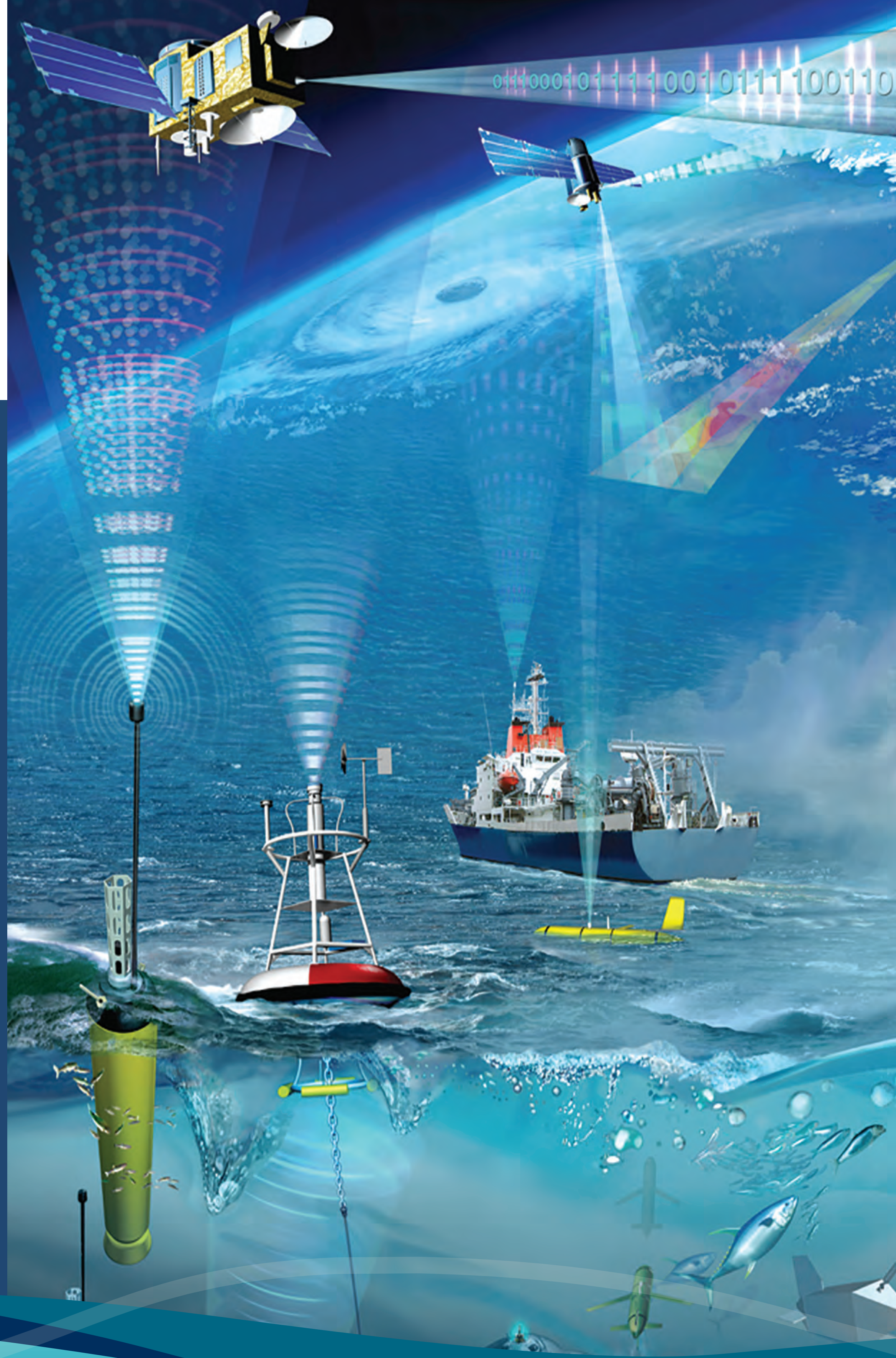
STATE OF THE OCEANS AND COASTS

AROUND SOUTH AFRICA 2017 REPORT CARD

BASED ON RESEARCH AND MONITORING OBSERVATIONS

REPORT NO: 17



environmental affairs

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REPUBLIC OF SOUTH AFRICA

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STATE OF THE OCEANS AND COASTS AROUND SOUTH AFRICA
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Cover design:

Artistic depiction of the Global Ocean Observing System (GOOS) and the ocean that it serves to monitor - Glynn Gorick (commissioned by GOOS office).

