwater Ecosystems. This could provide opportunities for the various key role-players in marine ecosystem management and conservation to establish shared objectives and to collaborate actively, and to clarify respective roles and responsibilities.
- Strengthen collaboration between DEA and DAFF around the management, sustainable use and conservation of marine ecosystems. Formal co-operation with clear roles and responsibilities is needed to support Marine Protected Area establishment and management, Integrated Coastal Management and other types of effective spatial management. The multiple objectives of MPAs including both biodiversity conservation and fisheries sustainability should be recognised and inter-departmental co-operation is critical to the success of MPAs.

Priority Action: Invest in the knowledge base to support biodiversity assessment and management

- Refine the marine and coastal habitat classification and map based on testing the validity of the current classification, high resolution bathymetric mapping, and systematic marine biodiversity surveys across broad ecosystem groups.
- Collate information and conduct dedicated sampling to develop descriptions of habitat types.
- Establish long-term in-situ monitoring sites across broad ecosystem groups to calibrate the assessment of ecosystem condition and inform responses to emerging impacts.
- Invest in improved baselines through the capture, analysis and management of historical datasets.
- Re-instate and secure the scientific observer program in the long term to improve the knowledge base that supports fisheries management, identification of key biodiversity impacts of fisheries and the development of appropriate mitigation measures.
- Secure resources for, develop and implement a marine biodiversity information strategy. This should support the development and management of appropriate co-ordinated

specimen, species and genetic databases and address taxonomic priorities, support conservation assessments and the identification of invasive species.

- Improve co-ordination and collaboration in the collation and management of marine biodiversity data. Encourage data sharing to catalyse increased benefits, application and data security.
- Develop opportunities for all stakeholders to contribute to the assessment and conservation of marine biodiversity. Collaborative mainstreaming initiatives, participatory research, citizen science initiatives & co-management arrangements can help to improve public participation.

18 References

Agenbag, JJ (Compiler). 2011. State of the oceans Report No. 10. Pretoria: Oceans and Coasts, Department of Environmental Affairs.

Agius C, Tanti J. 1997. Status of fish diseases in the Mediterranean. In: Flegel TW, MacRoe IH (eds), *Diseases in Asian Aquaculture III*. Manila: Fish Health Section, Asian Fisheries Society. Pp 155-160.

Al-Agha MR, Mortaja RS. 2005. Desalination in the Gaza Strip: drinking water supply and environmental impact. *Desalination* 173:157-171.

Allanson BR, Baird D (eds). 1999. *The estuaries of South Africa*. Cambridge: Cambridge University Press.

Allen BR, Cliff G. 2000. Sharks caught in the protective gill nets off KwaZulu-Natal, South Africa. 9. The spinner shark *Carcharhinus brevipinna* (Muller and Henle). *South African Journal of Marine Science* 22: 199-215.

Almany GR, Connolly SR, Heath DD, Hogan JD, Jones GP, McCook LJ, Mills M, Pressey RL, Williamson DH. 2009. Connectivity, biodiversity conservation and the design of networks for coral reefs. *Coral Reefs* 28: 339-351.

Alongi D. 1990. The ecology of tropical soft -bottom benthic ecosystems. *Oceanography and Marine Biology: An Annual Review* 28: 381-496.

Alverson DL, Freeberg MK, Murawski SA, Pope JG. 1994. *A global assessment of fisheries bycatch and discards.* FAO Fisheries Technical Paper No 339. Rome: FAO.

Anderson DM, Hoagland P, Kaoru Y, White AW. 2000. Estimated Annual Economic Impacts from Harmful Algal Bloom (HABs) in the United States, Technical Report WHOI-2000-11. Woods Hole, Massachusettes: Woods Hole Oceanographic Institute.

Anderson LWJ. 2005. California's reaction to *Caulerpa taxifolia*: a model for invasive species rapid response. *Biological Invasions* 7: 1003-1016.

Anderson ME, Hulley PA. 2000. Functional ecosystems: the Deep Sea. In: Durham BD, Pauw JC (eds), *Marine Biodiversity Status Report for South Africa at the end of the 20th Century*: Pretoria: National Research Foundation. Pp 20-25.

Anderson RJ, Levitt GJ, Share A. 1996. Experimental investigations for the mariculture of *Gracilaria* in Saldanha Bay, South Africa. *Journal of Applied Phycology* 8: 421-430.

Anderson RJ, Rothman MD, Share A, Drummond H. 2006. Harvesting of the kelp *Ecklonia maxima* in South Africa affects its three obligate, red algal epiphytes. *Journal of Applied Phycology* 18: 343-349.

Anderson RJ. 2000. Functional Ecosystems: Subtidal Hard Substrata. In: Durham BD, Pauw JC (eds), *Summary Marine Biodiversity Status Report for South Africa*. Pretoria: National Research Foundation.

André C, Larsson LC, Laikre L, Bekkevold D, Brigham J, Carvalho GR, Dahlgren TG, Hutchinson WF, Mariani S, Mudde K, Ruzzante DE, Ryman N. 2011. Detecting population structure in a high gene-flow species, Atlantic herring (*Clupea harengus*): direct, simultaneous evaluation of neutral vs putatively selected loci. *Heredity* 106: 270-280.

Angel A, Branch GM, Wanless RM, Siebert T. 2006. Causes of rarity and range restriction of an endangered, endemic limpet, *Siphonaria compressa*. *Journal of Experimental Marine Biology and Ecology* 330: 245-260.

Apitz SE. 2011. Conceptualizing the role of sediment in sustaining ecosystem services: Sediment-ecosystem regional assessment (SEcoRA). *Science of the Total Environment* in press. DOI: 10.1016/j.scitotenv.2011.05.060.

Arnaud F, Child CA. 1988. The South African Museum's Meiring Naudé cruises. Part 17. Pycnogonia. *Annals of the South African Museum* 98: 121-187.

Ashton G, Boos K, Shucksmith R, Cook E. 2006. Rapid assessment of the distribution of marine non-native species in marinas in Scotland. *Aquatic Invasions* 1: 209-213.

Atkinson L, Sink K. 2008. User profiles for the South African offshore environment. SANBI Biodiversity Series 10. Pretoria: South African National Biodiversity Institute.

Atkinson LJ, Field JG, Hutchings L. 2011b. Effects of demersal trawling along the west coast of southern Africa: multivariate analysis of benthic assemblages. *Marine Ecology Progress Series* 430: 241-255.

Atkinson LJ, Leslie R, Field JG, Jarre A. 2011a. Changes in demersal fish assemblages on the west coast of South Africa, 1986-2009. *African Journal of Marine Science* 33:157-170.

Atkinson LJ. 2010. Effects of demersal trawling on marine infaunal. epifaunal and fish assemblages: studies in the southern Benguela and Oslofjord. PhD Thesis, University of Cape Town, South Africa.

Attwood C, Moloney CL, Stenton-Dozey J, Jackson L.F, Heydorn AEF, Probyn TA. 2000. Conservation of Marine Biodiversity in South Africa, In: Durham BD, Pauw JC (eds), *Summary Marine Biodiversity Status Report.* Pretoria: National Research Foundation. Pp 68-83.

Attwood CG, Farquhar M. 1999. Collapse of linefish stocks between Cape Hangklip and Walker Bay, South Africa. *South African Journal of Marine Science* 21: 415-432.

Attwood CG, Mann BQ, Beaumont J, Harris JM. 1997. Review of the state of marine protected areas in South Africa. *South African Journal of Marine Science* 18: 341-367.

Attwood CG, Petersen SL, Kerwath SE. 2011. Bycatch in South Africa's inshore trawl fishery as determined from observer records. *ICES Journal of Marine Science* 68: 2163-2174. DOI:10.1093/icesjms/frs162.

Attwood CG. 2003. Dynamics of the fishery for galjoen *Dichistius capensis*, with an assessment of monitoring methods. *African Journal of Marine Science* 25: 311-330.

Augustyn CJ, Smale MJ. 1989. Cephalopods In: Payne AIL, Crawford RJM (eds), *Oceans of Life off southern Africa.* Cape Town: Vlaeberg Publishers. pp 91-104.

Avis AAM. 1995. An Evaluation of the Vegetation Developed after Artificially Stabilizing South African Coastal Dunes with Indigenous Species. *Journal of Coastal Conservation* 1:41-50.

Awad A, Clarke C, Greyling L, Hilliard R, Polglaze J, Raaymakers S. 2004. Ballast Water Risk Assessment, Port of Saldanha Bay, Republic of South Africa, November 2003: Final Report. GloBallast Monograph Series No. 13. London: International Maritime Organisation.

Awad A, Greyling L, Kirkman S, Botes L, Clark B, Prochazka K, Robinson T, Kruger N, Joyce L. 2003. Port Biological Baseline Survey Report, Port of Saldanha, South Africa. Report for the Global Ballast Water Management Programme, IMO/UNDP/GEF. London, UK: International Maritime Organisation.

Ayre DJ, Minchinton TE, Perrin C. 2009. Does life history predict past and current connectivity for rocky intertidal invertebrates across a marine biogeographic barrier? *Molecular Ecology* 18: 1887-1903.

Badenhorst A, Smale MJ. 1991. The distribution and abundance of seven commercial trawlfish from the Cape south coast of South Africa, 1986-1990. *South African Journal of Marine Science* 11: 377-393

Bailey GW, Rogers J. 1997. Chemical oceanography and marine geoscience off southern Africa: Past discoveries in the post-Gilchrist era, and future prospects. *Transactions of the Royal Society of South Africa* 52(1): 51-79.

Bakun A, Weeks SJ. 2004. Greenhouse gas buildup, sardines, submarine eruptions and the possibility of abrupt degradation of intense marine upwelling ecosystems. *Ecology Letters* 7: 1015-1023

Bakun A, Weeks SJ. 2006. Adverse feedback sequences in exploited marine systems: are deliberate interruptive actions warranted? *Fish and Fisheries* 7: 316-333.

Ball BJ, Fox G, Munday BW. 2000. Long and short-term consequences of a *Nephrops* trawl fishery on the benthos and environment of the Irish Sea. *ICES Journal of Marine Science* 57: 1315-1320.

Bally R, Griffiths CL. 1989. Effects of human trampling on an exposed rocky shore. *International Journal of Environmental Studies* 34:115-125.

Bally R, McQuaid CD, Brown AC. 1984. Shores of mixed sand and rock: an unexplored ecosystem. *South African Journal of Science* 80: 500-503.

Balmford A, Bruner A, Cooper P, Costanza R, Farber S, Green RE, Jenkins M, Jefferiss P, Jessamy V, Madden J, Munro K, Myers N, Naeem S, Paavola J, Rayment M, Rosendo S, Roughgarden J, Trumper K, Turner RK. 2002. Economic reasons for conserving wild nature. *Science* 297: 950-953.

Baloyi R. 2006. *Producers of sand and aggregate in South Africa.* Pretoria: Department of Minerals and Energy, South Africa.

Balvanera P, Pfisterer AB, Buchmann N, He J-S, Nakashizuka T, Rafaelli D, Schmid B. 2006. Quantifying the evidence for biodiversity effects on ecosystem functioning and services. *Ecology Letters* 9:1146-1156.

Barbier EB, Hacker SD, Kennedy CJ, Koch EW, Stier AC, Silliman BR. 2011. The value of estuarine and coastal ecosystem services. *Ecological Monographs* 81:169-193.

Barkai A, Bergh MO. 1992. The effect of marine diamond pumping operations on the littoral and shallow sublittoral benthos along the South African west coast, Namaqualand region, with special attention to possible effects on the rock lobster resource: a pilot study. Marine Diamond Mining Association (MDMA).

Barkai A, Branch GM. 1988. Energy requirements for a dense population of rock lobsters *Jasus lalandii*: novel importance of unorthodox food sources. *Marine Ecology Progress Series* 50: 83-96.

Barluenga M, Meyer A. 2010. Phylogeography, colonization and population history of the Midas cichlid species complex (*Amphilophus* spp.) in the Nicaraguan crater lakes. *BMC Evolutionary Biology* 10: 326.

Barnes KN, Ryan PG, Boix-Hinzen C. 1997. The impact of the hake *Merluccius* spp. longline fishery off South Africa on procellariiform seabirds. *Biological Conservation* 82: 227-234.

Barry SC, Hayes KR, Hewitt CL, Behrens HL, Dragsund E, Bakke SM. 2008. Ballast water risk assessment: principles, processes, and methods. *ICES Journal of Marine Science* 65: 121-131.

Beck MW, Heck KL, Able K, Childers D, Eggleston D, Gillanders B, Halpern BS, Hays C, Hoshino K, Minello T, Orth R, Sheridan PF, Weinstein M. 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. *BioScience* 51: 633.

Beck MW, Heck KL, Able K, Childers D, Eggleston D, Gillanders B, Halpern BS, Hays C, Hoshino K, Minello T, Orth R, Sheridan PF, Weinstein M. 2003. The role of nearshore ecosystems as fish and shellfish nurseries. *Issues in Ecology* 11: 1-12.

Bennett BA. 1993. The fishery for white steenbras *Lithognathus lithognathus* off the Cape coast, South Africa, with considerations for its management. *South African Journal of Marine Science* 13: 1-14.

Berkeley SA, Hixon MA, Larson RJ, Love MS. 2004. Fisheries sustainability via protection of age structure and spatial distribution of fish populations. *Fisheries* 29: 23-32.

Bernard KS. 2011. The impacts of ocean adicidfication on a keystone Southern Ocean species. In: Zietsman L (ed), *Observations on Environmental Change in South Africa*. Stellenbosch: SUN PReSS. Pp 273-275.

Berruti A, Adams NJ, Jackson S. 1989. The Benguela ecosystem VI: Seabirds. *Oceanography and Marine Biology: An Annual Review* 27: 273-335.

Berry PF, Hanekom P, Joubert C, Joubert F, Schleyer MH, Smale M, van der Elst R. 1979. Preliminary account of the biomass and major energy pathways through a Natal nearshore reef community. *South African Journal of Science* 75: 565.

Berry PF, Scheler MH. 1983. The brown mussel *Perna perna* on the Natal coast, South Africa: utilization of available food and energy budget. *Marine Ecology Progress Series* 13: 201-210.

Berry PF. 1969. The biology of *Nephrops andamanicus* Wood-Mason (Decapoda, Reptantia). *Oceanographic Research Institute Investigational Report* 22: 1-55.

Bianchi G, Gislason H, Graham K, Hill L, Jin X, Koranteng K, Manickchand-Heileman S, Paya I, Sainsbury K, Sanchez F, Zwanenburg KCT. 2000. Impact of fishing on size composition and diversity of demersal fish communities. *ICES Journal of Marine Science* 57: 558-571.

Birch GF, Rogers J. 1973. Nature of the seafloor between Lüderitz and Port Elizabeth. *South African Shipping News and Fishing Industry Review* 39 (7): 56-65.

BirdLife International 2008. *Morus capensis*. In: IUCN 2011. IUCN Red List of Threatened Species. Version 2011.1. <www.iucnredlist.org>. Downloaded on 03 November 2011.

Bjørn PA, Finstad B. 2002. Salmon lice, *Lepheophtheirus salmonis* (Krøyer), infestation in sympatric populations of Arctic char, *Salvelinus alpinus* (L.), and sea trout, *Salmo trutta* (L.), in areas near and distant from salmon farms. *ICES Journal of Marine Science* 59: 131-139.

Bjørn PA, Tveiten H, Johnsen HK, Finstad B, McKinley RS. 2002. Salmon lice and stress: effects on reproductive performance in Arctic charr. In: Riehl M, Struthers M (eds), *Aquanet II, Proceedings of the 2002 Annual Research Conference of Aquanet, September 14-17, 2002, Delta Beausejour, Moncton, New Brunswick, Canada.*

Black KD, Fleming S, Nickell TD, Pereira PMF. 1997. The effect of ivermectin, used to control sea lice on caged farmed salmonids, on infaunal polychaetes. *ICES Journal of marine Science* 54: 276-279.

Black KD, McLusky DS, Nickell TD, Pereira PM, Pereira PMF. 2004. Recovery of the sediments after cessation of marine fish farm production. *Aquaculture* 235: 315-330.

Blakeslee AMH, McKenzie CH, Darling JA, Byers JE, Pringle JM, Roman J. 2010. A hitchhiker's guide to the Maritimes: anthropogenic transport facilitates long-distance dispersal of an invasive marine crab to Newfoundland. *Diversity and Distributions* 16: 879-891.

Blamey L. 2010. Ecosystem effects of a rock-lobster 'invasion': comparative and modelling approaches. PhD Thesis, University of Cape Town, South Africa.

Blamey LK, Branch GM. 2009. Habitat diversity relative to wave action on rocky shores: implications for the selection of marine protected areas. *Aquatic Conservation: Marine and Freshwater Systems* 19: 645-657

Blood J, Corbett L. 2006. Proposed development of the Ibhubesi Gas Field and associated infrastructure: Final Scoping Report. Report no. FOR07IB/FSR/2 CCA Environmental. Prepared for Forest Exploration International.

Bogdanov YA. 1965. Suspended organic matter in the Pacific. *Oceanology* 5: 77-85.

Bolton JJ, Anderson RJ. 1997. Marine vegetation. In: Cowling RM, Richardson DM, Pierce SM (eds), *Vegetation of southern Africa*. Oxford: Cambridge University Press. Pp 348-370.

Bolton JJ, Leliaert F, De Clerck O, Anderson RJ, Stegenga H, Angledow HE, Coppejans E. 2004. Where is the western limit of the tropical Indian Ocean seaweed flora? An analysis of intertidal seaweed biogeography on the east coast of South Africa. *Marine Biology* 144: 51-59.

Bolton JJ, Stegenga H, Anderson RJ, Anderson P. 1997. Seaweeds of the South African west coast: a biogeographic analysis. *Phycologia* 36: 9-10.

Bongiorni L, Mirto S, Pusceddu A, Danovaro R. 2005. response of benthic protozoa and thraustochytrid protests to fish farm impact in seagrass (*Posidonia oceanica*) and soft bottom sediments. *Microbial Ecology* 50(2): 268-276.

Booth AJ, Hecht T. 2000. Utilisation of South Africa's living marine resources. In: Durham BD, Pauw JC (eds), *Summary of the Marine Biodiversity Status Report for South Africa at the end of the 20th Century*. Pretoria: National Research Foundation. Pp 57-67.

Bosman AL, Hockey PAR. 1986. Seabird guano as a determinant of rocky intertidal community structure. *Marine Ecology Progress Series* 32: 247-257.

Botes L, Awad A. 2004. Progress in investigating the possibility that the South African brown tide species is introduced. (oral). *11th International Conference on Harmful Algae, Cape Town, 15 - 19 November 2004, South Africa.*

Botes L. 2003. Phytoplankton identification catalogue - Saldanha Bay, April 2001. *GloBallast Monograph Series.* No. 7. London: International Maritime Organisation. pp 1 - 77.

Bownes SJ, McQuaid CD. 2006. Will the invasive mussel *Mytilus galloprovincialis* Lamark replace the indigenous *Perna perna* L. on the south coast of South Africa? *Journal of Experimental Marine Biology and Ecology* 338: 140-151.

Boyd J, Banzhaf S. 2007. What are ecosystem services? The need for standardized environmental accounting units. *Ecological Economics* 63:616-626.

Boyra A, Haroun RJ, Nascimento FJA, Sanchez-Jerez P, Tuya F. 2004. Impact of sea-cage farms on intertidal macrobenthic assemblages. *Journal of the Marine Biological Association of the United Kingdom* 84: 665-668.

Branch GM, Odendaal F, Robinson TB. 2008. Long-term monitoring of the arrival, expansion and effects of an alien mussel *Mytilus galloprovincialis* relative to wave action. *Marine Ecology Progress Series* 370: 171-183.

Branch GM, Odendaal F, Robinson TB. 2009. Competition and facilitation between the alien mussel *Mytilus galloprovincialis* and indigenous species: moderation by wave action. *Journal of Experimental Marine Biology and Ecology* 383: 65-78. DOI:10.1016/j.jembe.2009.10.007.

Branch GM, Odendaal F, Robinson TB. 2010. Competition and facilitation between the alien mussel *Mytilus galloprovincialis* and indigenous species: Moderation by wave action. *Journal of Experimental Marine Biology and Ecology* 383: 65-78.

Branch GM, Odendaal F. 2003. Marine protected areas and wave action: impacts on a South African limpet, *Cymbula oculus*. *Biological Conservation* 114: 255-269.

Branch GM, Pringle A. 1987. The impact of the sand prawn *Callianssa krausii* Stebbing on sediment turnover and on bacteria, meiofauna, and sediment microflora. *Journal of Experimental Marine Biology and Ecology* 107: 219 - 235.

Branch GM, Steffani CN. 2004. Can we predict the effects of alien species? A case-history of the invasion of South Africa by *Mytilus galloprovincialis* (Lamarck). *Journal of Experimental Marine Biology and Ecology* 300: 189-215.

Brandão A, Butterworth DS. 2008. An updated assessment of the South African kingklip resource including some sensitivity tests. Report No. MCM/2008/FEB/SWG-DEM/03-Rev2. Cape Town: Marine and Coastal Management.

Brenner JJ, Jiménez JA, Sardá R, Garola A. 2010. An assessment of the non-market value of the ecosystem services provided by the Catalan coastal zone, Spain. *Ocean and Coastal Management* 53: 27-38.

Brierley AS, Kingsford MJ. 2009. Impacts of Climate Change on Marine Organisms and Ecosystems Current Biology. *Current Biology* 19: R602-R614. DOI:10.1016/j.cub.2009.05.046.

Brooke RK, Crow TM. 1982. Variation in species richness among the offshore islands of the southwestern Cape. *South African Journal of Zoology* 17: 49-58.

Brooke RK, Prins AJ. 1986. Review of alien species on South African offshore islands. *South African Journal* of *Antarctic Research* 16: 102-109.

Brouwer SL, Buxton CD. 2002. Catch and effort of the shore and ski-boat linefisheries along the South African Eastern Cape coast. *South African Journal of Marine Science* 24: 341-354.

Brouwer SL, Griffiths MH. 2005a. Influence of sample design on estimates of growth and mortality in *Argyrozona argyrozona* (Pisces: Sparidae). *Fisheries Research* 74: 44-54.

Brouwer SL, Griffiths MH. 2005b. Reproductive biology of carpenter seabream (*Argyrozona argyrozona*) (Pisces: Sparidae) in a marine protected area. *Fishery Bulletin* 103: 258-269.