INTRODUCTION

The Department of Environmental Affairs (DEA) publishes a State of the Oceans and Coasts around South Africa Report Card annually, and this is the 17th issue covering some of the environmental monitoring activities and research results obtained during the 2017/2018 financial year. It describes scientific observations in the marine environment, from the inshore to the offshore and from the ocean surface to the ocean floor within South Africa's Exclusive Economic Zone. It is DEA's wish that the reader will gain insights into, and an appreciation for the taxpayers' investment in, the applied research conducted by the Chief Directorate: Oceans and Coastal Research under the Branch: Oceans and Coasts.

DEA is mandated to ensure the protection of the environment and conservation of natural resources, balanced with sustainable development and an equitable distribution of the benefits derived from natural resources. In its quest for better use and management of the natural environment, the Department is guided by its constitutional mandate, as contained in Section 24 of the Constitution. DEA fulfils its mandate through formulating, coordinating and monitoring the implementation of national environmental policies, programmes and legislation, The Department's Vision is a prosperous and equitable society living in harmony with our natural resources, and its Mission is to create a prosperous and equitable society that lives in harmony with our environment.

During the past financial year, DEA embarked on several major projects through cooperation and collaboration with other countries, national departments and organisations. Two of these projects are the Second International Indian Ocean Expedition (IIOE-2) and the Indian Ocean Rim Association (IORA), both of which carry significant responsibilities and benefits for South Africa as a maritime nation.

IORA was formed in 1997 to fulfil former President of democratic South Africa, the late Dr Nelson Mandela's vision motivated by a need to secure a better and sustainable life for all people living around the Indian Ocean, who said that "…the natural urge of the facts of history and geography should broaden itself to include the concept of an Indian Ocean Rim for socio-economic cooperation". This vision gave rise to the Indian Ocean Rim Association (www.IORA.net).

Meanwhile, in 2015, the Intergovernmental Oceanographic Commission of UNESCO (IOC) (www.IOC-unesco.org) declared the Indian Ocean as an area of high research priority for the period 2016–2020, and labelled it the IIOE-2. The IIOE-2 marked the 50th anniversary of the initial International Indian Ocean Expedition (IIOE), which was conducted in the mid-1960s and subsequently led to the establishment of the IOC. South Africa considered the IIOE-2 as a mechanism through which to enhance the region's human and infrastructural capacity shortcomings whilst addressing the lack of basic environmental data and information. It is envisaged that this will contribute to adequate ocean governance thus leading to better management and protection of the oceans.

The IOC established the Sub-Commission for Africa and the Adjacent Island States (IOC-Africa), which was chaired by South Africa (Dr Monde Mayekiso, the Deputy Director-General of the Branch: Oceans and Coasts in the Department of Environmental Affairs) between 2014 and 2017. It realized the IIOE-2 to be a most unique opportunity to rally African countries, particularly those in the Western Indian Ocean (WIO) region, to work collectively towards advancing the region's Marine Research agenda. One key output was the launching of regional research cruises in which experts, mid-career scientists, trainees and students originating from various institutions and agencies in the region will participate. A primary objective of these cruises is to develop human capacity of young African scientists in marine science disciplines such as meteorology; physical, chemical, and biological oceanography; marine pollution; seabirds; marine mammals; benthic biodiversity and marine geology, through the collection of data and samples in the Indian Ocean.

The Government of South Africa, through DEA, undertook to support the IIOE-2 programme by sponsoring two research cruises using its state-of-the-art research vessel SA Agulhas II in 2017 and 2018. The first regional cruise was conducted over 30 days during October-November 2017 with 92 participants from nine countries, viz. South Africa, Mozambique, Kenya, Tanzania, Nigeria, India, Egypt, France and Italy. Its research area spanned between Durban (South Africa) and Dar es Salaam (Tanzania) and also included several other activities in various ports en route. These activities included the following:

- 13 October 2017: launch of the IIOE-2 Regional Research and Training Cruise as well as a public and media briefing, Cape Town –- hosted by the Minister of Environmental Affairs (DEA), Dr BEE Molewa.
- 14-16 October 2017: printed and televised media leg of the IIOE-2 Expedition, Cape Town – Durban.
- 17 October 2017: IORA 17th Council of Ministers, Durban – hosted by the Minister of the Department of International Relations and Cooperation (DIRCO), Ms M-N Mashabane.
- 2 November 2017: Special Session on Second International Indian Ocean Expedition (2015-2020) during the 10th Western Indian Ocean Marine Science Association (WIOMSA) Scientific Symposium, Dar es Salaam, Tanzania. – hosted by Mr T Mseleku, South Africa's Ambassador to Tanzania.
- 3 November 2017: SA Agulhas II Open Day, Dar es Salaam, Tanzania.

The second South Africa-sponsored regional training cruise is expected to be undertaken in June-July 2018 covering the coastal areas of Tanzania and the Comoros islands. Various research disciplines to be covered during the 30-day cruise include oceanography, meteorology, geology, seabirds and marine mammals.

Ms Judy Beaumont
Deputy Director-General
Branch: Oceans and Coasts

1. OCEAN CIRCULATION BETWEEN MARION ISLAND AND SOUTH AFRICA

The large-scale movement of ocean water has a significant impact on chemical and biological phenomena. In addition, the ocean's capacity to transport vast amounts of energy has an impact on weather and climate across the globe.

The Department of Environmental Affairs routinely monitors the circulation of ocean waters by means of Acoustic Doppler Current Profilers (ADCPs) mounted to the hull of its research vessels.

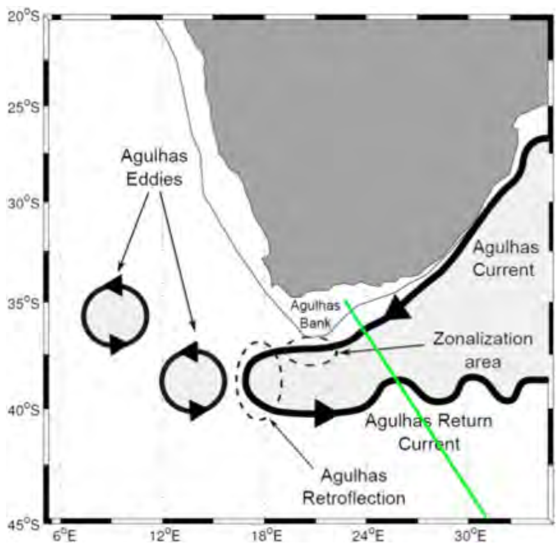


Figure 1: Schematic of the ocean circulation to the south of Africa, showing the Agulhas Current, Agulhas Retroflection and Agulhas Return Current (from Arruda et al. 2014). The approximate cruise track during annual relief voyages to Marion Island is shown in green.

Ocean current data collected during annual relief voyages to South Africa's research base on sub-Antarctic Marion Island provide information about how the surface circulation pattern in the Indian Ocean south of Africa varies from year to year.

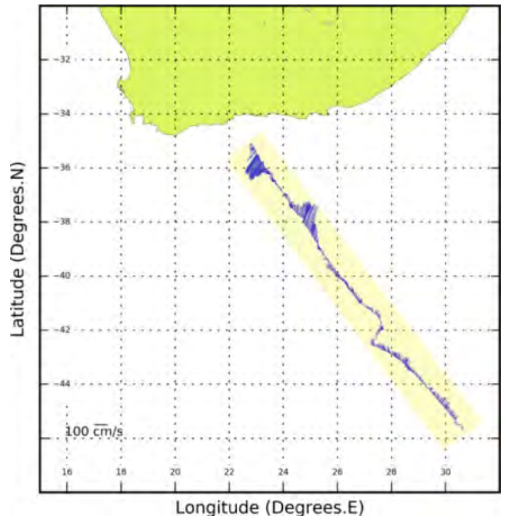


Figure 2: Surface ocean current vectors (blue) between Marion Island and South Africa measured during 2017; the study area is shaded in yellow. Current speed is proportional to the length of each individual vector; a scale vector of 100 cm per second is provided.

During the 2017 voyage (Fig. 2) the Agulhas Current (AC) can be seen at approximately 36° S and the Agulhas Return Current (ARC) at approximately 38° S. It is interesting to note that the maximum current speed recorded during this cruise was 184 cm s^{-1} with a current direction of 23.35°; this corresponds to the ARC.

A comparison between observations during three annual relief voyages (2013, 2014 and 2017) is displayed in Figure 3.

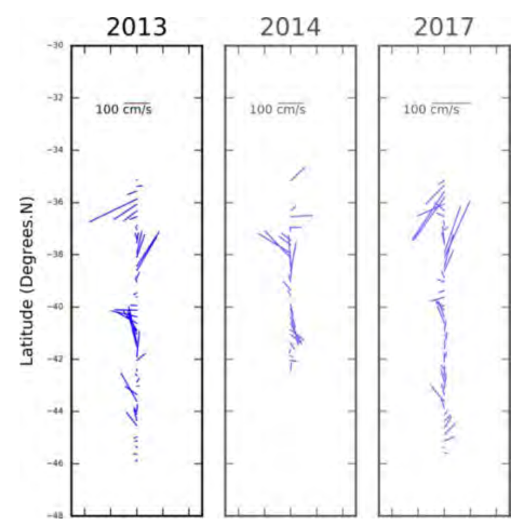


Figure 3: Zonally averaged surface water circulation observed during three Marion Island relief voyages in 2013, 2014 and 2017; a scale vector of 100 cm per second is provided.