Brouwer SL, Mann BQ, Lamberth SJ, Sauer WHH, Erasmus C. 1997. A survey of the South African shore-angling fishery. *South African Journal of Marine Science* 18: 165-177.

Brown AC, McLachlan A, Kerley GIH, Lubke RA. 2000. Functional ecosystems: sandy beaches and dunes. In: Durham BD, Pauw JC (eds), *Summary Marine Biodiversity Status Report for South Africa.* Pretoria: National Research Foundation. pp 4-5.

Brown AC, McLachlan A. 1990. *Ecology of Sandy Shores*. Amsterdam: Elsevier.

Brown AC. McLachlan A. 2002. Sandy shore ecosystems and the threats facing them: some predictions for the year 2025. *Environmental Conservation* 29: 62-77.

Bustamante RH, Branch GM, Eekhout S. 1997. The influences of physical factors on the distribution and zonation patterns of South African rocky-shore communities. *South African Journal of Marine Science* 18: 119-136.

Bustamante RH, Branch GM, Eekhout,S, Robertson B, Zoutendyk P, Schleyer M, Dye A, Keats D, Jurd M, McQuaid CD. 1995. Gradients of intertidal productivity around the coast of South Africa and their relationship with consumer biomass. *Oecologia*. 102: 189-201.

Bustamante RH, Branch GM. 1996a. Large scale patterns and trophic structure of southern African rocky shores: The role of geographic variation and wave exposure. *Journal of Biogeography* 23: 339-351.

Bustamante RH, Branch GM. 1996b. The dependence of intertidal consumers on kelp-derived organic matter on the west coast of South Africa. *Journal of Experimental Marine Biology and Ecology* 196: 1-28.

Butterworth DS, Rademeyer RA. 2005. Sustainable management initiatives for the southern African hake fisheries over recent years. *Bulletin of Marine Science* 76: 287-319.

Buxton CD. 1993. Life-history changes in exploited reef fishes on the east coast of South Africa. *Environmental Biology* of Fishes 36: 47-63.

Caldeira K, Wickett ME. 2003. Anthropogenic carbon and ocean pH. *Nature* 425: 365.

Campbell EE, Bate GC. 1988. The estimation of annual primary production in a high energy surf-zone. *Botanica Marina* 31:337-343.

Campbell EE, Bate GC. Ground water in the Alexandria dune field and its potential influence on the adjacent surf-zone. *Water SA* 17: 155-160.

Carlton JT. 1985. Transoceanic and interoceanic dispersal of coastal marine organisms: the biology of ballast water. *Oceanography and Marine Biology: An Annual Review* 23: 313-374.

Carr J, Whoriskey F. 2004. Sea lice infestation rates on wild and escaped farmed Atlantic salmon (*Salmo salar* L.) entering the Magaguadavic River, New Brunswick. *Aquaculture Research* 35: 723-729.

Carriker MR. 1992. Introductions and transfers of molluscs: risk considerations and implications. *Journal of Shellfish Research* 11: 507-510.

Carroll ML, Cochrane S, Fieler R, Velvin R, White P. 2003. Organic enrichment of sediments from salmon farming in Norway: environmental factors, management practices and monitoring techniques. *Aquaculture* 226: 165-180.

Casas G, Scrosati R, Piriz ML. 2004. The invasive kelp *Undaria pinnatifida* (Phaeophyceae, Laminariales) reduces native seaweed diversity in Nuevo Gulf (Patagonia, Argentina). *Biological Invasions* 6: 411-416.

Celliers L, Mann BQ, Macdonald AHH, Schleyer MH. 2007. A benthic survey of the rocky reefs off Pondoland, South Africa. *African Journal of Marine Science* 29: 65-77.

Celliers L, Moffett T, James NC, Mann BQ. 2004. A strategic assessment of recreational use areas for off-road vehicles in the coastal zone of KwaZulu-Natal, South Africa. *Ocean and Coastal Management* 47: 123-140.

Celliers L, Schleyer MH. 2008. Coral community structure and risk assessment of high-latitude reefs at Sodwana Bay, South Africa. *Biodiversity Conservation* 17: 3097-3117.

Chambers CB, Ernst I. 2005. Dispersal of the skin fluke *Benedenia seriolae* (Monogenea: Capsalidae) by tidal currents and implications for sea-cage farming of *Seriola* spp. *Aquaculture* 250: 60-69.

Chang AL, Blakeslee AMH, Miller AW, Ruiz GM. 2011. Establishment failure in biological invasions: a case history of *Littorina littorea* in California, USA. *PLoS One* 6: e16035.

Charlier RH, Chaineux MP. 2009. The Healing Sea: A Sustainable Coastal Ocean Resource: Thalassotherapy. *Journal of Coastal Research* 25:838-856.

Chen CA, Borges AV. 2009. Reconciling opposing views on carbon cycling in the coastal ocean: Continental shelves as sinks and near shore ecosystems as sources of atmospheric CO2. *Deep-Sea Research II* 56: 578-590.

Cheung WWL, Lam VWY, Sarmiento JL, Kearney K, Watson R, Pauly D. 2009. Projecting global marine biodiversity impacts under climate change scenarios. *Fish and Fisheries* 10: 235-251.

Christie ND. 1981. Primary production in Langebaan Lagoon. In Day JH (ed), *Estuarine Ecology with Special Reference to Southern Africa.* Cape Town: A.A. Balkema. Pp 101-116.

Churchill JH. 1998. Sediment resuspension by bottom fishing gear. In: Dorsey EM, Pederson EM (eds), *Effects of Fishing Gear on the Sea Floor of New England.* Boston: Conservation Law Foundation. pp 134-137.

Chust G, Borja A, Liria P, Galparsoro I, Marcos M, Caballero A, Castro R. 2009. Human impacts overwhelm the effects of sea-level rise on Basque coastal habitats (N Spain) between 1954 and 2004. *Estuarine, Coastal and Shelf Science* 84: 453-462.

Clark B, Lombard A. 2007. A marine conservation plan for the Agulhas Bioregion: options and opportunities for enhancing the existing MPA network. Cape Town: Anchor Environmental Consultants.

Clark BM, Hauck M, Harris JM, Salo K, Russell E. 2002. Identification of subsistence fishers, fishing areas, resource use and activities along the South African coast. *South African Journal of Marine Science* 24: 425-437.

Clark BM, Lombard AJ. 2007. A marine conservation plan for the Agulhas bioregion: options and opportunities for enhancing the existing MPA network. Cape Town: WWF South Africa.

Clark BM, Meyer WF, Ewart-Smith C, Pulfrich A, Hughes J. 1999. Synthesis and assessment of information on the BCLME Thematic report 3: Integrated overview of diamond mining in the Benguela Current Region. Anchor Environmental Report No. 1016/1. Cape Town: Benguela Current Large Marine Ecosystem Program.

Clark BM, Nel R. 2002. *Baseline Survey for sandy beaches in Mining Area 1.* Windhoek: NAMDEB Diamond Corporation.

Clark BM, Smith CE, Meyer WF. 1998. Ecological effects of fine tailings disposal and marine diamond pumping operations on surf zone fish assemblages near Lüderitz, Namibia. Anchor Environmental Consultants Report No. 1009/2.

Clarke RB. 1984. Impact of oil pollution on seabirds. *Environmental Pollution* 33: 1-22.

Claudi R, Ravishankar TJ. 2006. Quantification of risks of alien species introductions associated with ballast water discharge in the Gulf of St. Lawrence. *Biological Invasions* 8: 25-44.

Cliff G, Dudley SFJ, Davis B. 1989. Sharks caught in the protective gill nets off Natal, South Africa. 2. The great white shark (*Carcharodon carcharias*). *South African Journal of Marine Science* 8: 131-144.

Cliff G, Dudley SFJ. 2011. Reducing the environmental impat of shark-control programs: a case study from KwaZulu-Natal, South Africa. *Marine and Freshwater Research* 62: 700-709.

Clifford SL, McGinnity P, Ferguson,A. 1998. Genetic changes in Atlantic salmon (*Salmo salar*) populations of Northwest Irish rivers resulting from escapes of adult farm salmon. *Canadian Journal of Fisheries and Aquatic Sciences* 55: 358-363.

Cockcroft AC, Payne AIL. 1999. A cautious fisheries management policy in South Africa: the fisheries for rock lobster. *Marine Policy* 23: 587-600.

Cockcroft AC, Sauer WHH, Branch GM, Clark BM, Dye AH, Russell E. 2002. Assessment of resource availability and suitability for subsistence fishers in South Africa, with a review of resource management procedures. *South African Journal of Marine Science* 24:489-501.

Cockcroft AC. 1997. Biochemical composition as a growth predictor in male west-coast rock lobster (*Jasus lalandii*). *Marine and Freshwater Research* 48: 845-856.

Cockcroft AC. 2011. Large-scale shifts in the spatial distribution of West Coast rock lobster in South Africa. In: Zietsman L (ed), *Observations on Environmental Change in South Africa*. Stellenbosch: SUN PReSS. Pp 257-260.

Cockcroft VG. 1990. Dolphin catches in the Natal shark nets, 1980 to 1988. *South African Journal of Wildlife Research* 20: 44-51.

Cockcroft, AC, Goosen PC. 1995. Shrinkage at moulting in the rock lobster *Jasus lalandii* and associated changes in reproductive parameters. *South African Journal of Marine Science* 16: 195-203.

Cockroft AC, Mackenzie AJ. 1997. The recreational fishery for west coast rock lobster *Jasus lalandii* in South Africa. *South African Journal of Marine Science* 18: 75-84.

Cockroft AC, van Zyl D, Hutchings L. 2008 Large-scale changes in the spatial distribution of South African West Coast rock lobsters: an overview. *African Journal of Marine Science* 30: 149-159.

Coetzee JC, van der Lingen CD, Hutchings L, Fairwather TP. 2008. Has the fishery contributed to a major shift in the distribution of South African sardine? *ICES Journal of Marine Science* 65: 1676-1688. DOI:10.1093/icesjms/fsn184

Cohen AN, Carlton JT. 1998. Accelerated invasion rate in a highly invaded estuary. *Science* 279: 555-558.

Cohen DM. 1986. Latitudinal variation in diversity and biomass in IKMT catches from the western Indian Ocean. In: Pierrt-Bults AC, van der Spoel S, Zahuranec BJ, Johnson RK (eds), *Pelagic Biogeography*. *UNESCO Technical Papers in Marine Science* 49:54-59.

Cole VJ, McQuaid CD, 2010. Bioengineers and their associated fauna respond differently to the effects of biogeography and upwelling. *Ecology* 91: 3549-3562.

Collie JS, Escanero GA, Valentine PC. 1997. Effects of bottom fishing on the benthic megafauna of Georges Bank. *Marine Ecology Progress Series* 155: 159-172.

Connor DW, Allen JH, Golding N, Howell KL, Lieberknecht LM, Northen KO, Reker JB. 2004. *The marine habitat classification for Britain and Ireland.* Version 0405. Peterborough: Joint Nature Conservation Committee.

Connor DW, Gilliland PM, Golding N, Robinson P, Todd D, Verling E. 2006. *UKSeaMap: the mapping of seabed and water column features of UK seas.* Peterborough: Joint Nature Conservation Committee.

Cooper J, Brooke RK. 1986. Alien plants and animals on South African continental and oceanic islands: species richness, ecological impacts and management. In: Macdonald IAW, Kruger FJ, Ferrar AA (eds), *The ecology and management of biological invasions in southern Africa*. Cape Town: Oxford University Press. Pp 133-142.

Costanza R, D'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Niell RV, Paruelo J, Raskin RG, Sutton P, van den Belt M. 1997. The value of the world’s ecosystem services and natural capital. *Nature* 387:253-260.

Costanza R, Kubiszewski I, Ervin D, Bluffstone R, Boyd J, Brown D, Chang H, Dujon V, Granek E, Polasky S, Shandas V, Yeakley A. 2011. Valuing ecological systems and services. *F1000 Biology Reports* 3:1-6.

Coupland GT, Duarte CM, Walker DI. 2007. High metabolic rates in beach cast communities. *Ecosystems* 10: 1341-1350.

Coutts A, Taylor M, Hewitt C. 2007. Novel method for assessing the en route survivorship of biofouling organisms on various vessel types. *Marine Pollution Bulletin* 54: 97-116.

Coutts ADM, Forrest BM. 2007. Development and application of tools for incursion response: lessons learned from the management of a potential marine pest. *Journal of Experimental Marine Biology and Ecology* 342: 154-162.

Cowen R K, Sponaugle S. 2009. Larval Dispersal and Marine Population Connectivity. *Annual Review of Marine Science* 1:443-466.

Cowley PD, Brouwer SL, Tilney RL. 2002. The role of Tsitsikama National Park in the management of four shore-angling fish along the south-eastern Cape coast of South Africa. *South African Journal of Marine Science* 24: 27-35.

Crandall KA, Bininda-Emonds ORP, Mace GM, Wayne RK. 2000. Considering evolutionary processes in conservation biology. *Trends in Ecology and Evolution* 15**:** 291-295.

Cranford PJ, Gordon DC, Lee K, Armsworthy SL, Tremblay GH. 1999. Chronic toxicity and physical disturbance effects of water- and oil-based drilling fluids and some major constituents on adult sea scallops (*Placopecten magellanicus*). *Marine Environmental Research* 48: 225-256.

Crawford CM, Mitchell IM, Macleod CK, Macleod CKA. 2001. Video assessments of environmental impacts of salmon farms. *ICES Journal of Marine Science* 58: 445-452.

Crawford RJM, Davis SA, Harding R, Jackson LF, LeshoroTM, Meyer MA, Randal, RM, Underhil, LG, Upfold L, Van Dalsen AP, Van der Merwe E, Whittington PA, Williams AJ, Wolfaart AC. 2000. Initial impact of the Treasure oil spill on seabirds off western South Africa. *South African Journal of Marine Science* 22: 157-176.

Crawford RJM, Dyer BM, Cordes I, Williams AJ. 1999. Seasonal pattern of breeding, population trend and conservation status of bank cormorants *Phalacrocorax neglectus* off south western Africa. *Biological Conservation 87*: 49-58.

Crawford RJM, Sabarros PS, Fairweather T, Underhill LG, Wofaardt AC. 2008. Implications for seabirds off South Africa of a long-term change in the distribution of sardine. *African Journal of Marine Science* 30: 177-184.

Crawford RJM, Shannon LV, Pollock DE. 1987. The Benguela ecosystem. Part IV. The major fish and invertebrate resources. *Oceanography and Marine Biology: An Annual Review* 25: 353-505.

Crawford RJM. 1998. Responses of African Penguins to regime changes of sardine and anchovy in the Benguela system. *South African Journal of Marine Science* 19: 355-364.

Crooks JA, Chang AL, Ruiz GM. 2011. Aquatic pollution increases the relative success of invasive species. *Biological Invasions* 13: 165-176.

Crowther Campbell and Associates, Centre for Marine Studies. 2001. Generic Environmental Management Programme Reports for oil and gas prospecting off the coast of South Africa. 5 Volumes, Revision 2001. Cape Town: Petroleum Agency SA.

Culver CS, Kuris AM. 2000. The apparent eradication of a locally established introduced marine pest. *Biological Invasions* 2: 245-253.

Currie DR, Isaacs LR. 2005. Impact of exploratory offshore drilling on benthic communities in the Minerva gas field, port Campbell, Australia. *Marine Environmental Research* 59: 217-233.

Cury P, Bakun A, Crawford RJM, Jarre A, Quiñones RA, Shannon LJ, Verheye HM. 2000. Small pelagics in upwelling systems: patterns of interaction and structural changes in “wasp-waist” ecosystems. *ICES Journal of Marine Science* 57: 603-618.

Cwala Z, Igbinosa EO, Okoh AI. 2011. Assessment of antibiotics production potentials in four actinomycetes isolated from aquatic environments of the Eastern Cape Province of South Africa. *Journal of Pharmacy and Pharmacology* 5: 118-124.

Da Silva C, Burgener M. 2007. South Africa's demersal shark meat harvest. *TRAFFIC Bulletin* 21: 55-66.

Da Silva C. 2007. The status and prognosis of the smoothhound shark (*Mustelus mustelus*) fishery in the southeastern and southwestern Cape coasts, South Africa. PhD thesis, Rhodes University, South Africa.

DAFF (Department of Agriculture, Forestry and Fisheries). 2010. *Status of the South African marine fishery resources.* Cape Town: Chief Directorate Fisheries Research, Fisheries Branch, Department of Agriculture, Forestry and Fisheries.

Dahl E. 1952. Some Aspects of the Ecology and Zonation of the Fauna on Sandy Beaches. *Oikos* 4: 1-27.

Daniel H. 2001. Replenishment versus retreat: the cost of maintaining Delaware's beaches. *Ocean and Coastal Management* 44: 87-104.

Darling JA, Bagley MJ, Roman J, Tepolt CK, Geller JB. 2008. Genetic patterns across multiple introductions of the globally invasive crab genus *Carcinus*. *Molecular Ecology* 17: 4992-5007.

Davies IM, Gikllibrand PA, McHenry JG, Rae GH. 1998. Environmental risk of Ivermectin to sediment dwelling organisms. *Aquaculture* 163: 29-46.

Davies IM. 2000. A review of the use of ivermectin as a treatment for sea lice [*Lepeaphtheirus salmonis* (Kroyer) and *Caligus elongates* (Nordmann)] infestation in farmed Atlantic salmon (*Salmo salar* L.). *Aquaculture Research* 31: 869-883.

Davies RWD, Cripps SJ, Nickson A, Porter G. 2009. Defining and estimating global marine fisheries bycatch. *Marine Policy* 33: 661-672.

Davies-Coleman MT, Beukes DR. 2004. Ten years of marine natural products research at Rhodes University. *South African Journal of Science* 100: 539-544.

Davies-Coleman MT. 2010. Natural Products Research in South Africa: End of an Era on Land or the Beginning of an Endless Opportunity in the Sea? *South African Journal of Chemistry* 63: 105-113.

Davis DH. 1964. *About Sharks and Shark Attacks*. Pietermaritzburg: Shuter and Shooter.

Day JH (ed). 1981. *Estuarine Ecology with Particular Reference to Southern Africa*. Cape Town: A.A. Balkema.

Day JH. 1959. The biology of Langebaan Lagoon: A study of the effect of shelter from wave action. *Transaction of the Royal Society of South Africa* 53: 475-547.

Day JH. 1969. *A Guide to Marine Life on South African Shores*. Cape Town: A.A. Balkema.

Dayton PK, Hessler RR. 1972. Role of biological disturbance in maintaining diversity in the deep-sea. *Deep-Sea Research* 19: 199-208.

Dayton PK. 1971. Competition, disturbance and community organisation: the provision and subsequent utilization of space in a rocky intertidal community. *Ecological Monographs* 41: 351-389.

De Albuquerque PMC, Camargo JMFD, Mendonça JÂC. 2007. Bee community of a beach dune ecosystem on Maranhão Island, Brazil. *Brazilian Archives of Biology and Technology* 50: 1005-1018.

De Decker AHB. 1973. Agulhas Bank plankton. In Zeitzschel B (ed), *Ecological Studies: Analysis and Synthesis 3*. Berlin: Springer-Verlag.

De Decker AHB. 1984. Near-shore copepod distribution in the south-western Indian and south-eastern Atlantic Ocean. *Annals of the South African Museum* 93: 303-370.

De Fritas AJ. 1989. Shrimps and prawns. In: Payne AIL, Crawford RJM (eds), *Oceans of Life off southern Africa*. Cape Town: Vlaeberg Publishers. pp 81-90.

de Groot RS, Wilson MA, Boumans RMJ. 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics* 41: 393-408.

De Lange W, Nahman A, Theron AK. 2009. External costs of sand mining in rivers: Evidence from South Africa. In: *Environmental Resource Economics Conference. Cape Town, South Africa, 21 - 22 May 2009.* Pages 1-19.

De Ruyck AMC, Soares AG, McLachlan A. 1995. Factors influencing human beach choice on three South African beaches: A multivariate analysis. *GeoJournal* 36:345-352.

De Villiers CJ, Hodgson AN, Forbes AT. 1999. Studies on estuarine macroinvertebrates. In: Allanson BR, Baird D (eds), *Estuaries of South Africa*. Cambridge: Cambridge University Press. pp 167-207.

DEAT (Department of Environmental Affairs and Tourism). 1999. *State of the Environment South Africa.* Pretoria: Department of Environmental Affairs and Tourism, South Africa.

DEAT (Department of Environmental Affairs and Tourism). 2005. *Draft Policy for the allocation and management of commercial fishing rights in the Demersal shark fishery.* Cape Town: Marine and Coastal Management, Department of Environmental Affairs and Tourism, South Africa.

DEAT (Department of Environmental Affairs and Tourism). 2006. *South Africa Environment Outlook. A report of the state of the environment.* Pretoria: Department of Environmental Affairs and Tourism.

DEAT (Department of Environmental Affairs and Tourism). 2009. *State of the Environment: The Mussel Watch Programme.* Pretoria: Department of Environmental Affairs and Tourism, South Africa.

DEA (Department of Environmental Affairs). 2011. *South Africa's Second National Communication under the United Nations Framework Convention on Climate Change.* Pretoria: Department of Environmental Affairs, South Africa.

Defeo O, McLachlan A, Schoeman DS, Schlacher TA, Dugan J, Jones A, Lastra M, Scapini F. 2009. Threats to sandy beach ecosystems: A review. *Estuarine, Coastal and Shelf Science* 81: 1-12

Defeo O, McLachlan A, Schoeman DS, Schlacher TA, Dugan J, Jones A, Lastra M, Scapini F. 2009. Threats to sandy beach ecosystems: a review. *Estuarine, Coastal and Shelf Science* 81: 1-12.

Defeo O, McLachlan A. 2005. Patterns, processes and regulatory mechanisms in sandy beach macrofauna: a multi-scale analysis. *Marine Ecology Progress Series* 295**,** 1-20.

Demetriades NT, Forbes AT, Mwanyama N, Quinn NW., 2000. Damming the Thukela River: Impacts on the Thukela Bank shallow water prawn resource, Report for the Department of Water Affairs and Forestry, 22 pp.

Dicken ML, Hosking SG. 2009. Socio-economic aspects of the tiger shark diving industry within the Aliwal Shoal Marine Protected Area, South Africa. *African Journal of Marine Science* 31:227-232.