Due to the intense dynamics of the AC and the ARC, the substantial differences observed in the circulation pattern in the study area between 2013 and 2017 are within what can be expected for this region.

Why should we continue monitoring ocean circulation?

The behaviour of the AC plays a role in the Global Thermohaline Circulation and is thus also linked to the Earth's climate. Continued monitoring of the ocean circulation patterns allows researchers to improve our understanding of the trends and variability in ocean dynamics. This, in turn, will enhance our ability to enact responsible and informed governance while dealing with environmental issues such as climate change.

Further information:

Arruda W, Zharkov V, Deremble B, Nof D, Chassignet E. 2014. A New Model of Current Retroflection Applied to the Westward Protrusion of the Agulhas Current. *J. Phys. Oceanogr.* 44: 3118-3138

Author: S Bergman, H Ismail, W Sonnenberg

2. COASTAL UPWELLING INDICES ALONG THE WEST COAST OF SOUTH AFRICA

The west coast of South Africa, with an equatorward component in the prevailing longshore winds, is a site of coastal upwelling due to seaward acceleration of the surface layer by the Coriolis effect (Fig. 1). After modest reduction in sea level height, the offshore flow is balanced by onshore and rising flow in deeper layers. This brings nutrient-laden, relatively cold, deep water into the euphotic zone where phytoplankton blooms develop and consume the nutrients. This upwelling process supports abundant zooplankton and fish stocks, and is therefore critical to fisheries productivity of the Benguela Current upwelling ecosystem.

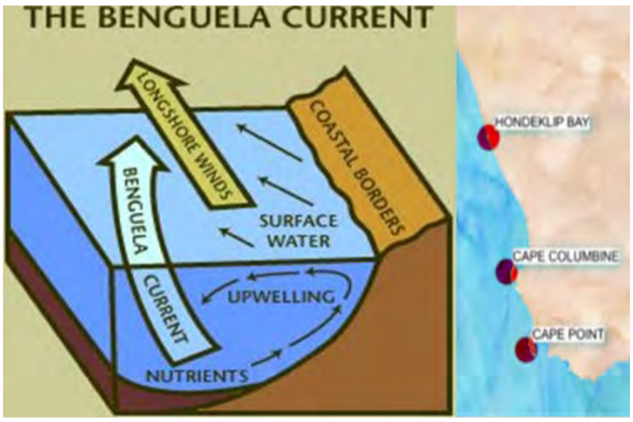


Figure 1: (left) Schematic of coastal upwelling in the Benguela region [from 'Living Edens: Namib', David Neiman, (ed.), US Public Broadcasting System online https://www-tc.pbs.org/edens/namib/images/map2.gif] and (right) map of the South African west coast showing the location of the Hondeklip Bay and Cape Columbine upwelling cells

Upwelling in the Benguela region is controlled by the north-south shifting of the South Atlantic atmospheric high pressure system as well as the intrusion of warm water into region. Large-scale climate variability, in the form of Pacific El Niño as well as the more local 'Benguela Niño' events, can weaken upwelling – the former by causing an equatorward shift in the South Atlantic high, which weakens the upwelling-favourable winds, the latter by replacing the upwelled water with warm, low-nutrient water. Both are periodic events, with the latest El Niño event having occurred in 2014 through to mid-2016, and the most recent Benguela Niño having been recorded in 2004.

The climatology of seasonal upwelling indices calculated for two upwelling sites on the west coast of South Africa, viz. Namaqua/Hondeklip Bay and Cape Columbine, are shown in Figure 1. Monthly values of the upwelling index, derived from 6-hourly data from the U.S. Navy Fleet Numerical Meteorology and Oceanography Centre (FNMOC) over the past two years, are compared with a 10-year (2007-2017) average of the monthly upwelling index for these two areas.

At the Hondeklip Bay site (Fig. 2) the magnitude of upwelling was much stronger than the ten-year average for the period from October to December 2016 and from January to March 2017.

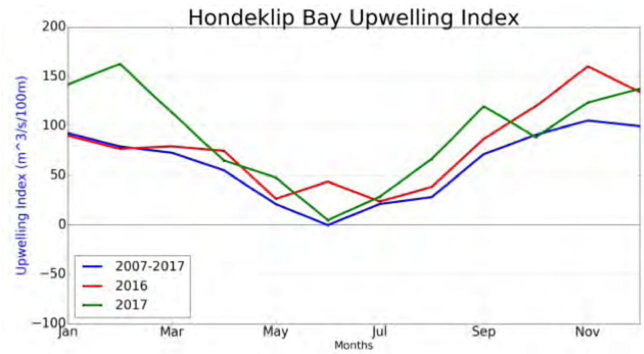


Figure 2: Monthly upwelling strength in Hondeklip Bay for 2016 and 2017 compared with the 2007-2017 average. A maximum well above the long-term mean is observed from October 2016 to March 2017.

The upwelling signal at the Cape Columbine site (Fig. 3) is generally weaker in strength compared with that in Hondeklip Bay. Upwelling was weak and below the ten-year average for the period from February to April 2016 and above average for most of the remainder of the year. In 2017, above-average values were observed during most of the year, except in June when a strong downwelling signal (the process of accumulation and sinking of cold coastal waters beneath warm, lower-density coastal waters) was observed, and in October.

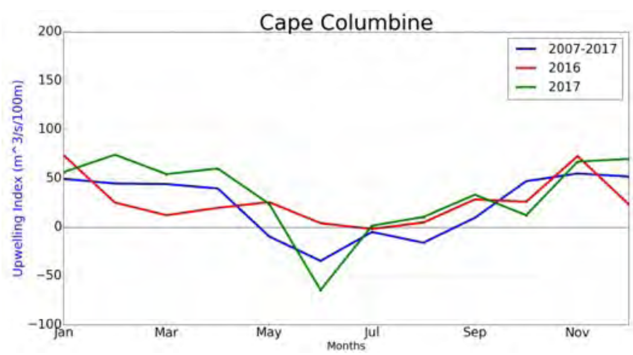


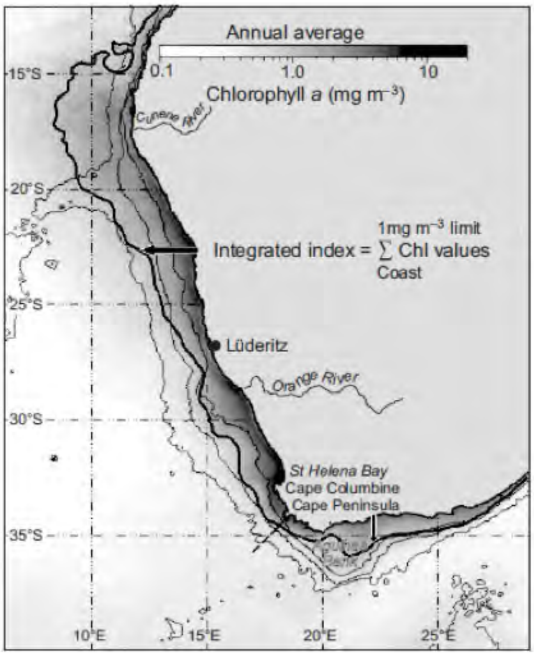
Figure 3: Monthly upwelling strength off Cape Columbine for 2016 and 2017 compared with the 2007-2017 average. Upwelling was stronger than usual during November 2016, and unusually weak in October 2017, with pronounced downwelling in June 2017.

Weak index values at Cape Columbine in the first part of 2016 imply less availability of nutrients in the sun-lit upper part of the water column for phytoplankton to develop. A maximum upwelling index well above the long-term mean observed in October 2016 to March 2017 in Hondeklip Bay suggests a nutrient-rich environment for this upwelling season.

Author: M Tyesi
Data source: https://coastwatch.pfeg.noaa.gov/erddap/griddap

3. CHLOROPHYLL VARIABILITY ON THE WEST AND SOUTH COASTS

An index of chlorophyll *a* concentration along the southern African coast is routinely computed by integrating satellite-derived surface chlorophyll *a* from the coast to the 1 mg m^{-3} level. Higher index values are usually associated with greater phytoplankton biomass and a more productive ecosystem, while lower values indicate lower phytoplankton biomass and a less productive ecosystem.