Dingle RV, Birch GF, Bremner JM, De Decker RH, Du Plessis A, Engelbrecht JC, Fincham MJ, Fitton T, Flemming BW, Gentle RI, Goodlad SW, Martin AK, Mills EG, Moir GJ, Parker RJ, Robson SH, Rogers J, Salmon DA, Siesser WG, Simpson ESW, Summerhayes CP, Westall F, Winter A, Woodborne MW. 1987. Deep-sea sedimentary environments around southren Africa (south-east Atlantic and southwest Indian Oceans). *Annals of the South African Museum* 98: 1-27.

Doblin M, Coyne K, Popels L, Hutchins D, Cary S, Rublee P, Dobbs F. Global transport and dispersal of HABs in ship's ballast water and recreational vessels. (oral). *11th International Conference on Harmful Algae, Cape Town, 15 - 19 November 2004, South Africa*.

Doblin MA, Coyne KJ, Popels LC, Hutchins D, Cary SC, Dobbs FC. 2004, Transport of the harmful bloom alga Aureococcus anophagefferens by oceangoing ships and coastal boats. *Applied and Environmental Microbiology* 70: 6495-6500.

Dobson A, Lodge D, Alder J, Cumming GS, Keymer J, McGlade J, Mooney H, Rusak JA, Sala O, Wolters V, Wall D, Winfree R, Xenopoulos MA. 2006. Habitat loss, trophic collapse, and the decline of ecosystem services. *Ecology* 87: 1915-1924.

Drake LA, Meyer AE, Forsberg RL, Baier RE, Doblin MA, Heinemann SH, Johnson WP, Koch M, Roblee PA, Dobbs FC.2005, Potential invasion of microorganisms and pathogens via 'interior hull fouling': biofilms inside ballast water tanks. *Biological Invasions* 7: 969-982.

Driver A, Maze K, Rouget M, Lombard AT, Nel J, Turpie JK, Cowling RM, Desmet P, Goodman P, Harris J, Jonas Z, Reyers B, Sink K, Strauss T. 2005. National Spatial Biodiversity Assessment 2004: Priorities for biodiversity conservation in South Africa. Strelitzia 17. Pretoria: South African National Biodiversity Institute.

Driver *et al*. In prep. National Biodiversity Assessment 2011: An assessment of South Africa's biodiversity and ecosystems. Pretoria: South African National Biodiversity Institute and Department of Environmental Affairs.

Duarte C. 2000. Marine biodiversity and ecosystem services: an elusive link. *Journal of Experimental Marine Biology and Ecology* 250: 117-131.

Dubula O, Taljaard S, Weerst SP. 2007. Land-based activities, pollution sources and levels in water and sediment in the coastal and marine area of South Africa. Nairobi, Kenya: WIO-LaB PMU.

Dudley S. 2003. Conservation status of the scalloped hammerhead shark (*Sphyrna lewini*). Unpublished Report Project RD30. Cape Town: Department of Environmental Affairs and Tourism, South Africa.

Dudley SFJ, Cliff G. 1993. Some effects of shark nets in the Natal nearshore environment. *Environmental Biology of Fishes* 36: 243-255.

Dudley SFJ, Cliff G. 2010. Shark control: methods, efficacy, and ecological impact. In: Carrier JC, Musick JA, Heithaus MR (ed), *Sharks and their Relatives II - Biodiversity, Adaptive Physiology, and Conservation.* Boca Raton: CRC Press. pp 567-591.

Dudley SFJ, Simpfendorfer CA. 2006. Population status of 14 shark species caught in the protective gillnets of KwaZulu-Natal beaches, South Africa. *Marine and Freshwater Research* 57: 225-240.

Dudley SFJ. 1997. A comparison of the shark control programs of New South Wales and Queensland (Australia) and KwaZulu-Natal (South Africa). *Ocean and Coastal Management* 34: 1-27.

Dugan J, Hubbard DM, McCrary MD, Pierson MO. 2003. The response of macrofauna communities and shorebirds to macrophyte wrack subsidies on exposed sandy beaches of southern California. *Estuarine Coastal and Shelf Science* 58: 25-40.

Dugan J, Hubbard DM, Rodil IF, Revell D, Schroeter S. 2008. Ecological effects of coastal armouring on sandy beaches. *Marine Ecology* 29: 160-170.

Dugan JE, Hubbard DM. 2010. Loss of coastal strand habitat in Southern California: The role of beach grooming. *Estuaries and Coasts* 33: 67-77.

Dulvy NK, Jennings S, Goodwin NB, Grant A, Reynolds JD. 2005. Comparison of threat and exploitation status in North-East Atlantic marine populations. *Journal of Applied Ecology* 42: 883-891.

Dunlop ES, Baskett ML, Heino M, Dieckmann U. 2009. Propensity of marine reserves to reduce the evolutionary effects of fishing in a migratory species. *Evolutionary Applications* 2: 371-393.

Durham BD, Pauw JC (eds). 2000. *Summary Marine Biodiversity Status Report for South Africa*. Pretoria: National Research Foundation.

DWAF (Department of Water Affairs and Forestry). 1995. *South African Water Quality Guidelines for Coastal Marine Waters.* Pretoria: Department of Water Affairs and Forestry, South Africa.

Dye AH, Branch GM, Castilla JC, Bennet BA. 1994a. Biological options for the management of the exploitation of intertidal and subtidal resources. In: Siegfried RW (ed), *Rocky Shores: Exploitation in Chile and South Africa*. *Ecological Studies* 103: 131-154.

Dye AH, Schleyer M, Lambert G, Lasiak TA. 1994b. Intertidal and subtidal filter feeders in Southern Africa In: Siegfried RW (ed), *Rocky Shores: Exploitation in Chile and South Africa*. *Ecological Studies* 103: 57-74.

Earl DA, Louie KD, Bardeleben C, Swift CC, Jacobs DK. 2010. Rangewide microsatellite phylogeography of the endangered tidewater goby, *Eucyclogobius newberryi* (Teleostei: Gobiidae), a genetically sub-divided coastal fish with limited marine dispersal. *Conservation Genetics* 11: 103-114.

Edwards CTT, Rademeyer RA, Butterworth DS, Plaganyi E. 2008. Investigating the consequences of Marine Protected Areas for the South African deep-water hake (*Merluccius paradoxus*) resource. *ICES Journal of Marine Science* 66: 72 -81.

Elner RW, Vadas Sr RL. 1990. Inference in Ecology: The sea urchin phenomenon in the Northwestern Atlantic. *The American Naturalist* 136: 108-125.

Emanuel BP, Bustamante RH, Branch GM, Eekhout S, Odendaal FJ. 1992. A zoogeographic and functional approach to the selection of marine reserves on the west coast of South Africa. *South African Journal of Marine Science* 12: 341-354.

Engledow HR, Bolton J, Stegenga H. 1992. The biogeography of the seaweed flora of Namibia. In: Mshingeni KE, Bolton JJ, Critchley AT, Kiangi G (eds), *Proceedings of the First International Workshop on Sustainable Seaweed Resource Development in Sub-Saharan Africa*. Windhoek. pp. 85-97.

Erlandsson J, McQuaid CD, Kostylev VE. 2005. Contrasting spatial heterogeneity of sessile organisms within mussel (*Perna perna* L.) beds in relation to topographic variability. *Journal of Experimental marine Biology and Ecology* 314:79-97.

Erlandsson J, McQuaid CD. 2004. Spatial structure of recruitment in the mussel Perna perna at local scales: effects of adults, algae and recruit size. *Marine Ecology Progress Series* 267: 173-185

Erwin PM, López-Legentil S, Schuhmann PW. 2010. The pharmaceutical value of marine biodiversity for anti-cancer drug discovery. *Ecological Economics* 70:445-451.

Fairweather PG. 1990. Ecological changes due to our use of the coast: research needs versus effort. *Proceedings, Ecological Society of Australia* 16: 71-77.

Fairweather TP, Hara M, van der Linden CD, Raakjaer J, Shannon LJ, Louw GG, Degnbol P, Crawford R. 2006a. A knowledge base for management of the capital-intensive fishery for small pelagic fish off South Africa. *African Journal of Marine Science* 28: 645-660.

Fairweather TP, van der Lingen CD, Booth AJ, Drapeau L, van der Westhuizen JJ. 2006b. Indicators of sustainable fishing for South African sardine *Sardinops sagax* and anchovy *Engraulis encrasicolus*. *African Journal of Marine Science* 28: 661-680.

Fairweather TP, Booth AJ, Sauer WHH, Leslie RW. 2006c. Spatial description of hake-directed fishing activity off the west coast of South Africa. *African Journal of Marine Science* 28: 13-24.

FAO (Food and Agriculture Organisation). 2010. *The state of the world fisheries and aquaculture* 2010:197. Rome: Food and Agriculture Organisation.

Feely RA, Sabine CL, Lee K, Berelson W, Kleypas J, Fabry VJ, Millero FJ. 2004. Impact of anthropogenic CO_2 on the $CaCO_3$ system in the oceans. *Science* 305: 362-371.

Feng YY, Hou LC, Ping NX, Ling TD, Kyo CI. 2004. Development of mariculture and its impacts in Chinese coastal waters. *Reviews in Fish Biology and Fisheries* 14: 1-10.

Fennessy ST, Groeneveld JC. 1997. A review of the offshore trawl fishery for crustaceans on the east coast of South Africa. *Fisheries Management and Ecology* 4: 135-147.

Fennessy ST, Isaksen B. 2007. Can bycatch reduction devices be implemented successfully on prawn trawlers in the Western Indian Ocean? *African Journal of Marine Science* 29: 453-463.

Fennessy ST, McDonald AM, Mann BQ, Everett BI. 2003. An assessment of the recreational and commercial skiboat fishery in the Transkei. *African Journal of Marine Science* 25: 61-78.

Fennessy ST. 1994a. The impact of prawn trawlers on linefish catches off the North coast of Natal. *South African Journal of Marine Science* 14: 263-279.

Fennessy ST. 1994b. Incidental capture of elasmobranchs by commercial prawn trawlers on the Tugela bank, Natal. South Africa. *South African Journal of Marine Science* 14: 287-296

Fennessy ST. 1995 Relative abundances of non-commercial crustaceans in the by-catch of Tugela Bank prawn trawlers off KwaZulu-Natal, South Africa. *Lammergeyer* 43:1-5.

Fennessy ST. 1999. A synthesis of available information on the Tugela Bank of KwaZulu-Natal. Unpublished Report No. 177. Durban: Oceanographic Research Institute.

Field JG, Griffiths CL, Griffiths RJ, Jarman N, Zoutendyk P, Velimirov B, Bowes A. 1980. Variation in structure and biomass of kelp communities along the south-west Cape coast. *Transactions of the Royal Society of South Africa* 44: 145-203.

Field JG, Griffiths CL. 1991. Littoral and sublittoral ecosystems of southern Africa. In: Mathieson AC, Nienhuis PH (eds), *Ecosystems of the World 24: Intertidal and Littoral Ecosystems*. New York: Elsevier.

Field JG, Moloney CL, du Buisson L, Jarre A, Stroemme T, Lipinski MR, Kainge P. 2008. Exploring the BOFFFF Hypothesis Using a Model of Southern African Deepwater Hake (*Merluccius paradoxus*). *Fisheries for Global Welfare and Environment 5th World Fisheries Congress 2008, p. 17 -26.* Tokyo: TERRAPUB.

Findlay KP. 1997. Attitudes and expenditures of whale watchers in Hermanus, South Africa. *South African Journal of Wildlife Research* 27: 57-62.

Fish MR, Cote IM, Horrocks JA, Mulligan B, Watkinson AR, Jones AP. 2008. Construction setback regulations and sea-level rise: Mitigating sea turtle nesting beach loss. *Ocean and Coastal Management* 51: 330-341.

Fisher B, Turner RK, Morling P. 2009. Defining and classifying ecosystem services for decision making. *Ecological Economics* 68: 643-653.

Fishing Industry Handbook 2006. Fishing Industry Handbook: South Africa, Namibia and Mozambique 34th Edition. Cape Town: George Warman Publications.

Foden W. 2005. Proceedings of the Workshop on Red Listing of South African Species: Distilling Best Practices and Lessons Learned (15 February 2005). Unpublished Report. Pretoria: South African National Biodiversity Institute.

Folk RL. 1954. The distinction between grain size and mineral composition in sedimentary rock nomenclature. *Journal Geology* 62: 344-359.

Forbes AT, Demetriades NT. 2005. A review of the commercial, shallow water Penaid prawn resource of South Africa: status, fisheries, aquaculture and management. Durban: Ezemvelo KZN Wildlife.

Ford JS, Meyers RA. 2008. A global assessment of salmon aquaculture impacts on wild salmonids. *PLoS Biology* 6: e33. DOI:10.1371/journal.pbio.0060033

Forrest BM, Gardner JPA, Taylor MD. 2009. Internal borders for managing invasive marine species. *Applied Journal of Ecology* 46: 46-54.

Fraser DJ, Bernatchez L. 2001. Adaptive evolutionary conservation: towards a unified concept for defining conservation units. *Molecular Ecology* 10**:** 2741-2752.

Fréon P, Drapeau L, David JHM, Meoreno AM, Leslie RW, Oosthuizen WH, Shannon LJ, van der Lingen CD. 2005. Spatialised ecosystem indicators in the southern Benguela. *ICES Journal of Marine Science* 62: 459-468.

Fuji A, Nomura H. 1990. Community structure of the rocky shore macrobenthos in southern Hokkaido, Japan. *Marine Biology* 107: 471-477.

Gage JD, Tyler PA. 1991. *Deep-sea Biology: A Natural History of Organisms at theDeep-Sea Floor.* Cambridge: Cambridge University Press.

Garcia de la Parra LM, Bautista-Covarrubias JC, Riveradela Rosa N, Betancourt-Lozano M, Guilhermino L. 2006. Effects of methamidophos on acetylcholi-nesterase activity, behaviour, and feeding rate of the white shrimp (*Litopenaeus vannamei*). *Ecotoxicology and Environmental Safety* 65: 372-380.

Garrat PA. 1985. The offshore fishery of Natal. 1. Exploited populations structures of the sparids *Chrysoblephus puniceus* and *Cheimerius nufar*. *Investigative Report Oceanographic Research Institute South Africa* 62: 1-18.

Garrison DL. 1976. Contribution of the net plankton and nanoplankton to the standing stocks and primary productivity in Monterey Bay, California, during the upwelling season. *Fishery Bulletin, NOAA* 74: 183-194.

Geller JB, Darling JA, Carlton JT. 2010. Genetic perspectives on marine biological invasions. *Annual Review of Marine Science* 2: 367-393.

Ghermandi A, Nunes PALD, Portela R, Rao N, Teelucksingh SS. 2009. Recreational, Cultural and Aesthetic Services from Estuarine and Coastal Ecosystems. In Carraro C (ed), *Sustainable Development Series.* Venice, Italy: Fondazione Eni Enrico Mattei. Pp 1-61.

Gibbons MJ, Barange M, Hutchings L. 1995. The zoogeography and diversity of euphausiids around southern Africa. *Marine Biology* 123: 257-268.

Gibbons MJ, Beucher E, Thibault-Botha D, Helm R. 2009. Patterns in marine hydrozoan richness and biogeography around southern Africa: implication of life cycle strategy. *Journal of Biogeography:* DOI:10.1111/j.1365-2699.2009.02237.x

Gillanders BM, Kingsford MJ. 2002. Impact of changes in flow of freshwater on estuarine and open coastal habitats and the associated organisms. *Oceanography and Marine Biology: An Annual Review* 40: 233-309.

Gillis NK, Walters LJ, Fernandes FC, Hoffman EA. 2009. Higher genetic diversity in introduced than in native populations of the mussel *Mytella charruana*: evidence of population admixture at introduction sites. *Diversity and Distributions* 15: 784-795.

GISP (Global Invasive Species Program). 2008. Marine Biofouling - An Assessment of Risks and Management Initiatives. Compiled by Lynn Jackson on behalf of Global Invasive Species Program and the UNEP Regional Seas Programme.

Glassom D, Celliers L, Schleyer MH. 2006. Coral recruitment patterns at Sodwana Bay, South Africa. *Coral Reefs* 25: 485-49.

Glazer JP, Butterworth DS. 2006. Some refinements of the assessment of the South African squid resource, *Loligo vulgaris reynaudii*. *Fisheries Research* 78: 14-25.

GloBallast Partnerships. 2011. The Problem. Available at http://globallast.imo.org/index.asp?page=problem.htmandmenu=true [accessed 20 June 2011].

Gopal K, Tolley KA, Groeneveld JC, Matthee CA. 2006. Mitochondrial DNA variation in spiny lobster *Palinurus delagoae* suggests genetically structured populations in the south-western Indian Ocean. *Marine Ecology Progress Series* 319: 191-198.

Goreau T, McClanahan T, Hayes R, Strong A. 2000. Conservation of coral reefs after the 1998 global bleaching event. *Conservation Biology* 14: 5-15.

Götz A, Kerwath SE, Attwood CG, Sauer WHH. 2009a. Effects of fishing on a temperate reef community in South Africa 1: ichthyofauna. *African Journal of Marine Science* 31: 241-251.

Götz A, Kerwath SE, Attwood CG, Sauer WHH. 2009b. Effects of fishing on a temperate reef community in South Africa 2: benthic invertebrates and algae. *African Journal of Marine Science* 31: 253-262.

Govender A, Van Der Elst RP, James N. 2002. Swordfish: global lessons: 1-33. Unpublished report. Cape Town: WWF-South Africa.

Government of South Africa. 2010. South African National Protected Area Expansion Strategy: priorities for expanding the protected area network for ecological sustainability and climate change adaptation. Pretoria: Government of South Africa.

Grant JS, Briggs AD. 2002. Toxicity of sediments from around a North Sea oil platform: are metals or hydrocarbons responsible for ecological impacts? *Marine Environmental Research* 53: 95-116.

Grantham BA, Eckert GL, Shanks AL. 2003. Dispersal potential of marine invertebrates in diverse habitats. *Ecological Applications* 13: S108-S116.

Grantham HS, Game ET, Lombard AT, Hobday AJ, Richardson AJ, Beckley LE, Pressey RL, Huggert JA, Coetzee JC, van der Lingen CD, Petersen SL, Merkle D, Possingham HP. 2011. Accomodating dynamic oceanographic processes and pelagic biodiversity in marine conservation planning. *PLoS ONE* 6: e16552. DOI:10.1371/journal.pone.0016552.

Grassle JF, Macionek NJ. 1992. Deep-sea species richness: Regional and local diversity estimates from quantitative bottom samples. *American Naturalist* 139: 313-341.

Gray J, Clarke KR, Warwick RM, Hobbs G. 1990. Detection of initial effects of pollution on marine benthos: an example from the Ekofisk and Eldfisk oilfields, North Sea. *Marine Ecology Progress Series* 66: 285-299.

Gray JS, Bakke T, Beck HJ, Nilssen I. 1999. Managing the environmental effects of the Norwegian oil and gas industry: from conflict to consensus. *Marine Pollution Bulletin* 38: 525-530.

Grémillet D, Pichegru L, Kuntz G, Woakes AJ, Wilkinson S, Crawford RJM, Ryan PG. 2008. A junk food hypothesis for gannets feeding on fishery waste. *Proceedings of the Royal Society of London B* 18:1-9.

Griffiths CL, Branch GM. 1997. The exploitation of coastal invertebrates and seaweeds in South Africa: historical trends, ecological impacts and implications for management. *Transactions of the Royal Society of South Africa* 52:121-148.

Griffiths CL, Hockey PAR, van Erkom Schurink C, Le Roux PJ. 1992. Marine invasive aliens on South African shores: implications for community structure and trophic functioning. *South African Journal of Marine Science* 12: 713-722.

Griffiths CL, McQuaid CD, Harris JM, Dye AH. 2000. Functional ecosystems: Rocky shores. In: Durham BD, Pauw JC (eds), *Summary Marine Biodiversity Status Report for South Africa*. Pretoria: National Research Foundation. Pp 1-3.

Griffiths CL, Mead A, Robinson TB. 2009a. A brief history of marine bio-invasions in South Africa. *African Zoology* 44: 241-247.

Griffiths CL, Robinson TB, Lange L, Mead A. 2010. Marine biodiversity in South Africa: an evaluation of current states of knowledge. *PLoS One* 5: 1-13. DOI:10.371/journal.pone.0012008

Griffiths CL, Robinson TB, Mead A. 2009b. The status and distribution of marine alien species in South Africa. In: Rilov G, Crooks JA (eds), *Biological Invasions in Marine Ecosystems*. Berlin: Springer-Verlag. pp 269-282.

Griffiths CL, van Sittert L, Best PB, Brown AC, Clark BM, Cook PA, Crawford RJM, David JHM, Griffiths MH, Hutchings K, Jerardino A, Kruger N, Lamberth S, Leslie RW, Melville-Smith R, Tarr R, Van der Lingen CD. 2004. Impacts of human activities on marine animal life in the Benguela: a historical overview. *Oceanographic Marine Biological Annual Reviews* 42: 303-392.

Griffiths CL. 1974. The gammaridean and caprellid Amphipoda of southern Africa. PhD thesis, University of Cape Town, South Africa.

Griffiths MH, Lamberth SJ. 2002. Chapter 16: Evaluating a marine recreational fishery in South Africa. In: Pitcher TJ, Hollingworth CE (eds), *Recreational Fisheries: Ecological, Economic and Social Evaluation*. Oxford, UK: Blackwell Science. pp 227-251.

Griffiths MH, Wilke CG. 2002. Long-term movement patterns of five temperate-reef fishes (Pisces: Sparidae): implications for marine reserves. *Marine and Freshwater Research* 53: 233-244.

Griffiths MH. 1997a. The application of per-recruit models to *Argyrosomus inodorus*, an important South African sciaenid fish. *Fishery Research* 30: 103-116.

Griffiths MH. 1997b. Management of South African dusky kob *Argyrozomus japonicus* (Sciaenidae) based on per-recruit models. *South African Journal of Marine Science* 18: 213-228.

Griffiths MH. 2000. Long-term trends in catch and effort of commercial linefish off South Africa's Cape Province: snapshots of the 20th century. *South African Journal of Marine Science* 22: 81-110.

Grindley JR, Penrith MJ. 1965. Notes on the bathypelagic fauna of the seas around South Africa. *Zoologica Africana* 1: 275- 295.

Grindley JR. 1977. The zooplankton of Langebaan Lagoon and Saldanha Bay. *Transactions of the Royal Society of South Africa* 42: 341-370.

GroblerJP, Jones JW, Johnson NA, Neves RJ, Hallerman EM. 2011. Homogeneity at Nuclear Microsatellite Loci Masks Mitochondrial Haplotype Diversity in the Endangered Fanshell Pearlymussel (*Cyprogenia stegaria*). *Journal of Heredity* 102: 196-206.

Groeneveld JC, Branch GM. 2002. Long-distance migration of South African deep-water rock lobster *Palinurus gilchristi*. *Marine Ecology Progress Series* 232: 225-238.

Groeneveld JC, Cockcroft AC. 1997. Potential of a trap-fishery for deep-water lobster *Palinurus delagoae* off South Africa. *Marine and Freshwater Research* 48: 993-1003.

Groeneveld JC, Melville-Smith R. 1995. Spatial and temporal variability in the multispecies crustacean trawl fishery along the east coast of South Africa and southern Mozambique, 1988-1993. *South African Journal of Marine Science* 15: 123-136.

Groeneveld JC. 1997. Growth of spiny lobster *Palinurus gilchristi* (Decapoda: Palinuridae) off South Africa. *South African Journal of Marine Science* 18: 19-29.

Groeneveld JC. 2003. Under-reporting of catches of South Coast rock lobster *Palinurus gilchristi*, with implications for the assessment and management of the fishery. *South African Journal of Marine Science* 25: 407-411.

Grosholz ED. 2002. Ecological and evolutionary consequences of coastal invasions. *Trends in Ecology and Evolution* 17: 22-27.

Gründlingh ML, Morant PD, van Ballegooyen RC, Badenhorst A, Gomes E, Greyling L, Guddal J, Hunter IT, Japp DW, Maartens L, Peard KR, Smith GG, Wainman CK. 2006. Environmental data requirements of maritime operations in the Benguela coastal ocean. In: Shannon V, Hempel G, Malanotte-Rizzoli P, Moloney C, Woods J (eds), *Large Marine Ecosystems Vol 14*. Amsterdam: Elsevier. pp 357-380.

Gubbay S. 2002. The Offshore Directory: Review of a selection of habitats, communities and species of the north-east Atlantic. Report for WWF UK.

Haedrich RL, Merrett NR. 1990. Little evidence for faunal zonation or communities in deep-sea demeral fish faunas. *Progress in Oceanography* 24: 239-250.

Haedrich RL, Merrett NR. 1992. Production/biomass ratios, size frequencies, and biomass spectra in deep-sea demersal fishes. In: Rowe GT, Pariente V (eds), *Deep-Sea Food Chains and the Global Carbon Cycle*. Dordrecht: Kluwer Academic Publication. Pp 157-182.

Hall SJ. 1994. Physical disturbance and marine benthic communitites: Life in unconsolidated sediments. *Oceanography and Marine Biology: An Annual Review* 32: 179-239.

Hall SJ. 2001. Is offshore oil exploration good for benthic conservation? *Trends in Ecology and Evolution* 16: 58.

Hallegraeff G, Bolch C. 1992. Transport of diatom and dinoflagellate resting spores in ships' ballast water: implications for plankton biogeography and aquaculture. *Journal of Plankton Research* 14: 1067-1084.

Halpern BS, Kappel CV, Selkoe KA, Micheli F, Ebert CM, Kontgis C, Crain CM, Martone R, Shearer C, Teck SJ. 2009. Mapping cumulative human impacts to California Current marine ecosystems. *Conservation Letters* 2: 138-148.

Halpern BS, Walbridge, S, Selkoe KA, Kappel CV, Micheli F, D'Agrosa C, Bruno JF, Casey KS, Ebert C, Fox HE, Fujita R, Heinemann D, Lenihan HS, Madin EMP, Perry MT, Selig ER, Spalding M, Steneck R, Watson R. 2008. A global map of human impact on marine ecosystems. *Science* 319: 948-952.

Hampton I, Boyer DC, Penney AJ, Pereira AF, Sardinha M. 1999. Integrated Overview of fisheries of the Benguela Current Region: A synthesis commissioned by the United Nations Development Programme (UNDP) as an Information Sourceh for the Benguela Current Large Marine Ecosystem (BCLME) Programme. Thematic Report 1: Synthesis and Assessment of information on the BCLME. Windhoek, Namibia: UNDP.

Hampton S, Griffiths CL. 2007. Why *Carcinus maenas* cannot get a grip on South Africa's wave exposed coastline. *African Journal of Marine Science* 9: 123-126.

Hanekom N, Nel P. 2002. Invasion of sandflats in Langebaan Lagoon, South Africa, by the alien mussel *Mytilus galloprovincialis*: size, composition and decline of the populations. *African Zoology* 37: 197-208.

Hanel C, Chown SL. 1999. Fifty years at Marion and Prince Edward Islands: a bibliography of scientific and popular literature. *South African Journal of Science* 95: 87-112.

Hansson M, Lindegarth M, Valentinsson D, Ulmestrand M. 2000. Effects of shrimp trawling on abundance of benthic macrofauna in Gullmarsfjorden, Sweden. *Marine Ecological Progress Series* 198: 191-201.

Hara M, Maharaj I, Pithers L. 2003. *Marine-based Tourism in Gansbaai: A Socio-economic Study.* Pretoria: Department of Environmental Affairs, South Africa.

Harley CDG, Hughes AR, Hultgren KM, Miner BG, Sorte CJB, Thornber CS, Rodriguez LF, Tomanek L, Williams SL. 2006. The impacts of climate change in coastal marine systems. *Ecology Letters* 9: 228-241.

Harris JM, Branch GM, Clark BM, Sibiya C. 2007. Redressing Access Inequities and Implementing Formal Management Systems for Marine and Estuarine Subsistence Fisheries in South Africa. In: McClanahan TR, Castilla JC (eds), *Fisheries Management: Progress Towards Sustainability*. Oxford: Blackwell. DOI: 10.1002/9780470996072.ch6.

Harris JM, Branch GM, Sibiya C, Bill C. 2003. The Sokhulu Subsistence Mussel Harvesting Project: Co-management in Action. In: Hauck M, Sowman M (eds), *Waves of Change*. Cape Town: University of Cape Town. Pp 61-98.

Harris L, Nel R, Campbell E. 2010. National beach classification and mapping. Unpublished Report. Cape Town: South African National Biodiversity Institute.

Harris L, Nel R, Schoeman D. 2011a. Mapping beach morphodynamics remotely: A novel application tested on South African sandy shores. *Estuarine, Coastal and Shelf Science* 92: 78-89.

Harris LR, Nel R, Smale M, Schoeman D. 2011b. Swashed away? Storm impacts on sandy beach macrofaunal communities. *Estuarine, Coastal and Shelf Science* 94: 210-221.

Harris LR. 2008. The ecological implications of sea-level rise and storms for sandy beaches in KwaZulu-Natal. MSc thesis, University of KwaZulu-Natal, South Africa.

Harris LR. 2011. Mapping Coastal Pressures in South Africa. Unpublished Report. Cape Town: South African National Biodiversity Institution.

Harris LR. In prep. An ecosystem-based spatial conservation plan for the sandy beaches of South Africa. PhD Thesis. Nelson Mandela Metropolitan University, South Africa.

Haupt P. 2011. The use of fish species in a marine conservation plan for KwaZulu-Natal. MSc Thesis, Nelson Mandela Metropolitan University, South Africa.

Haupt TM, Griffiths CL, Robinson TB, Tonin AFG, De Bruyn PA. 2010b. History and status of oyster exploitation and culture in South Africa. *Journal of Shellfish Research* 29: 151-159.

Haupt TM, Griffiths CL, Robinson TB, Tonin AFG. 2010a. Oysters as vectors of marine aliens, with notes on four introduced species associated with oyster farming in South Africa. *African Zoology* 45: 52-62.

Haupt TM. 2009. Translocation of marine alien species in South Africa. MSc thesis, University of Cape Town, South Africa.

Hauser L, Adcock GJ, Smith PJ, Ramirez JHB, Carvahlo GR. 2002. Loss of microsatellite diversity and low effective population size in an overexploited population of New Zealand snapper (*Pagrus auratus*). *Proceedings of the National Academy of Sciences of the USA* 99: 11742-11747

Haya K, Burridge LE, Chang BD. 2001. Environmental impact of chemical wastes produced by the salmon aquaculture industry. *ICES Journal of Marine Science* 59: 492-496.

Hays GC, Richardson AJ, Robinson C. 2005. Climate change and marine plankton. *Trends in Ecology and Evolution* 20: 337-344.

Hayward PJ, Cook PL. 1979. The South African Museum's Meiring Naudé cruises. Part 9. Bryozoa. *Annals of the South African Museum* 79: 97-140.

Heemstra PC, Fricke H, Hissmann K, Schauer J, Smale M, Sink K. 20067. Interactions of fishes with particular reference to coelacanths in the canyons at Sodwana Bay and the St Lucia Marine Protected Area of South Africa. *South African Journal of Science* 102: 461-465.

Heggoey E, Vassenden G, Johannessen P. 2004. Investigation of the marine biological environmental conditions at a fish farm site in Radfjorden, Lindas Municipality, western Norway in 2004. *Vestbio* 1: 35.

Helmuth BS, Harley CDG, Halpin P, O'Donnell M, Hofmann GE, Blanchette C. 2002. Climate change and latitudinal patterns of intertidal thermal stress. *Science* 298: 1015-1017.

Henry JL, Mostert SA. 1977. Phytoplankton production in the Langebaan Lagoon and Saldanha Bay. *Transactions of the Royal Society of South Africa* 42: 383 - 398.

Heuch PA, Bjorn PA, Finstad B, Holst JC, Asplin L, Nilsen F. 2005. A review of the Norwegian 'National plan of Action against salmon lice on salmonids': the effect on wild salmonids. *Aquaculture* 246: 79-92.

Hewitt CL, Campbell ML, McEnnulty F, Moore KM, Murfet NB, Robertson B, Schaffelke B, 2005. Efficacy of physical removal of a marine pest: the introduced kelp *Undaria pinnatifida* in a Tasmanian Marine Reserve. *Biological Invasions* 7: 251-263.

Hewitt CL, Campbell ML, Thresher RE, Martin RB, Boyd S, Cohen BF, Currie DR, Keough MJ, Lewis JA, Lockett MM, Mays N, McArthur MA, O'Hara TD, Poore GCB, Ross DJ, Storey MJ, Watson JE, Wilson RS. 2004. Introduced and cryptogenic species in Port Phillip Bay, Victoria, Australia. *Marine Biology* 144: 183-202.

Hietkamp S, Engelbrecht A, Scholes B, Golding A. 2008. Potential for sequestration of carbon dioxide in South Africa carbon capture and storage in South Africa. *Science real and relevant:*

2nd CSIR Biennial Conference, CSIR International Convention Centre Pretoria, 17 and 18 November 2008. Pretoria: Department of Minerals and Energy, South Africa. pp 7.

Hill JM, McQuaid CD, Kaehler S. 2006. Biogeographic and nearshore/offshore trends in isotope ratios of intertidal mussels and their food sources around the coast of southern Africa. *Marine Ecology Progress Series* 318: 63-73.

Hill JM, McQuaid CD, Kaehler S. 2008. Temporal isotopic variation in suspended particulate matter suggests strong links to nearshore hydrography and heavy dependence of mussels on very nearshore production. *Marine Biology* 154: 899-909.

Hinz H, Prieto V, Kaiser MJ. 2009. Trawl disturbance on benthic communitites: chronic effects and experimental predictions. *Ecological Applications* 19: 761-773.

Hoarau G, Boon E, Jongma DN, Ferber S, Palsson J, Van der Veer HW, Rijnsdorp AD, Stam WT, Olsen JL. 2005. Low effective population size and evidence for inbreeding in an overexploited flatfish, plaice (*Pleuronectes platessa* L.). *Proceedings of the Royal Society B* 272: 497-503.

Hockey PAR, Siegfried WR, Crowe AA. 1983. Ecological structure and energy requirements of the sandy beach avifauna of southern Africa. In: McLachlan A, Erasmus T (eds), *Sandy Beaches as Ecosystems*. The Hague: Junk. pp 501-506.

Hockey PAR, van Erkom Schurink C. 1992. The invasive biology of the mussel *Mytilus galloprovincialis* on the southern African coast. *Transaction of the Royal Society of South Africa* 48: 123-139.

Hockey PAR, Van Erkom Schurink C. 1992. The invasive biology of the mussel *Mytilus galloprovincialis* on the southern African coast. *Transactions of the Royal Society of South Africa* 48: 123-139.

Hofmeyr G, Gales N. 2008. *Arctocephalus pusillus*. In: IUCN 2010. IUCN Red List of Threatened Species. Version 2010.4. <www.iucnredlist.org>. Downloaded on 10 May 2011.

Holdway DA. 2002. The acute and chronic effects of wastes associated with offshore oil and gas production on temperate and tropical marine ecological processes. *Marine Pollution Bulletin* 44: 185-203.

Holmlund CM, Hammer M. 1999. Ecosystem services generated by fish populations. *Ecological Economics* 29: 253 - 268.

Hommersand MH. 1986. The biogeography of the South African marine red algae: A model. *Botanica Marina* 29: 257-270.

Howell KL, Davies JS, Narayanaswamy BE. 2010. Identifying deep-sea megafaunal epibenthic assemblages for use in habitat mapping and marine protected area network design. *Journal of the Marine Biological Association of the United Kingdom* 90: 33-68.

Howell KL. 2010. A benthic classification system to aid in the implementation of marine protected area networks in the deep/high seas of the NE Atlantic. *Biological Conservation* 143: 1041-1056.

Hulley PA, Lutjeharms JRE. 1989. Lanternfishes of the southern Benguela region. Part 3. The pseudoceanic-oceanic interface. *Annals of the South African Museum* 98: 409-435.

Hulley PA, Prosch RM. 1987. Mesopelagic fish derivatives in the southern Benguela upwelling regions. *South African Journal of Marine Science* 5: 597-611.

Hulley PA. 1981. Results of the research cruises of FRV "Walter Herwig" to South America. LVIII. Family Myctophidae (Osteichthyes, Myctophiformes). *Archiv fuer Fischereiwissenschaft* 31: 1-300.

Hulley PA. 1986. Lanternfishes of the southern Benguela region. Part 1. Faunal complexity and distribution. *Annals of the South African Museum* 97: 227-249.

Hulley PA. 1989. Lanternfishes of the southern Benguela region. Part 2. *Gymnoscopelus* (*Gymnoscopelus*) *bolini* Andriashev in South African waters, with comments on the distribution of subantarctic myctophids in the eastern South Atlantic. *Annals of the South African Museum* 98: 221-240.

Hulley PA. 1992. Upper-slope distributions of oceanic lanternfishes (family Myctophidae). *Marine Biology* 114: 365-383

Hutchings JA. 2000. Collapse and recovery of marine fishes. *Nature* 406: 882-885.

Hutchings L, Augustyn CJ, Cockcroft A, van der Lingen C, Coetzee J, Leslie RW, Tarr RJ, Oosthuizen H, Lipinski MR, Roberts MR, Wilke C, Crawford R, Shannon LJ, Mayekiso M. 2009. Marine fisheries monitoring programmes in South Africa. *South African Journal of Science* 105: 182-192.

Hutchings L, Augustyn CJ, Cockcroft A, van der Lingen C, Coetzee J, Leslie RW, Tarr RJ, Oosthuizen H, Lipinski MR, Roberts MR, Wilke C, Crawford R, Shannon LJ, Mayekiso M. 2009. Marine fisheries monitoring programmes in South Africa. *South African Journal of Science* 105: 182-192.

Hutchings L, Beckley LE, Griffiths MH, Roberts MJ, Sundby S, van der Lingen C. 2002. Spawning on the edge: spawning grounds and nursery areas around the southern African coastline. *Marine and Freshwater Research* 53: 307-318.

Hutchings L, Gibbons MJ, Crawford RJM. 2000. Functional Ecosystems: The Pelagic Open Ocean. In: Durham BD, Pauw JC (eds), *Summary Marine Biodiversity Status Report for South Africa*. Pretoria: National Research Foundation. Pp 16-19.

Hutchings P. 1992. Ballast water introductions of exotic marine organisms into Australia: current status and management options. *Marine Pollution Bulletin* 25: 196-199.

Hutchinson GE. 1950. Survey of contemporary knowledge of biogeochemistry 3: The biogeochemistry of vertebrate excretion. *Bulletin of the American Museum Natural History* 96: 1-554.

Hyland J, Hardin D, Steinhauer M, Coats D, Green RH, Neff J. 1994. Environmental impact of offshore oil development on the outer continental shelf and slope off Point Arguello, California. *Marine Environmental Research* 37: 195-229.

ICES (International Council for the Exploration of the Sea). 2005. *Code of Practice on the Introductions and Transfers of Marine Organisms: Cooperation Research Report*. Copenhagen: International Council for the Exploration of the Sea.

IMO (International Maritime Organisation). 2004*. International Convention for the Control and Management of Ships' Ballast Water and Sediments.* London, UK: International Maritime Organization.

IMO (International Maritime Organisation). 2005. Identification and Protections of Special Areas and Particularly Sensitive Sea Areas. Proposal for the designation of South Africa's southern continental shelf waters as a Special Area under MARPOL Annex I. Prepared by the Marine Environment Protection Committee. London : INTERNATIONAL MARITIME ORGANISATION.

IPCC (Intergovernmental Panel on Climate Change). 2007. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds), *Climate Change 2007: The Physical Science Basis*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. pp. 1-18.

IUCN (International Union for Conservation of Nature). 2010a. Spheniscus demersus. In: IUCN 2011. IUCN Red List of Threatened Species. Version 2011.1. <www.iucnredlist.org>. Downloaded on 21 June 2011.

IUCN (International Union for Conservation of Nature). 2010b. Phalacrocorax neglectus. In: IUCN 2011. IUCN Red List of Threatened Species. Version 2011.1. <www.iucnredlist.org>. Downloaded on 21 June 2011.

Iwamoto T, Anderson ME. 1994. Review of the grenadiers (Teleostei: Gadiformes) of southern Africa, with descriptions of four new species. *Bulletin of the JLB Smith Institute of Ichthyology* 61: 1-18.

Jackson AC, McIlvenny J. 2011. Coastal squeeze on rocky shores in northern Scotland and some possible ecological impacts. *Journal of Experimental Marine Biology and Ecology* 400: 314-321.

Jackson DWT, Cooper JAG, del Rio L. 2005. Geological control of beach morphodynamic state. *Marine Geology* 216: 297-314.

Japp DW. 1989. An assessment of the South African longline fishery with emphasis on stock integrity of kingklip *Genypterus capensis* (Pisces: Ophidiidae). MSc. Thesis, Rhodes University, South Africa.

Japp DW, Sims P, Smale M. 1994. A review of the fish resources of the Agulhas Bank. *South African Journal of Science* 90: 123-135.

Japp DW. 1997. Discarding practices and bycatches for fisheries in the Southeast Atlantic Region (Area 47). In: Clucas IJ, James DG (eds), *Papers presented at the Technical Consultation on Reduction of Wastage in Fisheries. Tokyo. FAO Fisheries Report No. 547.* Rome: FAO.

Japp DW. 2004. Target Resource Oriented Management (TROM) Reports (several fishery sectors). Prepared for Ecosystem Approaches to Fisheries Management, BCLME Project. Report No. LMR/EAF/03/01. Cape Town: BCLME Project.

Jarre-Teichmann A, Shannon LJ, Moloney CL, Wickens PA. 1998. Comparing trophic flows in the southern Benguela to those in other ecosystems. *South African Journal of Marine Science* 19: 391-414.

Jennings S, Greenstreet SPR, Reynolds JD. 1999. Structural change in an exploited fish community: a consequence of differential fishing effects on species with contrasting life histories. *Journal of Animal Ecology* 68: 617-627.

Jennings S, Kaiser MJ. 1998. The effects of fishing on marine ecosystems. *Advances in Marine Biology* 34: 201-352.

Jensen HS, Mortensen PB, Andersen FO, Rasmussen E, Jensen A. 1995. Phosphorus cycling in a coastal marine sediment, Aarhus Bay, Denmark. *Limnology and Oceanography* 40: 908-917.

Kaiser MJ, Collie JS, Hall SJ, Jennings S, Poiner IR. 2002. Modification of marine habitats by trawling activities: prognosis and solutions. *Fish and Fisheries* 3: 1-24.

Kaiser MJ, Spencer BE. 1996. The effects of beam-trawl disturbance on infaunal communities in different habitats. *Journal of Animal Ecology* 65: 348-358.

Karenyi N. 2009. Review of known diamond mining impacts on the biota of the West Coast of Southern Africa. Unpublished Report. Cape Town: South African National Biodiversity Institute.

Kemper J, Underhill LG, Crawford RJM, Kirkman SP. 2007. Revision of the conservation status of seabirds and seals breeding in the Benguela Ecosystem. In: Kirkman SP (ed), *Final Report of the BCLME (Benguela Current Large Marine Ecosystem) Project on Top Predators as Biological Indicators of Ecosystem Change in the BCLME*. Cape Town: Avian Demography Unit, University of Cape Town.

Kensley B. 1983. Biogeographical relationships of some South African benthic Crustacea. In: Lowry JK (ed), *Papers from the Conference on the Biology and Evolution of Crustacea held at the Australian Museum, Sydney, 1980*. *Australian Museum Memoir* 18: 173-181.

Kensley B. 1984. The South African Museum's Meiring Naudé cruises. Part 15: Marine Isopoda of the 1977, 1978, 1979 cruises. *Annals of the South African Museum* 93: 213-301.

Keough MJ, Quinn GP. 1998. Effects of periodic disturbances from trampling on rocky intertidal algal beds. *Ecological Applications* 8: 141-161.

Kerr RA, Kintisch E, Schenkman L, Stokstad E. 2010. Five questions on the spill. *Science* 328: 962-963.

Kerry J, Hiney M, Coyne R, NicGabhainn S, Gilroy D, Cazabon D, Smith P. 1995. Fish feed as a source of oxytetracycline-resistant bacteria in the sediments under fish farms. *Aquaculture* 131: 101-113.

Kerstan M, Leslie RW. 1994. Horse mackerel on the Agulhas Bank - summary of current knowledge. *South African Journal of Science* 90: 173-178.

Kerwath SE, Götz A, Attwood CG, Cowley PD, Sauer WHH. 2007a. Movement pattern and home range of roman *Chrysoblephus laticeps. African Journal of Marine Science* 29: 93-103.