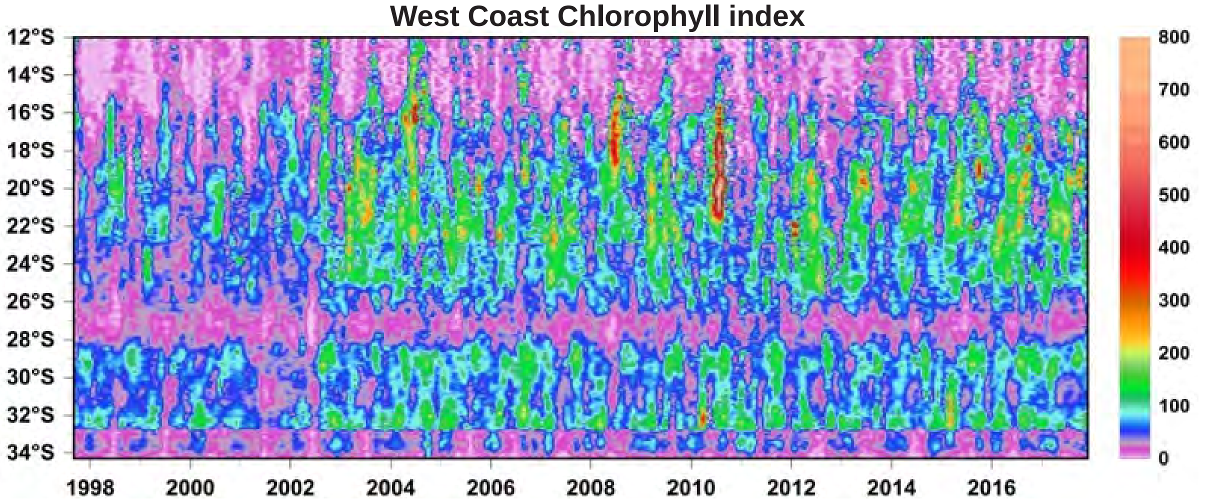


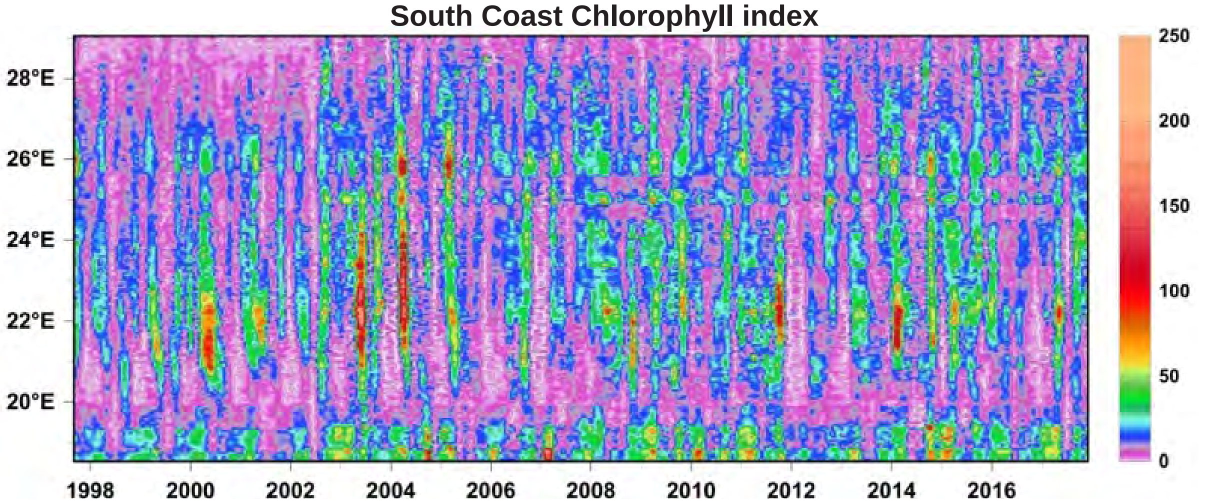
On the West Coast, the highest chlorophyll index values are found off Namibia (16-26°S). During the first half of 2016, the index shows higher values, suggesting a more productive ecosystem than in 2013, 2014, and 2015. During 2017, values were similar to 2015, except in July, when peak values were more similar to the 2016 data.

Off South Africa (28-34°S), elevated chlorophyll index values on the west coast occur in regions affected by the Namaqualand, Cape Columbine, and Cape Peninsula upwelling cells. During the first half of 2015, the index shows higher values than in 2013 and 2014. During 2017, values were overall lower than those observed in 2015 and 2016, suggesting a decrease in the productivity.

Along the South Coast (18.5-29°E), chlorophyll index values are generally lower than on the West Coast. During 2016, the index was overall lower than that in 2015. Throughout 2017, index values were higher than those in 2016, suggesting an increase in productivity, with maxima occuring in the central part of the region in May and September.