Kerwath SE, Götz A, Attwood CG, Sauer WHH. 2007b. Area utilisation and activity patterns of roman *Chrysoblephus laticeps* (Sparidae) in a small marine protected area. *African Journal of Marine Science* 29: 259-270.

Ketmaier V, De Matthaeis E, Fanini L, Rossano C, Scapini F. 2010. Variation of genetic and behavioural traits in the sandhopper *Talitrus saltator* (Crustacea: Amphipoda) along a dynamic sand beach. *Ethology, Ecology and Evolution* 22: 17-35

Kingston PF. 1992. Impact of offshore oil production installations on the benthos of the North Sea. *ICES Journal of Marine Science* 49: 45-53.

Kingston PF. 2002. Long-term environmental impact of oil spills. *Spill Science and Technology Bulletin* 7: 53-61.

Klein YL, Osleeb JP, Viola MR. 2004. Tourism-Generated Earnings in the Coastal Zone: A Regional Analysis. *Journal of Coastal Research* 20: 1080-1088.

Kleypas JA, Feely RA, Fabry VJ, Langdon C, Sabine CL, Robbins LL. 2006. Impacts of ocean acidification on coral reefs and other marine calcifiers. A guide for future research. Report of a workshop sponsored by NSF, NOAA and the USGS. St Petersburg, Florida.

Kloskowski J. 2005. Otter *Lutra lutra* damage at farmed fisheries in southeastern Poland, I: an interview survey. *Wildlife Biology* 11: 201-206.

Koop K, Griffiths CL. 1982. The relative significance of bacteria, meio- and macrofauna on an exposed sandy beach. *Marine Biology* 66: 295-300.

Krefft G. 1978. Distribution patterns of oceanic fishes in the Atlantic Ocean. Selected problems. *Revue des Travaux de l'Institut des Peches Maritimes* 40: 439-460.

Krkošek M, Ford JS, Morton A, Lele S, Myers RA, Lewis MA. 2007. Declining wild salmon populations in relation to parasites from farm salmon. *Science* 318: 1772-1775.

Kroese M. 1999. An overview of swordfish catches in the South African experimental pelagic longline fishery. In: BQ Mann (ed), Proceedings of the third southern African Marine Linefish Symposium, Arniston, 28 April-1 May *1999. South African Network for Coastal and Oceanic Research Occasional Report No.* 5: 88-89.

Krogh M, Reid D. 1996. Bycatch in the protective shark meshing programme off south-eastern New South Wales, Australia. *Biological Conservation* 77: 219-226

Kyle R, Robertson WD, Birnie SL. 1997. Subsistence shellfish harvesting in the Maputaland Marine Researve in northern KwaZulu-Natal, South Africa: Sandy beach organisms. *Biological Conservation* 82: 173-182.

La Cock GD, Burkinshaw JR. 1985. Management implications of development resulting in disruption of a headland bypass dunefield and its associated river, Cape St Francis, South Africa. *Landscape and Urban Planning* 34: 373-381.

La Rosa T, Maugeri TL, Mazzola A, Mirto S. 2004. Benthic microbial indicators of fish farm impact in a coastal area of the Tyrrhennian Sea. *Aquaculture* 230: 153-167.

Lagabrielle E. 2009. *Preliminary report: National Pelagic Bioregionalisation of South Africa.* Cape Town: South African National Biodiversity Institute.

Laikre L. 2010. Genetic diversity is overlooked in international conservation policy implementation. *Conservation Genetics* 11: 349-354.

Laird MC, Griffiths CL. 2008. Present distribution and abundance of the introduced barnacle *Balanus glandula* Darwin in South Africa. *African Journal of Marine Science* 30: 93-100.

Lamberth S, Turpie J. 2003. The role of estuaries in South African fisheries: economic importance and management implications. *African Journal of Marine Science* 25: 131-157.

Lamberth SJ, Drapeau L, Branch GM. 2009. The effects of altered freshwater inflows on catch rates of non-estuarine-dependent fish in a multispecies nearshore linefishery. *Estuarine Coastal and Shelf Science* 84: 527-538.

Lane SB, Carter RA. 1999. Generic Environmental Management Programme for marine diamond mining off the west coast of South Africa. 6 Volumes. Cape Town: Marine Diamond Mines Association.

Lapinski MR, Soule MA. 2007. A new direct method of stock assessment of the loliginid squid. *Reviews in Fish Biology and Fisheries* 17: 437-453.

Larsson LC, Laikre L, Andre C, Dahlgren TG, Ryman N. 2010. Temporally stable genetic structure of heavily exploited Atlantic herring (*Clupea harengus*) in Swedish waters. *Heredity* 104: 40-51.

Lastra M, Page HM, Dugan JE Hubbard DM, Rodil IF. 2008. Processing of allochthonous macrophyte subsidies by sandy beach consumers: estimates of feeding rates and impacts on food resources. *Marine Biology* 154: 163-174.

Laudien J, Flint NS, van der Bank FH, Brey T. 2003. Genetic and morphological variation in four populations of the surf clam *Donax serra* (Röding) from southern African sandy beaches. *Biochemical Systematics and Ecology* 31: 751-772.

Lawrence C. 2005. Biodiversity survey towards conservation of subtidal reef habitats in KwaZulu-Natal: Biogeography and depths patterns. MSc thesis, University of Cape Town, South Africa.

Lawrie SM, McQuaid CD. 2001. Scales of mussel bed complexity: structure, associated biota and recruitment. *Journal of Experimental Marine Biology and Ecology* 257: 135-161.

Le Clus F, Hennig HF-KO, Melo YC, Boyd AJ. 1994. Impact of the extent and locality of mud patches on the density and geographic distribution of juvenile Agulhas sole *Austroglossus pectoralis* (Soleidae). *South African Journal of Marine Science* 14: 19-36.

Le Clus F, Hennig HF-KO, Rogers J. 1996. Bathymetry and sediment type effects on catch rates of *Austroglossus pectoralis* (Soleidae) on the inner central Agulhas Bank. *South African Journal of Marine Science* 17: 79-92.

Le Clus F, Roberts MJ. 1995. Topographic and hydrographic effects on catch rates of *Austroglossus pectoralis* (Soleidae) on the Agulhas Bank. *South African Journal of Marine Science* 16: 321-332.

Le Roux PJ, Branch GM, Joska MAP. 1990 On the distribution, diet and possible impact of the invasive European shore crab *Carcinus maenas* (L.) along the South African coast. *South African Journal of Marine Science* 9: 85-93.

Lejeusne C, Bock DG, Therriault TW, MacIsaac HJ, Cristescu ME. 2011. Comparative phylogeography of two colonial ascidians reveals contrasting invasion histories in North America. *Biological Invasions* 13: 635-650.

Lemm S, Attwood C. 2003. State of Marine Protected Area Management in South Africa. Unpublished Report. Cape Town: WWF-South Africa.

Lerdau M, Slobodkin L. 2002. Trace gas emissions and species-dependent ecosystem services. *Trends in Ecology and Evolution* 17: 309-312.

Leseberg A, Hockey PAR, Loewenthal D. 2000. Human disturbance and the chick-rearing ability of African black oystercatchers (*Haematopus moquini*): a geographical perspective. *Biological Conservation* 96: 379-385.

Leslie RW, Tilney RL, Rogers J. 2000. Functional ecosystems: soft subtidal substrates. In: Durham BD, Pauw JC (eds), *Summary Marine Biodiversity Status Report for South Africa*. Pretoria: National Research Foundation. Pp 13-15.

Levitt GJ, Anderson RJ, Boothroyd CJT, Kemp FA. 2002. The effects of kelp harvesting on its regrowth and the understorey benthic community at Danger Point, South Africa and a new method of harvesting kelp fronds. *South African Journal of Marine Science* 24: 71-85.

Lindegarth M, Valentinsson D, Hansson M, Ulmestrand M. 2000. Effects of trawling disturbances on temporal and spatial structure of benthic soft-sediment assemblages in Gullmarsfjorden, Sweden. *ICES Journal of Marine Science* 57: 1369-1376.

Lombard AT, Attwood C., Sink K. Grantham H. 2010. *Use of Marxan to identify potential closed areas to reduce bycatch in the South African trawl fishery.* Cape Town: WWF South Africa and the Responsible Fisheries Alliance.

Lombard AT, Reyers B, Schonegevel LY, Cooper J, Smith-Adao AB, Nel DC, Froneman PW, Ansorge IJ, Bester MN, Tosh CA, Strauss T, Akkers T, Gon O, Leslie RW, Chown SL. 2007. Conserving pattern and process in the southern ocean: designing a marine protected area in the Prince Edwards Islands. *Antarctic Science* 19: 39-54.

Lombard AT, Strauss T, Harris J, Sink K, Attwood C, Hutchings L. 2004. *South African National Spatial Biodiversity Assessment 2004: Technical Report. Volume 4: Marine Component*. Pretoria: South African National Biodiversity Institute.

Louw D. 2003. Thukela Water Project Decision Support Phase. Reserve Determination Module. Unpublished report for Department of Water Affairs and Forestry.

Love MS, Caselle J, Snook L. 1999. Fish assemblages around seven oil platforms in the Santa Barbara Channel area. *Fisheries Bulletin* 98: 96-117.

Love MS, Schroeder DM, Lenarz WH. 2005. Distribution of bocaccio (*Sebastes paucispinis*) and cowcod (*Sebastes levis*) around oil platforms and natural outcrops off California with implications for larval production. *Bulletin of Marine Science* 77: 397-408.

Lowe S, Browne M, Boudjelas S, De Poorter M. 2000. *100 of the World's worst invasive alien species: A selection from the global invasive species database.* Published by The Invasive Species Specialist Group (ISSG) a specialist group of the Species Survival Commission (SSC) of the World Conservation Union (IUCN).

Luck GW, Daily GC, Ehrlich PR. 2003. Population diversity and ecosystem services. *Trends in Ecology and Evolution* 18: 331-336.

Lucrezi S, Schlacher TA, Robinson W. 2010. Can storms and shore armouring exert additive effects on sandy-beach habitats and biota? *Marine and Freshwater Research* 61: 951-962.

Lukoschek V, Waycott M, Keogh JS. 2008. Relative information content of polymorphic microsatellites and mitochondrial DNA for inferring dispersal and population genetic structure in the olive sea snake, *Aipysurus laevis*. *Molecular Ecology* 17: 3062-3077.

Mack RN, Simberloff D, Lonsdale WM, Evans H, Clout M, Bazzaz FA. 2000. Biotic invasions: Causes, epidemiology, global consequences, and control. *Ecological Applications* 10: 689-710.

Mackey KRM, van Dijken GL, Mazloom S, Erhardt AM, Ryan J, Arrigo KR, Paytan A. 2010. Influence of atmospheric nutrients on primary productivity in a coastal upwelling region. *Global Biogeochemical Cycles* 24:1-19.

Macpherson E, Roel BA. 1987. Trophic relationships in the demersal fish community off Namibia. In: Payne AIL, Gulland JA, Brink KH (eds), *The Benguela and Comparable Ecosystems*. *South African Journal of Marine Science* 5: 585-596.

Mann BQ, Celliers L, Fennessy ST, Bailey S, Wood AD. 2006. Towards the declaration of a large marine protected area: a subtidal ichthyofaunal survey of the Pondoland coast in the Eastern Cape, South Africa. *African Journal of Marine Science* 28: 535-551.

Mann BQ, McDonald AM, Sauer WHH, Hecht T. 2003. Evaluation of participation in and management of the Transkei Shore Linefishery. *African Journal of Marine Science* 25: 79-97.

Mann BQ. 2000. *Status Reports for Key Linefish Species*. Durban: Oceanographic Research Institute Special Publication.

Margules JM, Pressey RL. 2000. Systematic conservation planning. *Nature* 405: 243-253.

Marine Reserves Task Group. 1997. Towards a new policy on marine protected areas for South Africa. *South African Network for Coastal and Oceanographic Research Occasional Report 2.*

Marko PB, Hoffman JM, Emme SA, McGovern TM, Keever CC, Cox LN. 2010. The expansion-contraction model of Pleistocene biogeography: rocky shores suffer a sea change? *Molecular Ecology* 19: 146-169.

Martínez ML, Intralawan A, Vázquez G, Pérez-Maqueo O, Sutton P, Landgrave R. 2007. The coasts of our world: Ecological, economic and social importance. *Ecological Economics* 63:254-272.

Mather AA, Garland GG, Stretch DD. 2009. Southern African sea levels: corrections, influences and trends. *African Journal of Marine Science* 31: 145-156.

Matthee CA, Cockroft AC, Gopal K, von der Heyden S. 2007. Mitochondrial DNA variation of the west coast rock lobster, *Jasus lalandii*: marked genetic diversity differences among sampling sites. *Marine Freshwater Research* 58**:** 1130-1135.

Mayfield S, Branch GM. 2000. Interrelations among rock lobsters, sea urchins, and juvenile abalone: implications for community management. *Canadian Journal of Fisheries and Aquatic Science* 57: 2175-2185.

McClanahan TR, Ateweberhan M, Graham NAJ, Wilson SK, Ruiz Sebastián C, Guillaume MMM, Bruggemann JH. 2007a. Western Indian Ocean coral communities: bleaching responses and susceptibility to extinction. *Marine Ecology Progress Series* 337: 1-13.

McClanahan TR, Ateweberhan M, Ruiz Sebastián C, Graham NAJ, Wilson SK, Bruggemann H, Guillaume MMM. 2007b. Predictability of coral bleaching from synoptic satellite and in situ temperature observations. *Coral Reefs* 26: 695-701.

McCord ME. 2005. Aspects of the ecology and management of the soupfin shark (*Galeorhinus galeus*) in South Africa. MSc Thesis, Rhodes University, South Africa.

McGinnis RF. 1982. Biogeography of lanternfishes (Mycotophidae) south of 30°S. *Antarctic Research Series* 35: 1-110.

McGinnity P, Prodöhl P, Ferguson A, Hynes R, Ó Maoiléidigh N, et al. 2003. Fitness reduction and potential extinction of Atlantic salmon, *Salmo salar*, as a result of interactions with escaped farm salmon. *Proceedings of the Royal Society B*: *Biological Sciences* 270: 2443-2450.

McGrath MD, Horner CCM, Brouwer SL, Lamberth SJ, Mann BQ, Sauer WHH, Erasmus C. 1997. An economic valuation of the South African linefishery. *South African Journal of Marine Science* 18: 203-211.

McLachlan A, Dugan JE, Defeo O., Ansell AD, Hubbard DM, Jaramillo E, Penchaszadeh P. 1996. Beach clam fisheries. *Oceanography and Marine Biology: An Annual Review* 34: 163-232.

McLachlan A, Dye A, Harty B. 1981. Simulation of the interstitial system of exposed sandy beaches. *Estuarine, Coastal and Shelf Science* 12: 267-278.

McLachlan A, Eliot I, Clarke D. 1985. Water filtration through reflective microtidal beaches and shallow sublittoral sands and its implications for an inshore ecosystem in Western Australia. *Estuarine, Coastal and Shelf Science* 21: 91-104.

McLachlan A, Illenberger WK. 1986. Significance of groundwater nitrogen input to a beach/surf zone ecosystem. *Stygologia* 2:291-296.

McLachlan A, Jaramillo E, Don TE, Wessels F. 1993. Sandy beach macrofauna communitites and their control by the physical environment: a geographical comparison. *Journal of Coastal Research* 15: 27-38.

McLachlan A, Nel R, Bentley A, Sims R, Schoeman D. 1994. Effects of diamond mine fine tailings on sandy beaches in the Elizabeth Bay area, Namibia. Windhoek: Consolidated Diamond Mines.

McLachlan A, Siebe PR, Ascaray C. 1982. Survey of a major coastal dunefield in the Eastern Cape. Report no. 10. In: *University of Port Elizabeth Zoology Report Series*. Port Elizabeth: University of Port Elizabeth. pp 1e48.

McLachlan A. 1979. Volumes of sea water filtered through Eastern Cape sandy beaches. *South African Journal of Science* 75: 75-79.

McLachlan A. 1989. Water Filtration by Dissipative Beaches. *Limnology and Oceanography* 34: 774-780.

McLachlan A. 1991. Ecology of coastal dune fauna. *Journal of Arid Environments* 21: 229-243.

McLure J. 2001. Predicting the dispersion of nutrients from aquaculture cages. Unpublished Honours thesis for a bachelor of Engineering. Centre for Water Research, Western Australia.

McQuaid CD, Branch GM. 1984. Influence of sea temperature, substratum and wave exposure on rocky intertidal communities: an analysis of faunal and floral biomass. *Marine Ecology Progress Series* 19: 145-161.

McQuaid CD, Branch GM. 1985. trophic structure of rocky intertidal communities: response to wave action and implications energy flow. *Marine Ecological Progress Series* 22: 153-161.

McQuaid CD, Dower KM. 1990. Enhancement of habitat heterogeneity and species richness on rocky shores inundated by sand. *Oecologia* 84: 142-144.

McQuaid CD, Lawrie SM. 2005. Supply-side ecology of the brown mussel, *Perna perna*: an investigation of spatial and temporal variation in, and coupling between, gamete release and larval supply. *Marine Biology* 147: 955-963.

McQuaid CD, Lindsay JR. 2005. Interacting effects of wave exposure, tidal height and substratum on spatial variation in densities of mussel (*Perna perna*) plantigrades. *Marine Ecology Progress Series* 301: 173-184.

McQuaid CD, Lindsay TL. 2000. Effect of wave exposure on growth and mortality rates of the mussel *Perna perna*: bottom-up regulation of intertidal populations. *Marine Ecology Progress Series* 206: 147-154.

McQuaid CD, Lindsay TL. 2007. Wave exposure effects on population structure and recruitment in the mussel *Perna perna* suggest regulation primarily through availability of recruits and food, not space. *Marine Biology* 151: 2123-2131.

McQuaid CD, Phillips TE. 2000. Limited wind-driven dispersal of intertidal mussel larvae: in situ evidence from the plankton and the spread of the invasive species *Mytilus galloprovincialis* in South Africa. *Marine Ecology Progress Series* 201: 211-220.

McQuaid CD, Phillips TE. 2006. Mesoscale variation in reproduction, recruitment and population structure of intertidal mussels with low larval input: a bay/open coast comparison. *Marine Ecology Progress Series* 327:193-206.

McQueen N, Griffiths MH. 2004. Influence of sample size and sampling frequency on the quantitative dietary descriptions of a predatory fish in the Benguela Ecosystem. *African Journal of Marine Science* 26: 205-217.

Mead A, Carlton JT, Griffiths CL, Rius M. 2011a. Introduced and cryptogenic marine and estuarine species in South Africa. *Journal of Natural History* 45: 2463-2524.

Mead A, Carlton JT, Griffiths CL, Ruis M. 2011b. Revealing the scale of marine bioinvasions in developing regions: a South African re-assessment. *Biological Invasions* 13: 1991-2008.

Mead A. 2011. The rocky intertidal: Are marine introduced species and climate change forcing significant spatial and temporal community assemblage shifts in South Africa? PhD Thesis, University of Cape Town, South Africa.

MENZ (Ministry of the Environment of New Zealand). 2005. Ministry for the Environment Offshore options: Managing Environmental effects in New Zealand's Exclusive economic zone. Wellington: Ministry of the Environment, New Zealand.

Meyer M, Smale MJ. 1991a. Predation patterns of demersal teleosts from the Cape south and west coasts of South Africa. 1. Pelagic Predators. *South African Journal of Marine Science* 10: 173-191.

Meyer M, Smale MJ. 1991b. Predation patterns of demersal teleosts from the Cape south and west coasts of South Africa. 2. Benthic and epibenthic predators. *South African Journal of Marine Science* 11: 409-442.

Mieszkowska N, Kendall MA, Hawkins SJ, Leaper R, Williamson P, Hardman-Mountford NJ, Southward AJ. 2006. Changes in the range of some common rocky shore species in Britain - a response to climate change? *Hydrobiologia* 555: 241-251.

Milazzo M, Badalamenti F, Riggio S, Chemello R. 2004. Patterns of algal recovery and small-scale effects of canopy removal as a result of human trampling on a Mediterranean rocky shallow community. *Biological Conservation* 117:191-202.

Milewski I. 2001 Impacts of salmon aquaculture on the coastal environment: A review. In: Tlusty MF, Bengston DH, Halvorson HO, Oktay SE, Pearce JB, Rheault RB (eds), *Marine Aquaculture and the Environment: A meeting for Stakeholders in the Northeast*. Falmouth: Cape Cod Press. Pp 166-197.

Millard NAH. 1978. The geographical distribution of southern African hydroids. *Annals of the South African Museum* 74(6): 159-200.

Millennium Ecosystem Assessment. 2003. *Ecosystems and Human Well-Being: A Framework for Assessment.* Washington, DC: Island Press.

Millennium Ecosystem Assessment. 2005. *Ecosystems and Human Well-Being: Synthesis.* Washington, DC: Island Press.

Miller AW, Chang AL, Cosentino-Manning N, Ruiz GM. 2004. A new record and eradication of the northern Atlantic alga *Ascophyllum nodosum* (Phaeophyceae) from San Francisco Bay, California, USA. *Journal of Phycology* 40: 1028-1031.

Miller K, Williams A, Rowden AA, Knowles C, Dunshea G. 2010. Conflicting estimates of connectivity among deep-sea coral populations. *Marine Ecology* 31: 144-157. DOI:10.1111/j.1439-0485.2010.00380.x.

Moffet MD, McLachlan A, Winter PED, de Rouyok AMC. 1996. Impact of trampling on sandy beach fauna. *Journal of Coastal Conservation* 4: 87-90.

Moldan AGS. 1989. Marine Pollution In: Payne AIL, Crawford RJM (eds), *Oceans of Life off southern Africa*. Cape Town: Vlaeberg Publishers.

Molnar JL, Gamboa RL, Revenga C, Spalding MD. 2008. Assessing the global threat of invasive species to marine biodiversity. *Frontiers in Ecology and Environment* 6: 485-492.

Monniot C, Monniot F, Griffiths CL, Schleyer M. 2001. South African ascidians. *Annals of the South African Museum* 108: 1-141.

Morton A, Routledge R, Peet C, Ladwig A. 2003. Sea lice (*Lepeophtheirus salmonis*) infection rates on juvenile pink (*Oncorhynchus gorbuscha*) and chum (*Onchorhynchus keta*) salmon in the nearshore marine environment of British Columbia, Canada. *Canadian Journal of Fisheries Aquatic Science* 61: 147-157.

Myers JH, Simberloff D, Kuris AM, Carey JR. 2000. Eradication revisited: dealing with exotic species. *Trends in Ecology and Evolution* 15: 316-320.

Myers RA, Worm B. 2003. Rapid worldwide depletion of predatory fish communities. *Nature* 423: 280-283.

Myeza J, Mason RB, Peddemors VM. 2010. Socio-economic implications of the KwaZulu-Natal sardine run for local indigenous communities. *African Journal of Marine Science* 32:399-404.

Nahman A, Wise R, De Lange W. 2009. Environmental and resource economics in South Africa: Status quo and lessons for developing countries. *South African Journal of Science* 105: 350-355.

Naidoo S. 2008. List of Pipelines in the Eastern Cape. Compiled as part of the submission to Marine and Coastal Management. Port Elizabeth: Department of Environmental Affairs, South Africa.

Napier VR, Branch GM, Harris JM. 2005. Evaluating conditions for successful co-management of subsistence fisheries in KwaZulu-Natal, South Africa. *Environmental Conservation* 32: 165-177.

Naylor RL, Williams SL, Strong DR. 2001. Aquaculture - A gateway for exotic species. *Science* 294: 1655-1656.

Neethling M, Matthee CA, Bowie RCK, von der Heyden S. 2008. Evidence of successful dispersal across a major oceanographic barrier in the southern African endemic, *Caffrogobius caffer* (Teleostei: Gobiidae). *BMC Evolutionary Biology* 8: 325.

Neff JM, Bothner MH, Maciolek NJ, Grassle JF. 1989. Impacts of exploratory drilling for oil and gas on the benthic environment of Georges Bank. *Marine Environmental Research* 27: 77-114.

Nel DC. 2004. Bycatch of threatened seabirds, sharks and turtles in longline fisheries in the Benguela Current Large Marine Ecosystem (BCLME): An integrated approach. Preliminary Report prepared by WWF for the BCLME. Cape Town: Benguela Current Large Marine Ecosystem Project.

Nel DC. 2005. Report on the Risk Assessment for Sustainable Fisheries (RASF) Workshop for the South African demersal hake fishery, Cape Town, 30 May-3 June 2005. Cape Town: Department of Environmental Affairs and Tourism, South Africa.

Nel R, Pulfrich A, PENNEY AJ. 2003. Impacts of beach mining operations on sandy beach macrofaunal communities on the beaches of Geelwal Karoo. Unpublished Report. Cape Town: Trans Hex Operations (Pty) Ltd.

Nel R, Pulfrich A. 2002. An assessment of the impacts of beach mining operations on beach macrofaunal communities between the Sout River and Olifants River mouth. Unpublished Report. Cape Town: Trans Hex Operations (Pty) Ltd.

Nel R. 2010. Sea Turtles of KwaZulu-Natal: Data Report for the 2009/10 Season. Unpublished report. Port Elizabeth: Nelson Mandela Metropolitan University.

Newell RC, Field JG, Griffiths CL. 1982. Energy balance and significance of micro-organisms in a kelp bed community. *Marine Ecology Progress Series* 8: 103-113.

Newell RC, Seiderer LJ, Hitchcock DR. 1998. The impact of dredging works in coastal waters: A review of the sensitivity to disturbance and subsequent recovery of biological resources on the sea bed. *Oceanography and Marine Biology: An Annual Review* 36: 127-178.

Nicastro KR, Zardi GI, McQuaid CD, Teske PR, Barker NP. 2008. Coastal topography drives genetic structure in marine mussels. *Marine Ecology Progress Series* 368: 189-195.

Nicholson E, Keith DA, Wilcove DS. 2009. Assessing the threat status of ecological communities. *Conservation Biology* 23: 259-274.

O'Donoghue S, Marshall DJ. 2003. Marine pollution research in South Africa: A status report. *South African Journal of Science* 99: 349 - 356.

Occhipinti-Ambrogi A, Savini D. 2003. Biological invasions as a component of global change in stressed marine ecosystems. *Marine Pollution Bulletin* 46: 542-551.

Olenin S, Minchin D, Daunys D. 2007. Assessment of biopollution in aquatic ecosystems. *Marine Pollution Bulletin* 55: 379-394.

Olsgard F, Gray JS. 1995. A comprehensive analysis of the effects of offshore oil and gas exploration and production on the benthic communities of the Norwegian continental shelf. *Marine Ecology Progress Series* 122:277-306.

Olyott LJH, Sauer WHH, Booth AJ. 2007. Spatial patterns in the biology of the chokka squid, *Loligo reynaudii* on the Agulhas Bank, South Africa. *Reviews in Fish Biology and Fisheries* 17: 159-172.

Oosthuizen A, Roberts MJ. 2009. Bottom temperature and in situ development of chokka squid eggs (*Loligo vulgaris reynaudii*) on mid-shelf spawning grounds, South Africa. *ICES Journal of Marine Science* 66: 1967-1971.

Orr JC, Fabry VJ, Aumont O, Bopp L, Doney SC, Feely RA, Gnanadesikan A, Gruber N, Ishida A, Joos F, Key RM, Lindsay K, Maier-Reimer E, Matear R, Monfray P, Mouchet A, Najjer RG, Plattner G, Rodgers KB, Sabine CL, Sarmiento JL, Schlitzer R, Slater RD, Totterdell IJ, Weirig M, Yamanaka Y, Yool A. 2005: Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature* 437(7059) :681-686.

Page HM, Dugan JE, Culver CS, Hoesterey JC. 2006. Exotic invertebrate species on offshore oil platforms. *Marine Ecology Progress Series* 325: 101-107.

Palmer RM, Cowley PD, Mann BQ (eds). 2008. A century of linefish research in South Africa: Bibliography and review of research trends. *South African Network for Coastal and Oceanic Research Occasional report No. 6.*

Palstra FP, Ruzzante DE. 2008. Genetic estimates of contemporary effective population size: what can they tell us about the importance of genetic stochasticity for wild population persistence? *Molecular Ecology* 17: 3428-3447.

Palumbi SR, Sandifer PA, Allan JD, Beck MW, Fautin DG, Fogarty MJ, Halpern BS, Incze LS, Leong J-A, Norse E, Stachowicz JJ, Wall DH. 2009. Managing for ocean biodiversity to sustain marine ecosystem services. *Frontiers in Ecology and the Environment* 7: 204-211.

Palumbi SR. 2004. Marine Reserves and ocean neighbourhoods: the spatial scale of marine populations and their management. *Annual Review of Environment and Resources* 29: 31-68.

Parkins CA, Branch GM. 1995. The effects of the Elizabeth Bay fines deposit on the intertidal rocky shore in the Bay, and the effects of the contractor diamond divers on the intertidal rocky shore communities of the Sperrgebiet coast. Report prepared by the Coastal Ecology Unit at the University of Cape Town. Windhoek: NAMDEB Diamond Corporation (Pty) Ltd.

Parkins CA, Branch GM. 1996. The effects of diamond mining on the shallow subtidal zone: An assessment of the Elizabeth bay fine-tailings deposit, and contractor diamond divers, with special attention to the rock lobster, *Jasus lalandii*. Coastal Ecology Unit, University of Cape Town. Report prepared for NAMDEB Diamond Corporation (Pty) Ltd. 44pp

Parkins CA, Branch GM. 1997. The effects of the Elizabeth Bay fines deposit and contractor diamond diver activities on biological communities: intertidal and subtidal monitoring report - 1997. Report prepared by the Coastal Ecology Unit at the University of Cape Town. Windhoek: NAMDEB Diamond Corporation (Pty) Ltd.

Paterson R. 1979. Shark meshing takes a heavy toll of harmless marine animals. *Australian Fisheries* 38: 17-23.

Paterson RA. 1990. Effects of long-term anti-shark measure on target and non-target species in Queensland, Australia. *Biological Conservation* 52: 147-159. DOI: 10.1016/0006-3207(90)90123-7

Pattrick P, Strydom NA. 2008. Composition, abundance, distribution and seasonality of larval fishes in the shallow nearshore of the proposed Greater Addo Marine Reserve, Algoa Bay, South Africa. *Estuarine, Coastal and Shelf Science* 79: 251-262.

Pauly D, Watson R, Alder J. 2005. Global trends in world fisheries: impacts on marine ecosystems and food security. Global trends in world fisheries. *Philosophical Transaction of the Royal Society B* 360: 5-12

Pauw JC. 2011. *Combat change with change*. Pretoria: South African Environmental Observation Network.

Payne AIL, Crawford RJM, Van Dalsen AP. 1995. Oceans of life off southern Africa. Cape Town: Vlaeberg.

Payne AIL, Rose B, Leslie RW. 1987. Feeding of hake and a first attempt at determining their trophic role in the South African west coast marine environment. *South African Journal of Marine Science* 5: 471-501.

Pecquerie L, Drapeau L, Fréon P, Coetzee JC, Leslie RW, Griffiths MH. 2004. Distribution patterns of key fish species of the Southern Benguela Ecosystem: an approach combining fishery-dependent and fishery-independent data. *African Journal of Marine Science* 26: 115-139.

Pecquerie L, Drapeau L, Fréon P, Coetzee JC, Leslie RW, Griffiths MH. 2004. Distribution patterns of key fish species of the Southern Benguela Ecosystem: an approach combining fishery-dependent and fishery-independent data. *African Journal of Marine Science* 26: 115-139.

Pederson HG, Johnson CR. 2006. Predation of the sea urchin *Heliocidaris erythrogramma* by rock lobsters (*Jasus edwardsii*) in no-take marine reserves. *Journal of Experimental Marine Biology and Ecology* 336: 120-134.

Pelc RA, Baskett ML, Tanci T, Gaines SD, Warner RR. 2009. Quantifying larval export from South African marine reserves. *Marine Ecology Progress Series* 394: 65-78.

Pemberton D, Shaughnessy PD. 1993. Interaction between seals and fish farms in Tasmania, and management of the problem. *Aquatic Conservation: Marine and Freshwater Ecosystems* 3: 149-158.

Penney A, Pulfrich A, Rogers J, Steffani N, Mabille V. 2008. Data gathering and gap analysis for assessment of cumulative effects of marine diamond mining activities in the BCLME Region. Report prepared by Pisces Environmental Services (Pty) Ltd. Cape Town: Benguela Current Large Marine Ecosystem Programme.

Penney AJ, Mann-Lang JB, Van Der Elst RP, Wilke CG. 1999. Long-term trends in catch and effort in the KwaZulu-Natal nearshore linefisheries. *South African Journal of Marine Science* 21: 51-76.

Penney AJ, Pulfrich A. 2004. Recovery and rehabilitation of deepwater marine diamond mining operations off the southern African west coast. An Environmental overview. Cape Town: De Beers Marine.

Penny A. 2005. Review of the EIA and EMPR for De Beers South African Sea Areas Prospecting and Mining Concessions along the West Coast. Unpublished report. Cape Town: De Beers.

Petersen SL, Honig MB, Nel DC. 2007. The impact of longline fisheries on seabirds in the Benguela Current Large Marine Ecosystem. In Petersen S, Nel D, Omardien A (eds), *Towards an Ecosystem Approach to Longline Fisheries in the Benguela: An Assessment of Impacts on Seabirds, Sea Turtles and Sharks.* WWF South Africa Report Series - 2007/Marine/001. Cape Town: WWF-South Africa.

Petersen SL, Honig MB, Ryan PG, Nel R, Underhill LG. 2009a. Turtle bycatch in the pelagic longline fishery off southern Africa. *African Journal of Marine Science* 31: 87-96.

Petersen SL, Honig MB, Ryan PG, Nel R, Underhill LG. 2009b. Seabird bycatch in the pelagic longline fishery off southern Africa. *African Journal of Marine Science* 31: 191-204.

Petersen SL, Honig MB, Ryan PG, Underhill LG, Compagno LJV. 2009d. Pelagic shark bycatch in the tunaand swordfish-directed longline fishery off southern Africa. *African Journal of Marine Science* 31: 215-225.

Petersen SL, Honig MB, Ryan PG, Underhill LG, Goren M. 2009c. Seabird bycatch in the demersal longline fishery off southern Africa. *African Journal of Marine Science* 31: 205-214.

Petersen SL, Nel DC. 2007. Ecological Risk Assessment (ERA) for the South African Squid Fishery. In: Nel DC, Cochrane K, Petersen SL, Shannon LJ, van Zyl B, Honig MB (eds), *Ecological Risk Assessment: A Tool for implementing and Ecosystem Approach for Southern African Fisheries*. WWF South Africa Report Series - 2007/Marine/002. Cape Town: WWF-South Africa.

Petersen SL, Ryan PG, Gre´millet D. 2006 Is food availability limiting African penguins at Boulders? A comparison of foraging effort at mainland and island colonies. *Ibis* 148: 14-26. DOI:10.1111/j.1474-919X.2006.00459.x

Petersen SL, Ryan PG, Grémillet D. 2006 Is food availability limiting African penguins at Boulders? A comparison of foraging effort at mainland and island colonies. *Ibis* 148, 14-26. DOI:10.1111/j.1474-919X.2006.00459.x.

Peterson CH, Rice SD, Short JW, Esler D, Bodkin JL, Ballachey BE, Irons DB. 2003. Long-term ecosystem response to the Exxon Valdez oil spill. *Science* 302: 2082-2086.

Pfaff MC, Branch GM, Wieters EA, Branch RA, Broitman BR. 2011. Upwelling intensity and wave exposure determine recruitment of intertidal mussels and barnacles in the southern Benguela upwelling region. *Marine Ecology Progress Series* 425: 141-152.

Pichegru L, Gremillet D, Crawford RJM, Ryan PG. 2010. Marine no-take zone rapidly benefits endangered penguin. *Biological Letters*: DOI:10.1098/rsbl.2009.0913. Available at http://rsbl.royalsocietypublishing.org/ [accessed on 10 February 2010].

Pichegru L, Ryan PG, Le Bohec C, Van der Lingen CD, Navarro R, Petersen S, Lewis S, Van der Westhuizen J, Gre´millet D. 2009 Overlap between vulnerable top predators and fisheries in the Benguela upwelling system: implications for marine protected areas. *Marine Ecology Progress Series* 391: 199-208. DOI:10.3354/ meps08283.

Pichegru L, Ryan PG, Le Bohec C, Van der Lingen CD, Navarro R, Petersen S, Lewis S, Van der Westhuizen J, Grémillet D. 2009 Overlap between vulnerable top predators and fisheries in the Benguela upwelling system: implications for marine protected areas. *Marine Ecological Progress Series* 391: 199-208. DOI:10.3354/ meps08283.

Pichegru L, Ryan PG, van der Lingen CD, Coetzee JC, Ropert-Coudert Y, Gremillet D. 2007. Foraging behavior and energetic of Cape gannets Morus capensis feeding on live prey and fishery discards in the Benguela upwelling system. *Marine Ecology Progress Series* 350: 127-136.

Pilkey OH, Neal WJ, Kelley JT, Cooper JAG. 2010. *The world's beaches: a global guide to the science of the shoreline.* California: University of California Press.

Pillay D, Branch GM, Griffiths CL, Williams C, Prinsloo A. 2010. Ecosystem change in a South African marine reserve (1960-2009): role of seagrass loss and anthropogenic disturbance. *Marine Ecology Progress Series* 415: 35-48.

Pinnegar JK, Plunin NVC, Francour P, Badalamenti F, Chemello R, Harmelin-Vivien M-L, Hereu B, Milazzo M, Zabala M, D'Anna G, Pipitone C. 2000. Trophic cascades in marine ecosystems lessons for fisheries and protected-area management. *Environmental Conservation* 27: 179-200.

Pisces Environmental Services. 2007. Assessment of cumulative impacts of scouring of sub-tidal areas and kelp cutting by diamond divers in near-shore areas of the BCLME region. Project report BEHP/CEA/03/04. Cape Town: BCLME mining and petroleum activities task group.

Pitta P, Apostolaki ET, Giannoulaki M, Karakassis I. 2005. Mesoscale changes in the water column in response to fish farming zones in three coastal areas in the eastern Mediterranean Sea. *Estuarine Coast and Shelf Science* 65(3): 501-512.

Planes S, Jones GP, Thorrold SR. 2009. Larval dispersal connects fish populations in a network of marine protected areas. *Proceedings of the National Academy of Sciences of the United States of America* 14: 5693-5697.

Plass-Johnson JG, McQuaid CD, Porri F, 2010. Top-down effects on intertidal mussel populations: assessing two predator guilds in a South African marine protected area. *Marine Ecology Progress Series* 411: 149-159.

Pollock DE, Augustyn CJ. 1982. Biology of the rock lobster Palinurus gilchristi with notes on the South African fishery. *Fisheries Bulletin of South Africa* 16: 57-73.

Pollock DE, Cockcroft AC, Groeneveld AC, Schoeman DS. 2000 The fisheries for Jasus species in the south-east Atlantic and for the Palunirus species of the south-west Indian Ocean. In: Phillips BF, Kittaka J (eds), *Spiny Lobsters: Fisheries and Culture 2nd edition*. Oxford: Fishing News Books, Blackwell Science.

Pollock DE. 1989. Spiny Lobsters. In Payne AIL, Crawford RJM (eds), *Oceans of Life off Southern Africa*. Cape Town: Vlaeberg Publishers.

Porrello S, Tomassetti P, Manzueto L, Finoia MG, Persia E, Mercatali I, Stipa P. 2005. The influence of marine cages on the sediment chemistry in the Western Mediterranean sea. *Aquaculture* 249(1-4): 145-158.

Porter S. 2009. Biogeography and potential factors regulating shallow subtidal reef communities in the western Indian Ocean, PhD thesis, University of Cape Town, South Africa.

Porter SN, Sink KJ, Holness S, Lombard AT. 2011. Review to support the development of marine biodiversity targets for South Africa. Unpublished report. Cape Town: South African National Biodiversity Institute.

Pulfrich A, Clark BM, Hutchings K. 2007. Monitoring environmental effects of pocket beach mining on sandy beach and rocky intertidal biota of southern Namibia. Report prepared PISCES Environmental Services (Pty) Ltd and Anchor Environmental Consultants CC. Windhoek: NAMDEB Diamond Corporation (Pty) Ltd.

Pulfrich A, Parkins CA, Branch GM, Bustamante RH, Velásquez CR. 2003a. The effects of sediment deposits from Namibian diamond mines on intertidal and subtidal reefs and rock lobster populations. *Aquatic Conservation: Marine and Freshwater Ecosystems* 13:257-278

Pulfrich A, Parkins CA, Branch GM. 2003b. The effects of shore-based diamond-diving on intertidal and subtidal biological communities and rock lobsters in southern Namibia. *Aquatic Conservation: Marine and Freshwater Ecosystems* 13:233-255.

Pulfrich A, Penney AJ. 1999. The Effects of Deep-Sea Diamond Mining on the Benthic Community Structure of the Atlantic 1 Mining Licence Area. Annual Monitoring Report - 1998. Report prepared by Pisces Research and Management Consultants and the University of Cape Town. Cape Town: De Beers Marine (Pty) Ltd.

Pulfrich A. 1998. Assessment of the impact of diver-assisted near-shore diamond mining on marine benthic communities in the Kerbe Huk area, Namibia. Pisces Environmental Services (Pty) Ltd and Marine biology Research Institute, UCT. Report for NAMDEB Diamond Corporation (Pty) Ltd. 29pp

Pulfrich A. 2004. Baseline survey of sandy beach macrofaunal communities at Elizabeth Bay: Beach monitoring report 2004. Report prepared by Pisces Environmental Services (Pty) Ltd. Windhoek: NAMDEB Diamond Corporation (Pty) Ltd.

Pulfrich A. 2007a. Assessment of cumulative impacts of scouring of subtidal areas and kelp cutting by diamond divers in near-shore areas of the BCLME region. Report prepared by Pisces Environmental Services (Pty) Ltd. Windhoek: NAMDEB Diamond Corporation (Pty) Ltd.

Pulfrich A. 2007b. Baseline survey of near-shore marine benthic communities in the Bogenfels area, off southern Namibia. Report prepared Pisces Environmental Services (Pty) Ltd. Cape Town: Benguela Current Large Marine Ecosystem Programme.

Punt AE, Japp DW.1994. Stock assessment of the kingklip *Genypterus capensis* off South Africa. *South African Journal of Marine Science* 14: 133-149.

Puttick GM 1977. Spatial and temporal variations in intertidal animal distribution at Langebaan Lagoon, South Africa. *Transactions of the Royal Society of South Africa*. 42: 403-433.

Queiros AM, Hiddink JG, Kaiser MJ, Hinz H. 2006. Effects of chronic bottom trawling disturbance on benthic biomass, production and size spectra in different habitats. *Journal of Experimental Marine Biology and Ecology* 335: 91-103.

Quiñones RA, Montes RM. 2001. Relationship between freshwater input to the coastal zone and the historical landing of the benthic/demersal fish *Eleginops maclovinus* in central-south Chile. *Fisheries Oceanography* 10: 311-328.

Rademeyer RA, Butterworth DS, Playányi ÉE. 2008a. Assessment of the South African hake resource taking its two-species nature into account. *African Journal of Marine Science* 30: 263-290.

Rademeyer RA, Butterworth DS, Playányi ÉE. 2008b. A history of recent bases for management and the development of a species-combined Operations Management Procedure fro the South African hake resource. *African Journal of Marine Science* 30: 291-310.

Rand RW. 1972. The Cape fur seal Arctocephalus pusillus. 4. Estimates of population size. Investigational Report, Division Sea Fisheries, South Africa 89: 1-28.

Reaugh-Flower KE, Branch GM, Harris JM, McQuaid CD, Currie B, Dye A, Robertson B. 2010. Patterns of mussel recruitment in southern Africa: a caution about using artificial substrata to approximate natural recruitment. *Marine Biology* 157: 2177-2185.

Reay DS, Dentener F, Smith P, Grace J, Feely RA. 2008. Global nitrogen deposition and carbon sinks. *Nature* 1:430-437.

RSA-DEAT (Republic of South Africa, Department of Environmental Affairs and Tourism). 2008. South Africa's National Programme of Action for Protection of the Marine Environment from Land-based Activities. First Edition. Cape Town.

RSA-DWAF (Republic of South Africa, Department of Water Affairs and Forestry). 2004. Water Quality Management Series, Sub-Series No. MS 13.4. Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa. Edition 1. Pretoria: Department of Water Affairs and Forestry, South Africa.