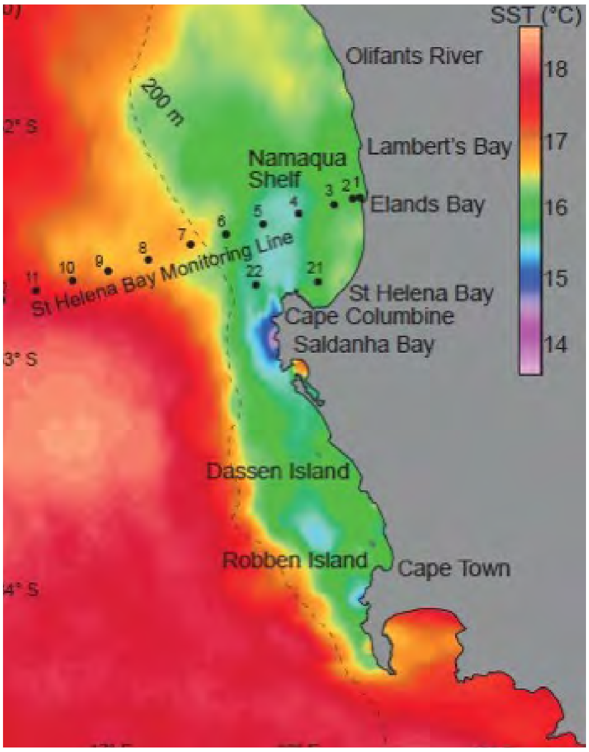
Author: T Lamont Contributor: K Britz





4. SURFACE CHLOROPHYLL *A* CONCENTRATIONS ALONG THE ST HELENA BAY MONITORING LINE (SHBML)

On the west coast of South Africa, St Helena Bay is one of the most productive regions of the Benguela Current Large Marine Ecosystem (BCLME), and has been the focus of environmental research and monitoring for many decades.

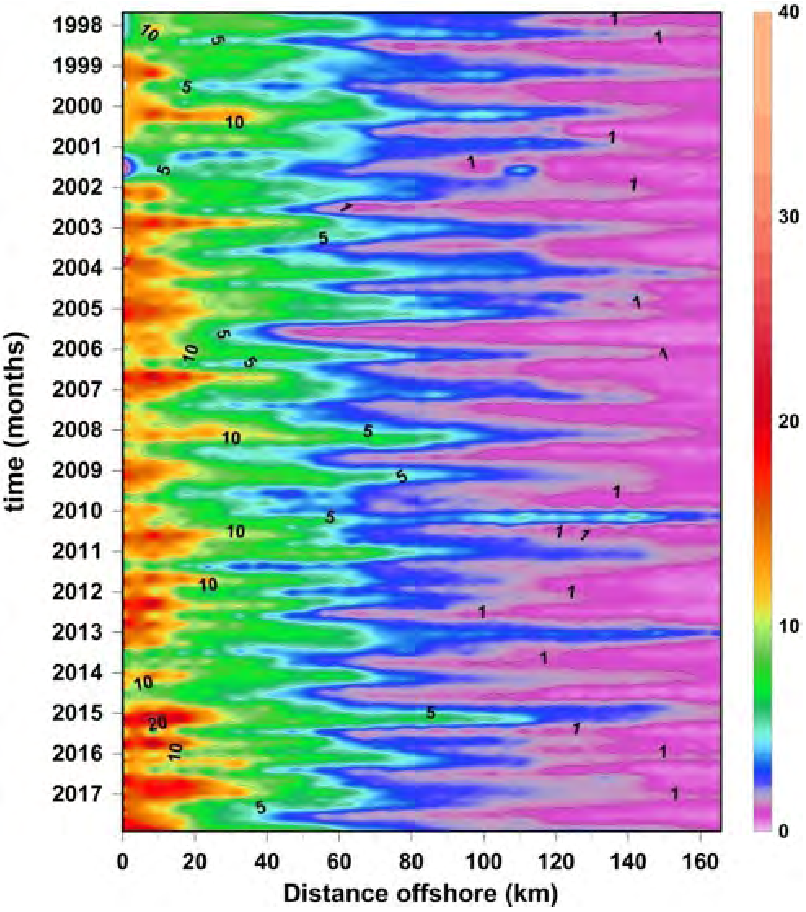


Satellite-derived surface chlorophyll *a* concentrations show a clear seasonal signal, with maxima in spring/early summer and late summer/autumn. Higher concentrations are usually associated with greater phytoplankton biomass and a more productive ecosystem, while lower values indicate lower phytoplankton biomass and a less productive ecosystem.

Generally, higher concentrations always occur close to the coast and decrease with distance offshore. During 2015, concentrations above 20 mg m^{-3} occurred close to the coast in autumn (March) and late spring/early summer (September to November), and elevated chlorophyll (> 5 mg m^{-3}) extended ~110 km offshore in March; the furtherest offshore extension since March 2010.