Reusch TBH, Bolte S, Sparwel M, Moss AG, Javidpour J. 2010. Microsatellites reveal origin and genetic diversity of Eurasian invasions by one of the world's most notorious invaders, *Mnemiopsis leidyi* (Ctenophora). *Molecular Ecology* 19: 2690-2699.

Richardson AJ, Poloczanska ES. 2008. Under-resourced, under threat. *Science* 320: 1294-1295.

Richardson MD, Briggs KB, Young DK. 1985. Effects of biological activity by abyssal benthic macroinvertebrates on a sedimentary structure in the Venezuela Basin. *Marine Geology* 68: 243-267.

Ridgway T, Riginos C, Davis J, Hoegh-Guldberg O. 2008. Genetic connectivity patterns of *Pocillopora verrucosa* in southern African Marine Protected Areas. *Marine Ecology Progress Series* 354: 161-168.

Riedl R, Huang N, Machan R. 1972. The Subtidal Pump: A Mechanism of Water Exchange by Wave Action. *Marine Biology* 13: 210-21.

Riegl B, Branch GM. 1995. Effects of sediment on the energy budgets of four scleractinian (Bourne 1900) and five alcyonacean (Lamouroux 1816) corals. *Journal of Experimental Marine Biology and Ecology* 186: 259-275.

Riegl B, Schleyer MH, Cook PJ, Branch GM. 1995. The structure of Africa's southernmost coral communities. *Bulletin of Marine Science* 56: 676-691.

Rius M, Matthee CA, von der Heyden S. The invasion history of co-occurring widespread species: comparing regional and global genetic signatures. In review

Rius M, Pascual M, Turon X. 2008. Phylogeography of the widespread marine invader *Microcosmus squamiger* (Ascidiacea) reveals high genetic diversity of introduced and non-independent colonizations. *Diversity and Distributions* 14: 818-828

Roberts MJ, Mullon C. 2010. First Lagrangian ROMS-IBM simulations indicate large losses of chokka squid *Loligo reynaudii* paralarvae from South Africa's Agulhas bank. *African Journal of Marine Science* 32: 71-84.

Robinson TB, Branch GM, Griffiths CL, Govender A, Hockey PAR. 2007a. Effects of the invasive mussel *Mytilus galloprovincialis* on rocky intertidal community structure in South Africa. *Marine Ecology Progress Series* 340: 163-171.

Robinson TB, Branch GM, Griffiths CL, Govender A. 2007b. The invasion and subsequent die-off of *Mytilus galloprovincialis* in Langebaan Lagoon, South Africa: effects on natural communities. *Marine Biology* 152: 225-232

Robinson TB, CL Griffiths 2002. Invasion of Langebaan Lagoon, South Africa, by *Mytilus galloprovincialis* - effects on natural communities. *African Zoology* 37: 151-158.

Robinson TB, Griffiths CL, McQuaid CD, Rius M. 2005. Marine alien species of South Africa - status and impacts. *African Journal of Marine Science* 27: 297-306.

Rocha LA, Craig MT, Bowen BW. 2007. Phylogeography and the conservation of marine fishes. *Coral Reefs* 26: 501-512.

Rodrigues-Labajos B, Binimelis R, Monterroso I. 2009. Multi-level driving forces of biological invasions. *Ecological Economics* 69: 63-75.

Roel BA. 1987. Demersal communities off the west coast of South Africa. In: Payne AIL, Gulland JA, Brink KH (eds), *The Benguela and Comparable Ecosystems*. *South African Journal of Marine Science* 5: 575-584.

Roeleveld MAC, Lipinski MR, Augustyn CJ, Stewart BA. 1992. The distribution and abundance of cephalopods on the continental slope of the eastern South Atlantic. *South African Journal of Marine Science* 12: 739-752.

Rogers AD. 1994. The biology of seamounts. *Advances in Marine Biology* 30: 305-350.

Rogers J, Bremner JM. 1991. The Benguela ecosystem. Part VII. Marine-geological aspects. *Oceanography and Marine Biology: An Annual Review* 29: 1-85.

Roodt-Wilding R. 2007. Abalone ranching: a review on genetic considerations. *Aquaculture Research* 38: 1229-1241.

Roos L. 2005. Environmental Management Programme Report for South African Sea Areas Mining Licence ML3/2003. Cape Town: De Beers Marine , De Beers Consolidated Mines.

Rosenzweig C, Casassa G, Karoly DJ, Imeson A, Liu C, Menzel A, Rawlins S, Root TL, Seguin B, Tryjanowski P. 2007. Assessment of observed changes and responses in natural and managed systems. In Parry ML, Canziani O, Palutikof JP, van der Linden PJ, Hanson CE (eds), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Rouault M, Penven P, Pohl B. 2009. Warming in the Agulhas Current system since the 1980's. *Geophysical Research Letters* 36: L12602. DOI: 10.1029/2009GL037987.

Rouault M, Pohl B, Penven P. 2010. Coastal oceanic climate change and variability from 1982 to 2009 around South Africa. *African Journal of Marine Science* 32: 237-246.

Rowden AA, Clark MR, Wright IC. 2005. Physical characterization and a biologically focused classification of "seamounts' in the New Zealand region. *New Zealand Journal of Marine and Freshwater Research* 39: 1039-1059.

Rowe GT, Pariente V (eds). 1992. *Deep-Sea Food Chains and Global Carbon Cycle*. Amsterdam: Kluwer Academic Publishers.

Rowe GT. 1971. Observations on bottom currents and epibenthic populations in Hatteras Submarine Canyon. *Deep-Sea Research* 18: 569-581.

Roy C, van der Lingen CD, Coetzee JC, Lutjeharms JRE. 2007. Abrupt environmental shift associated with changes in the distribution of Cape anchovy *Engraulis encrasicolus* spawners in the southern Benguela. *African Journal of Marine Science* 29: 309-319.

RSA (Republic of South Africa). 1998. National Water Act (Act No. 36 of 1998). *Government Gazette, South Africa* 389 (1091).

RSA (Republic of South Africa). 2008. National Environmental Management: Integrated Coastal Management Act (Act No. 24 of 2008). *Government Gazette, South Africa* 524 (31884).

Rubies P. 1985. Zoogeography of the lanternfishes (Osteichthyes, Myctophidae) off southwest Africa. In: Bas C, Margalef R, *Rubies P (eds), Simposio internacional sobre las areas de afloramiento mas importantes del Oeste Africano (cabo Blanco y Benguela). Barcelona: Instituto* de Investigaciones *Pes-* '| queras *.* Pp 573-586.

Ruesink JL, Lenihan HS, Trimble AC, Heiman KW, Micheli F, Byers JE, Kay MC. 2005. Introduction of non-native oysters: ecosystem effects and restoration implications. *Annual Review of Ecology and Evolutionary Systems* 36: 643-689.

Ruiz GM, Fofonoff PW, Hines AH, Grosholz ED. 1999. Non-indigenous species as stressors in estuarine and marine communities: assessing invasion impacts and interactions. *Limnology and Oceanography* 44: 950-972.

Ruiz Sebastain C, Sink KJ, McClanahan T, Cowan D. 2009. Bleaching response of corals and their Symbiodinium communities in southern Africa. *Marine Biology* 56: 2049-2062.

Ruiz Sebastián C, O'Ryan C. 2001. Single-cell sequencing of dinoflagellate (Dinophyceae) nuclear ribosomal genes. *Molecular Ecology Notes* 1: 329-331.

Ruiz Sebastián C, Steffani CN, Branch GM. 2002. Homing and movement patterns of a South African limpet *Scutellastra argenvillei* in an aria invaded by an alien mussel *Mytilus galloprovincialis*. *Marine Ecology Progress Series* 243: 111-122.

Ryan PG, Keith DG, Kroese M. 2002. Seabird bycatch by tuna longline fisheries off southern Africa. *South African Journal of Marine Science* 24, 103-110.

Ryan PG, Keith DG, Kroese M. 2002. Seabird bycatch by tuna longline fisheries off southern Africa. *South African Journal of Marine Science* 24: 103-110.

Ryder OA. 1986. Species conservation and systematics: the dilemma of subspecies. *Trends in Ecology and Evolution* 1: 9-10.

Ryther JH, Hall JR, Pease AK, Bakun A, Jones MM. 1966. Primary organic production in relation to the chemistry and hydrography of the western Indian Ocean. *Limnology and Oceanography* 11: 371-380.

Safriel O, Bruton MN. 1984. Aquaculture in South Africa: A cooperative research programme. South African National Scientific Programmes Report No. 89. Pretoria: CSIR.

SAHO, 2009. South African History Online: Under the Waters - Historical ships and shipwrecks along the South African coast. Available at http://www.sahistory.org.za/historical-ships-and-shipwrecks-along-south-african-coast [accessed on the 21 June 2011]

Salvat B. 1964. Les conditions hydrodynamiques interstitielles de sediments meubles intertidaux et la rapartition verticale de la fauna endogee. *CR Academic Sciences Paris* 259: 1576-1579.

Samaai T, Gibbons MJ, Kerwath S, Yemane D, Sink K. 2010. Sponge richness along a bathymetric gradient within the iSimangaliso Wetland Park, South Africa. *Marine Biodiversity* 40: 205-217. DOI 10.1007/s12526-010-0046-z.

Sammarco PW, Atchison AD, Boland GS. 2004. Expansion of coral communities within the Northern Gulf of Mexico via offshore oil and gas platforms. *Marine Ecology Progress Series* 280: 129-143.

SANBI (South African National Biodiversity Insittute). 2008. Report on Threatened Marine Species Workshop, South African National Biodiversity Institute, 1 September 2008. Cape Town: South African National Biodiversity Institute.

Sara G, Scilipoti D, Mazzola A, Modica A. 2004. Effects of fish farming waste to sedimentary and particulate organic matter in a southern Mediterranean area (Gulf of Catellammare, Sicily): a multiple stable isotope study. *Aquaculture* 234: 199-213.

Sauer WHH, Hecht T, Britz PJ, Mather D. 2003. An economic and sectoral study of the South African fishing industry. Volume 2. Fishery profiles. Report prepared by Rhodes University. Cape Town: Marine and Coastal Management.

Sauer WHH, Penney AJ, Erasmus C, Mann BQ, Brouwer SL, Lamberth SJ, Stewart TJ. 1997. An evaluation of attitudes and responses to monitoring and management measures for the South African boat-based linefishery. South African Journal of Marine Science 18: 147-163.

Savage C, Field JG, Sauer WHH, 2001. Comparative meta-analysis of the impact of offshore marine mining on macrobenthic communities versus organic pollution studies. *Marine Ecology Progress Series* 221: 265-275.

Savage C. 1996. Multivariate analyses of the impact of offshore marine mining on the benthic macrofauna off the west coast of southern Africa. M.Sc thesis. University of Cape Town, South Africa.

Schaanning MT, Trannum HC, Oxnevad S, Carroll J, Bakke T. 2008. Effects of drill cuttings on biogeochemical fluxes and macrobenthos of marine sediments. *Journal of Experimental Marine Biology and Ecology* 361: 49-57.

Schlacher TA, Dugan J, Schoeman DS, Lastra M, Jones A, Scapini F, McLachlan A, Defeo O. 2007. Sandy beaches at the brink. *Diversity and Distributions* 13: 556-560.

Schleupner C. 2008. Evaluation of coastal squeeze and its consequences for the Caribbean island Martinique. *Ocean and Coastal Management* 51: 383-390.

Schleyer MH, Celliers L. 2003. Coral dominance at the reef-sediment interface in marginal coral communities at Sodwana Bay, South Africa. *Marine and Freshwater Research* 54: 967-972.

Schleyer MH, Celliers L. 2003a. Biodiversity on the marginal coral reefs of South Africa: what does the future hold? *Zoologische Verhandelingen* 345: 387-400.

Schleyer MH, Celliers L. 2003b. Coral dominance at the reef-sediment interface in marginal coral communities at Sodwana Bay, South Africa. *Marine and Freshwater Research* 54: 967-972.

Schleyer MH, Heikoop JM, Risk MR. 2006. A benthic survey of Aliwal Shoal and assessment of the effects of a wood pulp effluent on the reef. *Marine Pollution Bulletin* 52: 503-514.

Schleyer MH, Kruger A, Celliers L. 2008. Long-term community changes on high-latitude coral reefs in the Greater St Lucia Wetland Park, South Africa. *Marine Pollution Bulletin* 56: 493-502.

Schoeman DS, McLachlan A, Dugan JE. 2000. Lessons from a disturbance experiment in the intertidal zone of an exposed sandy beach. *Estuarine, Coastal and Shelf Science* 50: 869-884.

SeaPLAN. In prep. *Ezemvelo Marine Systematic Conservation Plan*. Durban: Ezemvelo KwaZulu-Natal Wildlife, South Africa.

Selkoe KA, Henzler CM, Gaines SD. 2008. Seascape genetics and the spatial ecology of marine populations. *Fish and Fisheries* 9: 363-377

Sellner KG, Doucette GJ, Kirkpatrick GJ. 2003. Harmful Algal blooms: causes, impacts and detection. *Journal of Industrial Microbiology and Biotechnology* 30: 383-406.

Senanan W, Tangkrock-Olan N, Panutrakul S, Barnette P, Wongwiwatanawute C, Niphonkit N, Anderson DJ. 2007. The presence of the Pacific whiteleg shrimp (*Litopenaeus vannamei* Boone, 1931) in the wild in Thailand. *Journal of Shellfish Research* 26:1187-1192.

Serôdio J, Catarino F. 2000. Modelling the primary productivity of intertidal microphytobenthos: time scales of variability and effects of migratory rhythms. *Marine Ecology Progress Series* 192:13-30.

Serrano A, Sanchez F, Preciado I, Parra S, Frutos I 2006. Spatial and temporal changes in benthic communities of the Galician continental shelf after the Prestige oil spill. *Marine Pollution Bulletin* 53: 315-331.

Shanks AL. 2009. Pelagic larval duration and dispersal distance revisited. *Biological Bulletin* 216: 373-385.

Shannon LJ, Cury PM, Nel D, van der Lingen CD, Leslie RW, Brouwer SL, Cockcroft AC, Hutchings L. 2006. How can science contribute to an ecosystem approach to pelagic, demersal and rock lobster fisheries in South Africa? *African Journal of Marine Science* 28: 115-157.

Shannon LV, Stander GM. 1977. Physical and chemical characteristics of water in Saldanha Bay and Langebaan Lagoon. *Transaction of the Royal Society of South Africa* 42: 411 - 461.

Shannon LV, Van der Elst RP, Crawford RJM. 1989. Tunas, bonitos, Spanish mackerels and billfish. In: Payne AIL, Crawford RJM (eds), *Oceans of Life off southern Africa*. Cape Town: Vlaeberg Publishers. pp 188-198.

Sheehy D, Vik S. 2010. The role of constructed reefs in non-indigenous species introductions and range expansions. *Ecological Engineering* 36: 1-11.

Shine KH. 2008. Biogeographic Patterns and Assemblages of Demersal Fishes on the south and west coasts of South Africa, report BCLME Project BEHP/BAC/03/03 Khara Shine. pp105.

Short AD. 2006. Australian beach systems - nature and distribution. *Journal of Coastal Research* 22: 11-27.

Siebert T, Branch GM. 2005a. Influences of biological interactions between *Zostera capensis* and *Callianassa kraussi* on community composition and functioning within eelgrass beds and sandflats. *African Journal of Marine Science* 27: 345-356.

Siebert T, Branch GM. 2005b. Interaction between *Zostera capensis* and *Callianassa kraussi*: influences on community composition of eelgrass beds and sandflats. *African Journal of Marine Science* 27: 357-374.

Siebert T, Branch GM. 2006. Ecosystem engineers: Interaction between eelgrass *Zostera capensis* and the sandprawn *Callianassa kraussi* and their indirect effect on the mudprawn *Upogebia africana*. *Journal of Experimental Marine Biology and Ecology* 338: 253-270.

Siebert T, Branch GM. 2007. Influences of biological interactions on community structure within seagrass beds and sandprawn-dominated sandflats. *Journal of Experimental Marine Biology and Ecology* 340: 11-24.

Silver MW, Alldredge AL. 1981. Bathypelagic marine snow: deep-sea algal and detrital community. *Journal of Marine Research* 39(3): 501-530.

Simon-Blecher N, Granevitze Z, Achituv Y. 2008. *Balanus glandula*: from North-West America to the west coast of South Africa. *African Journal of Marine Science* 30: 85-92.

Sink K, Attwood C. 2008. Guidelines for Offshore Marine Protected Areas in South Africa. SANBI Biodiversity Series 9. Pretoria: South African National Biodiversity Institute.

Sink K, Samaai T. 2009. The offshore MPA project report: Identifying Offshore Vulnerable Marine Ecosystems in South Africa. Unpublished Report. Cape Town: South African National Biodiversity Institute.

Sink K. 2004. Threats affecting marine biodiversity on South Africa. Appendix 2: South African National Spatial Biodiversity Assessment, Technical Report Volume 4: Marine Component. Cape Town: South African National Biodiversity Institute.

Sink KJ, Atkinson LJ, Kerwath S, Samaai T. 2010. Assessment of offshore benthic biodiversity on the Agulhas Bank and the potential role of petroleum infrastructure in offshore spatial management. Report prepared for WWF South Africa and PetroSA through a SANBI initiative. Cape Town: South African National Biodiversity Institute.

Sink KJ, Attwood CG, Lombard AT, Grantham H, Leslie R, Samaai T, Kerwath S, Majiedt P, Fairweather T, Hutchings L, van der Lingen C, Atkinson LJ, Wilkinson S, Holness S, Wolf T. 2011. Spatial planning to identify focus areas for offshore biodiversity protection in South Africa. Unpublished Report. Cape Town: South African National Biodiversity Institute.

Sink KJ, Boshoff W, Samaai T, Timm PG, Kerwath SE. 2006. Observations of the habitats and biodiversity of the submarine canyons at Sodwana Bay. *South African Journal of Science* 102: 466-474.

Sink KJ, Harris J, Lombard A. 2004. Appendix 1: South African marine bioregions. In: *Appendices of the National Spatial Biodiversity Assessment 2004*. Pretoria: South African National Biodiversity Institute. Pp 1-13.

Sink KJ. 2001. A hierarchical analysis of abiotic determinants and harvesting impacts in the rocky intertidal communities of KwaZulu-Natal. PhD thesis, University of Cape Town, South Africa.

Sink, KJ, Branch GM, Harris JM. 2005. Biogeographic patterns in rocky intertidal communities in KwaZulu-Natal, South Africa. *African Journal of Marine Science* 27: 81-96.

Smale MJ, Badenhorst A. 1991. The distribution and abundance of linefish and secondary trawlfish on the Cape south coast of South Africa, 1986-1990. *South African Journal of Marine Science* 11: 195-408.

Smale MJ, Roel BA, Badenhorst A, Field JG. 1993. Analysis of the demersal community of fish and cephalopods on the Agulhas Bank, South Africa. *Journal of Fisheries Biology* 43: 169-191.

Smale MJ, Roel BA, Badenhorst A, Field JG. 1993. Analysis of demersal community of fish and cephalopods on the Agulhas Bank, South Africa. *Journal of Fisheries Biology 43*: 169-191.

Small C, Nicholls RJ. 2003. A Global Analysis of Human Settlement in Coastal Zones. *Journal of Coastal Research* 19: 584-599.

Smith AA, Guastella LA, Bundy SC, Mather AA. 2007. Combined marine storm and Saros spring high tide erosion events along the KwaZulu-Natal coast in March 2007. *South African Journal of Science* 103: 274-276.

Smith AM, Mather AA, Bundy SC, Cooper JAG, Guastella LA, Ramsay PJ, Theron A. 2010. Contrasting styles of swell-driven coastal erosion: examples from KwaZulu-Natal, South Africa. *Geological Magazine* 147: 940-953.

Smith MM, Heemstra PC (eds). 1986. *Smiths' Sea Fishes*. Johannesburg: MacMillan South Africa.

Snelder T, Leathwick J, Dey K, Rowden A, Weatherhead M, Fenwick G, Francis M, Gorman R, Grieve J, Hadfield M, Hewitt J, Richardson K, Uddstrom M, Zeldis J. 2006. Development of an Ecologic Marine Classification in the New Zealand Region. *Environmental Management* 39: 12-29.

Soulé ME, Estes JA, Berger J, Del Rio CM. 2003. Ecological Effectiveness: Conservation Goals for Interactive Species. *Conservation Biology* 17: 1238-1250.

Spalding MD, Fox HE, Allen GR, Davidson N, Ferdaña ZA, Finlayson M, Halpern BS, Jorge MA, Lombana A, Lourie SA, Martin KD, McManus E, Molnar J, Recchia CA, Robertson J. 2007. Marine Ecoregions of the World: a bioregionalization of coast and shelf areas. *BioScience* 57: 573-583.

Sparks-McConkey PJ, Watling L. 2001. Effects on the ecological integrity of a soft-bottom habitat from a trawling disturbance. *Hydrobiologia* 456: 73-85.

Statistics South Africa. 2010. Tourism, 2010. Report no. 03-51-02 (2010). Pretoria: South Africa. Pages 1-45

Statistics South Africa. 2011. Mining: Production and sales (Preliminary) July 2011. Pages 1-15. Statistical Release P2041. Pretoria: South Africa.

Steffani CN, Branch GM. 2003a. Spatial comparisons of populations of an indigenous limpet *Scutellastra argenvillei* and an alien mussel *Mytilus galloprovincialis* along a gradient of wave energy. *African Journal of Marine Science* 25: 195-212.

Steffani CN, Branch GM. 2003b. Temporal changes in an interaction between an indigenous limpet *Scutellastra argenvillei* and an alien mussel *Mytilus galloprovincialis*: effects of wave exposure. *African Journal of Marine Science* 25: 213-229.

Steffani CN, Branch GM. 2005. Mechanisms and consequences of competition between an alien mussel, *Mytilus galloprovincialis*, and an indigenous limpet, *Scutellastra argenvillei*. *Journal of Experimental Marine Biology and Ecology* 317:127-142.

Steffani CN, Pulfrich A. 2004. Environmental Baseline Survey of the Macrofaunal Benthic Communities in the De Beers ML3/2003 Mining License Area. Cape Town: De Beers Marine (Pty) Ltd.

Steffani CN, Pulfrich A. 2007. Biological Survey of the Macrofaunal Communities in the Atlantic 1 Mining Licence Area and the Inshore Area between Kerbehuk and Lüderitz 2001 - 2004 Surveys. Cape Town: De Beers Marine Namibia.

Steinhauer M, Crecelius E, Steinhauer W. 1994. Temporal and spatial changes in the concentrations of hydrocarbons and trace metals in the vicinity of an offshore oil-production platform. *Marine Environmental Research* 37: 129-163.

Stephenson TA, Stephenson A. 1972. *Life between tidemarks on rocky shores*. San Francisco: WH Freeman.

Stephenson TA. 1948. The constitution of the intertidal fauna and flora of South Africa, II. *Annals of the Natal Museum* 11: 261-358.

Stevens JD, Bonfil R, Dulvy NK, Walker PA. 2000. The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecostystems. *ICES Journal of Marine Science* 57: 476-494.

Stockton WL, De Laca TE. 1982. Food falls in the deep-sea: occurrence, quality and significance. *Deep-Sea Research* 29(2A): 157-169.

Tallis H, Kareiva P, Marvier M, Chang A, Mwinyi AH. 2008. An ecosystem services framework to support both practical conservation and economic development. *Proceedings of the National Academy of Sciences of the United States of America* 105: 9457-9465.

Tamelander J, Riddering L, Haag F, Matheickal J. 2010. Guidelines for Development of National Ballast Water Management Strategies. GEF-UNDP-IMO GloBallast, London, UK and IUCN, Gland, Switzerland. GloBallast Monographs No. 18.

Tanner JE. 2003. The influence of prawn trawling on sessile benthic assemblages in Gulf St. Vincent, South Australia. *Canadian Journal of Fisheries and Aquatic Sciences* 60: 517-526.

Tarr RJQ, Williams PVG, MacKenzie AJ. 1996. Abalone, sea urchins and rock lobster: a possible ecological shift may affect traditional fisheries. *South African Journal of Marine Science* 17: 319-323.

Tarr RJQ, Williams PVG, MacKenzie L. 1992. Abalone, sea urchins and rock lobster: implications for community management. *Canadian Journal of Fisheries Aquatic Science* 57: 2175-2185.

Tarr RJQ. 2000. The South African abalone (*Haliotis midae*) fishery: a decade of challenges and change. *Canadian Special Publications in Fisheries and Aquatic Sciences* 130: 32-40.

Teck SJ, Halpern BS, Kappel CV, Micheli F, Selkoe KA, Crain CM, Martone R, Shearer C, Arvai J, Fischhoff B, Murray G, Neslo R, Cooke R. 2010. Using expert judgment to estimate marine ecosystem vulnerability in the California Current. *Ecological Applications* 20: 1402-1416.

TEEB (The Economics of Ecosystems and Biodiversity). 2010. The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB. Geneva: TEEB.

Tegner MJ, Dayton PK. 2000. Ecosystem effects of fishing in kelp forest communities. *ICES Journal of Marine Science* 57: 579-589.

Teske PR, Forget FRG, Cowley PD, von der Heyden S, Beheregaray LB. 2010. Connectivity between marine reserves and exploited areas in the philopatric reef fish *Chrysoblephus laticeps* (Teleostei: Sparidae). *Marine Biology* 157: 2029-2042.

Teske PR, McQuaid CD, Froneman PW, Barker NP. 2006. Impacts on marine biogeographic boundaries on phylogeographic patterns of three South African estuarine crustaceans. *Marine Ecology Progress Series* 314: 283-293.

Teske PR, Papadopoulos I, Newman BK, Dworschak PC, McQuaid CD, Barker NP, 2008. Oceanic dispersal barriers, adaptation and larval retention: an interdisciplinary assessment of potential factors maintaining a phylogeographic break between sister lineages of an African prawn. *BMC Evolutionary Biology* 8: 341.

Teske PR, Papadopoulos I, Zardi GI, McQuaid CD, Edkins MT, Griffiths CL, Barker NP. 2007. Implications of life history for genetic structure and migration rates of southern African coastal invertebrates: planktonic, abbreviated and direct development. *Marine Biology* 152:697-711.

Teske PR, Winker H, McQuaid CD, Barker NP. 2009. A tropical/subtropical biogeographic disjunction in southeastern Africa separates two Evolutionarily Significant Units of an estuarine prawn. *Marine Biology* 156: 1265-1275.

Thander AS. 1989. Zoogeography of the southern African echinoderm fauna. *South African Journal of Zoology 24*: 311-318.

Theron A, Rossouw M. 2008. Analysis of potential coastal zone climate change impacts and possible response options in the southern African region*. Real and Relevant 2nd CSIR Biennial Conference, Pretoria, 17 and18 November 2008.* Pretoria: CSIR.

Thomas K, Kvitek R, Bretz C. 2001. Effects of human activity on the foraging behaviour of sanderlings *Calidris alba. Biological Conservation* 109: 67-71.

Tinley KL. 1985. Coastal dunes of South Africa. South African National Scientific Programmes Report No. 109. Pretoria: CSIR.

Tolley KA, Groeneveld JC, Gopal K, Matthee. 2005. Mitochondrial DNA panmixia in spiny lobster Palinuris *gilchristi* suggests a population expansion. *Marine Ecology Progress Series* 297: 225-231.

Tomalin BJ, Kyle R. 1998. Subsistence and recreational mussel (*Perna perna*) collecting in KwaZulu-Natal, South Africa: fishing mortality and precautionary management. *South African Journal of Zoology* 33: 12-22.

Toral-Granda MV, Moloney CL, Harris JM, Mann BQ. 1999. Ecosystem impacts of the KwaZulu-Natal reef fishery, South Africa: an exploratory model. In: *Ecosystem approaches for fisheries management*. Fairbanks: University of Alaska Sea Grant. pp. 211-219.

Tourism-KZN. 2007. Tourism Statistics 2007 brochure. Durban: Department of Environmental Affairs and Tourism, South Africa.

Troell M, Robertson-Andersson D, Anderson R, Bolton J, Maneveldt G, Halling C, Probyn T. 2006. Abalone farming in South Africa: An overview with perspectives on kelp resources, abalone feed, potential for on-farm seaweed production and socio-economic importance. *Aquaculture* 257: 266-281.

Tunley K. 2009. State of Management of South Africa's Marine Protected Areas. WWF South Africa Report Series - 2009/Marine/001. Cape Town: WWF- South Africa.

Turpie JK, Beckley LE, Katua SM. 2000. Biogeography and the selection of priority areas for conservation of South African coastal fishes. *Biological Conservation* 92: 59-72.

Turpie JK, Heydenrych BJ, Lamberth SJ. 2003. Economic value of terrestrial and marine biodiversity in the Cape Floristic Region: implications for defining effective and socially optimal conservation strategies. *Biological Conservation* 112: 233-251.

Turpie JK, Marais C, Blignaut JN. 2007. The working for water programme: evolution of a payments for ecosystem services mechanism that addresses both poverty and ecosystem service delivery in South Africa. *Ecological Economics* 65: 788-798.

Turpie JK, Ryan PG. 1998. The nature and value of birding in South Africa. *BirdLife South Africa Research Series* 1: 1-41.

Turpie JK. 2003. The existence value of biodiversity in South Africa: how interest, experience, knowledge, income and perceived level of threat influence local willingness to pay. *Ecological Economics* 46: 199-216.

Twatwa NM, van der Lingen CD, Drapeau L, Moloney CL, Field JG. 2005. Characterizing and comparing the spawning habitats of anchovy (*Engraulis encrasicolus*) and sardine (*Sardinops sagax*) in the southern Benguela upwelling ecosystem. *African Journal of Marine Science* 27: 587-499.

Tyler PA. 1980. Deep-sea ophiuroids. *Oceanography Marine Biology Annual Review* 18: 125-153.

Tymchuk WE, Abrahams MV, Devlin RH. 2005. Competetive ability and mortality of growth enhanced transgenic Coho salmon fry and parr when foraging for food. *Transaction of the American Fisheries Society* 134: 381-389.

Underhil, LG, Bartlett PA, Baumann L, Crawford RJ M, Dyer BM, Gildenhuys A, Nel DC, Oatley TB, Thornton M, Upfold L, Williams AJ, Whittington PA, Wolfaart AC. 1999. Mortality and survival of African penguins *Sphenisicus demersus* involved in the Apollo Sea oil spill; an evaluation of rehabilitation efforts. *Ibis* 141: 29-37.

Underhill LG, Crawford RJM, Wolfaardt AC, Whittington PA, Dyer BM, Leshoro TM, Ruthenberg M, Upfold L, Visagie J. 2006. Regionally coherent trends in colonies of African penguins *Spheniscus demersus* in the Western Cape, South Africa, 1987- 2005. *African Journal of Marine Science* 28: 697-704.

UNEP (United Nations Environment Program). 2011. Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication - A Synthesis for Policy Makers. Available at http://www.unep.org/greeneconomy/GreenEconomyReport/tabid/29846/Default.aspx.

UNESCO (*United Nations Educational, Scientific and Cultural Organization)*. 2009. Global Open Oceans and Deep Seabed (GOODS) - biogeographic classification. IOC Technical Series, 84. Paris: UNESCO-IOC.

Van Ballegooyen RC, Taljaard S, van Niekerk, L, Lamberth SJ, Theron AK, Weerts SP. 2007. Freshwater flow dependency in South African Marine Ecosystems: A proposed assessment framework and initial assessment of South African Marine Ecosystems. Report No. K.V. 191/07. Pretoria: Water Research Commission.

Van der Elst RP, Garratt PA. 1984. Draft management proposals for the Natal deep reef fishery: 1-32. Unpublished document. Durban: Oceanographic Research Institute.

Van der Elst RP. 1979. A proliferation of small sharks in the shore-based Natal sport fishery. *Environmental Biology of Fishes* 4: 349-362.

Van der Lingen CD, Coetzee JC, Demarcq H, Drapeau L, Fairweather T, Hutchings L. 2005. An eastward shift in the distribution of southern Benguela sardine. *GLOBEC International Newsletter* 11: 17-22.

Van der Lingen CD, Shannon LJ, Cury P, Kreiner A, Moloney CL, Roux JP, Vaz-Velho F. 2006. Resource and Ecosystem Variability, Including Regime Shifts. In: Shannon V, Hempel G, Malanotte-Rizzoli P, Moloney C, Woods J (eds), *Benguela: Predicting a Large Marine Ecosystem*. *Large Marine Ecosystems 14.* Amsterdam: Elsevier. pp 147-185.

Van der Merwe K. 1996. Assessing the Rate of Recovery of Benthic Macrofauna after Marine Mining off the Namibian Coast. MSc. Thesis, University of Cape Town, South Africa.

Van Erkom Schurink C, Griffiths CL. 1990. Marine mussels of southern Africa - their distribution patterns, standing stocks, exploitation and culture. *Journal of Shellfish Research* 9: 75-85.

Van Niekerk L, Turpie JK (eds). 2011. South African National Biodiversity Assessment 2011: Technical Report. Volume 3: Estuary Component. Pretoria: South African National Biodiversity Institute. CSIR Report CSIR/NRE/ECOS/ER/2011/0045/B. Stellenbosch: Council for Scientific and Industrial Research.

van Wilgen BW, le Maitre DC, Cowling RM. 1998. Ecosystem services, efficiency, sustainability and equity: South Africa's Working for Water Programme. *Trends in Ecology and Evolution* 13:378.

Vandenbohede A, Houtte E, Lebbe L. 2008. Sustainable groundwater extraction in coastal areas: a Belgian example. *Environmental Geology* 57:735-747.

Verhulsta S, Oosterbeeka K, Ens BJ. 2001. Experimental evidence for effects of human disturbance on foraging and parental care in oystercatchers. *Biological Conservation* 101: 375-380.

Vita R, Marin A, Madrid JA, Jimenez-Brinquis B, Cesar A, Marin-Guirao L. 2004. Effects of wild fishes on waste exportation from a Mediterranean fish farm. *Marine Ecology Progress Series* 277: 253-261.

von der Heyden S Lipinski MR Matthee CA. 2010a. Remarkably low mtDNA control region diversity in an abundant demersal fish. *Molecular Phylogenetics and Evolution* 55: 1183-1188.

von der Heyden S, Barendse J, Seebregts AJ, Matthee CA. 2010b. Misleading the masses: detection of mislabeled and substituted frozen fish products in South Africa. *ICES Journal of Marine Science* 67: 176-185.

von der Heyden S, Groeneveld JC, Matthee CA. 2007b 'Long current to nowhere?' - genetic connectivity of *Jasus tristani* in the southern Atlantic Ocean. *African Journal of Marine Science* 29: 491-497.

von der Heyden S, Lipinski MR, Matthee CA. 2007a. Mitochondrial DNA analyses of the Cape hakes reveal an expanding, panmictic population for *Merluccius capensis* and population structuring for mature fish in *Merluccius paradoxus. Molecular Phylogenetics and Evolution* 42: 517-527.

von der Heyden S, Lipinski MR, Matthee CA. 2007c. Species-specific genetic markers for identification of early life history stages of Cape hakes, *Merluccius capensis* and *M. paradoxus* in the southern Benguela Current. *Journal of Fish Biology* 70: 262-256.

von der Heyden S, Lipinski MR, Matthee CA. 2010a. Remarkably low mtDNA control region diversity in an abundant demersal fish. *Molecular Phylogenetics and Evolution* 55: 1183-1188.

von der Heyden S, Prochazka K, Bowie RCK. 2008. Significant population structure amidst expanding populations of *Clinus cottoides* (Perciformes, Clinidae): application of molecular tools to marine conservation planning in South Africa. *Molecular Ecology* 17: 4812-4826.

von Der Heyden S. 2009. Why do we need to integrate population genetics into South African marine protected area planning? *African Journal of Marine Science* 31:263-269.

von der Heyden S. 2011. "Carry on sampling!" - Assessing marine fish biodiversity and discovery rates in southern Africa. *Diversity and Distributions* 17: 81-92.

Wabnitz C, Taylor M, Green E, Razak T. 2003. From Ocean to Aquarium. Cambridge, UK: UNEP-WCMC.

Wakefield WW, Smith KL Jr. 1990. Ontogenetic vertical migration in *Sebastolobus altivelis* as a mechanism for transport of particulate organic matter at continental slope depths. *Limnology and Oceanography* 35(6): 1314-1328.

Waldron HN, Monteiro PMS, Swart NC. 2009. Carbon export and sequestration in the southern Benguela upwelling system: lower and upper estimates. *Ocean Science Discussions* 6: 1173-1192.

Wallace JH. 1975. The estuarine fishes of the east coast of South Africa III Reproduction. Investigational Report No. 41. Durban: Oceanographic Research Institute.

Wallace KJ. 2007. Classification of ecosystem services: problems and solutions. *Biological Conservation* 139: 235-246.

Walmsley SA, Leslie RW, Sauer WHH. 2007a. Managing South Africa's trawl bycatch. *ICES Journal of Marine Science* 64: 405-412.

Walmsley SA, Leslie RW, Sauer WHH. 2007b. Bycatch and discarding in the South African demersal trawl fishery. *Fisheries Research* 86: 15-30.

Wanless RM, Angel A, Cuthbert RJ, Hilton GM, Ryan PG. 2007. Can predation by invasive mice drive seabird extinctions? *Biology Letters* 3: 241-244. DOI:10.1098/rsbl.2007.0120

Wanless RM, Ryan PG, Altwegg R, Angel A, Cooper J, Cuthbert R, Hilton GM. 2009. From both sides: dire demographic consequences of carnivorous mice and longlining for the Critically Endangered Tristan albatrosses on Gough Island. *Biological Conservation* 142: 1710-1718. DOI:10.1016/j.biocon.2009.03.008

Watkins BP, Petersen SL, Ryan PG. 2008. Interactions between seabirds and deepwater hake (*Merluccius* spp) trawl gear: an assessment of impacts in South African waters in 2004-2005. *Animal Conservation* 11: 247-254.

Watling L, Norse EA. 1998. Disturbance of the seabed by mobile fishing gear: A comparison to forest clearcutting. *Conservation Biology* 12: 1180-1197.

Watling L. 1991. The sedimentary milieu and its consequences for resident organisms. *American Zoology* 31: 789-796.

Weerts SP, Taljaard S, Dubula O. 2009. Status report on coastal and marine pollution from land-based activities in South Africa. Final Report. Nairobi, Kenya: WIO-LaB PMU.

Whitfield A. 1989. Ichthyoplankton in a southern african surf zone: Nursery area for the postlarvae of estuarine associated fish species? *Estuarine, Coastal and Shelf Science* 29: 533-547.

Whitfield AK. 1998. Biology and Ecology of Fishes in Southern African Estuaries*. Ichthyological Monographs of the J.L.B. Smith Institute of Ichthyology* No. 2: 1-223.

Whitfield AK. 2010. A century of fish research in South African estuaries. *African Journal of Aquatic Science* 35: 211-225.

Wilcove DS, Rothstein D, Dubow J, Phillips A, Losos E. 1998. Assessing the relative importance of habitat destruction, alien species, pollution, over-exploitation, and disease. *BioScience* 48: 607-616.

Wilkinson S, Japp DW. 2005a. Assessment of the impact of the proposed PetroSA South Coast Gas Development on the south coast fishing industry. Cape Town: PetroSA (Pty) Ltd.

Wilkinson S, Japp DW. 2005b. A survey of the trawl door types used in the Blues fishing grounds: 1-28. Cape Town: PetroSA (Pty) Ltd.

Wilkinson S, Japp DW. 2005c. Description and evaluation of hake-directed trawling intensity on benthic habitat in South Africa. Cape Town: South African Deepsea Trawling Industry Association.

Williams AJ, Klages NTW, Crawford RJM. 2000.Functional Ecosystems: Coastal Islands. In Durham BD, Pauw JC (eds), *Summary Marine Biodiveristy Status Report for South Africa*. Pretoria: National Research Foundation. Pp 26-29.

Williams GC. 1990. The Pennatulacea of southern Africa (Coelenterata, Anthozoa). *Annals of South African Museum* 99: 31-119.

Williams GC. 1992. Biogeography of the octocorallian coelenterate fauna of southern Africa. *Biological Journal of the Linnean Society* 46: 351-401.

Wilson MA, Costanza R, Boumans R, Liu S. 2005. Integrated assessment and valuation of ecosystem goods and services provided by coastal systems. In: Wilson JG (ed), *The Intertidal Ecosystem: The Value of Ireland's Shores.* Dublin: Royal Irish Academy. Pp 1-24.

Wilson WH Jr, Brown B. 1991. Introduction to the symposium: mTrends in soft-sediment ecology during the period 1970-1989. *American Zoology* 31:785-788.

Winckler, H. 1999. The application of univariate and distributional analyses to assess the impacts of diamond mining on marine macrofauna off the Namibian coast. M.Sc thesis, University of Cape Town, South Africa.

Wishner KF. 1980. The biomass of the deep-sea benthopelagic plankton. *Deep-Sea Research* 27A: 203-216.

Wooldridge TH. 1994. The effect of periodic inlet closure on recruitment in the estuarine mudprawn, Upogebia africana (Ortmann). In: Dyer KR, Orth RJ (eds), *Changes in fluxes in estuaries: implications from science to management.* Fredensborg: Olsen and Olsen.

World Meteorological Organization 2010 Climate, carbon and coral reefs, World Metereological Organization Report No. 1063. Geneva, Switzerland: World Meteorological Organization.

Worm B, Barbier EB, Beaumont N, Duffy JE, Folke C, Halpern BS, Jackson JBC, Lotze HK, Micheli F, Palumbi SR, Sala E, Selkoe KA, Stachowicz JJ, Watson R. 2006. Impacts of Biodiversity Loss on Ocean Ecosystem Services. *Science* 314: 787-790.

Wotton DM, O'Brien C, Stuart MD, Fergus DJ. 2004. Eradication success down under: heat treatment of a sunken trawler to kill the invasive seaweed *Undaria pinnatifida*. *Marine Pollution Bulletin* 49: 844-849.

Wright LD, Short AD. 1984. Morphodynamic variability of surf zones and beaches: a synthesis. *Marine Geology* 50: 93-118.

Wu RSS. 1995. The environmental impact of marine fish culture: Towards a sustainable future. *Marine Pollution Bulletin* 31: 159-166.

Wuersig B, Gailey GA. 2002. Marine mammals and aquaculture: conflicts and potential resolutions. In: Stickney RR, McVey JP (eds); *Responsible Marine Aquaculture*. New York: CABI Publishing,

Wynberg RP, Branch GM. 1991. An assessment of bait-collecting for *Callianassa kraussi* Stebbing in Langebaan Lagoon, Western Cape, and of associated avian predation. *South African Journal of Marine Science* 11: 141-153.

Wynberg RP, Branch GM. 1994. Disturbance associated with bait-collecting for sandprawns (*Callianassa kraussi*) and mudprawns (*Upogebia africana*): long term effects on the biota of intertidal sandflats. *Journal of Marine Research* 52: 523- 558.

Wynberg RP, Branch GM. 1997. Trampling associated with bait-collecting for sandprawns *Callianassa kraussi* Stebbing: effects on biota of an intertidal sandflat. *Environmental Conservation* 24: 139-148.

Wynberg RP. 1991. The ecological effects of collecting *Callianassa kraussi* Stebbing and *Upogebia africana* (Ortmann) for bait: Impacts on the biota of an intertidal sandflat. MSc. Thesis, University of Cape Town, South Africa.

Yemane D, Field JG, Leslie RW. 2008. Indicators of change in the size structure of fish communities: A case study from the south coast of South Africa. *Fisheries Research* 93: 163-172.

Yemane D, Field JG, RW Leslie. 2009. Spatio-temporal patterns in the diversity of demersal fish communities of south coast of South Africa. *Marine Biology* 157: 269 - 281.

Zardi GI, McQuaid CD, Teske PR, Barker NP. 2007. Unexpected genetic structure of mussel populations in South Africa: indigenous *Perna perna* and invasive *Mytilus galloprovincialis*. *Marine Ecology Progress Series* 337: 135-144.

Zardi GI, Nicastro KR, McQuaid CD, Hancke L, Helmuth B. In press. The combination of selection and dispersal helps explain genetic structure in intertidal mussels*. Oecologia 165: 947-958*.

Zeeman S. 2010. Influence of abalone harvesting on subtidal benthic communities. Honours Thesis, University of Cape Town, South Africa.

Zehr JP, Kudela RM. 2009. Photosynthesis in the open ocean. *Science* 326: 945-946.

Zhang D-X, Hewitt GM. 2003. Nuclear DNA analyses in genetic studies of populations: practice, problems and prospects. *Molecular Ecology* 12: 563-584.