In contrast, values > 20 mg m^{-3} were observed close to the coast between August and October 2016, and only during June, August and December 2017. In 2016, the furthest offshore extent (~80 km) of values above 5 mg m^{-3} was observed in February, while in January 2017, these values extended only ~70 km offshore. The lower values in 2017 suggest that the ecosystem was less productive than in 2016.

Author: T Lamont
Contributor: K Britz



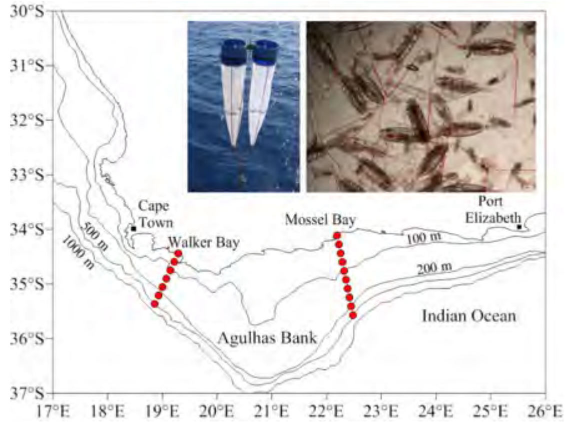
5. LONG-TERM VARIABILITY IN COPEPODS OFF THE SOUTH COAST DURING SPRING AND EARLY SUMMER, 1988-2017

Copepods dominate the zooplankton community and are an important food source for organisms such as fish and squid. With their short life-spans, they respond quickly to their environment and make excellent indicators of changing conditions in marine ecosystems.

Annual sampling of copepods off the south coast of South Africa during spring and early summer (October-December) was initiated in 1988, although there was a four-year ship-related hiatus in sampling from 2012 to 2015. The map indicates the location of sampling stations over the continental shelf off Walker Bay (western Agulhas Bank, WAB) and Mossel Bay (central Agulhas Bank, CAB) between 1988 and 2017.

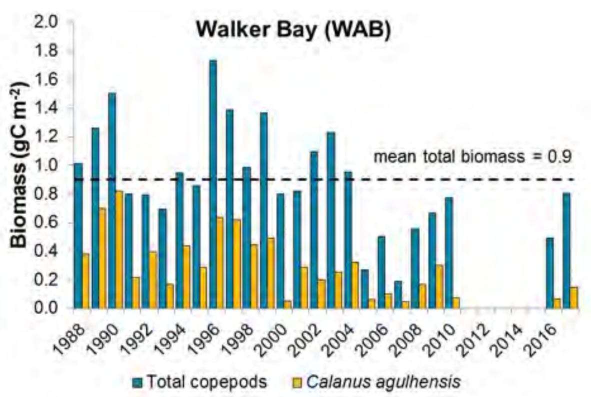
Copepod biomass on the WAB has been variable over the time-series, but shows a gradual decline since a peak in 1996, and was just below average in 2017 (0.8 gC m^{-2}). There was also a long-term decline in the biomass of *Calanus agulhensis,* the dominant large copepod on the Agulhas Bank. Copepod species composition (in terms of biomass, shown below) indicates very low proportions of *Calanus* in 2016 and 2017 (<20%).

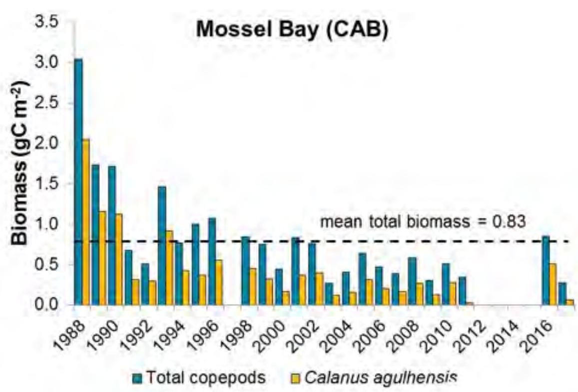
There was a significant long-term decline in both total copepod biomass and biomass of *C. agulhensis* on the CAB between 1988 and 2011. Copepod species composition for the CAB shows the decline in *C. agulhensis* over much of the time-series, and a corresponding increase in small calanoid copepods. In 2016 the biomass and proportion of *C. agulhensis* were much greater than in 2011, an apparent reversal of these trends. However, in 2017 both total copepod biomass and *C. agulhensis* biomass were the second lowest recorded over the time series (0.28 and 0.07 gCm $^{-2}$ respectively). Changes in copepod biomass and composition on the Agulhas Bank are thought to be largely driven by predation by pelagic fish, but are also influenced by environmental variability.

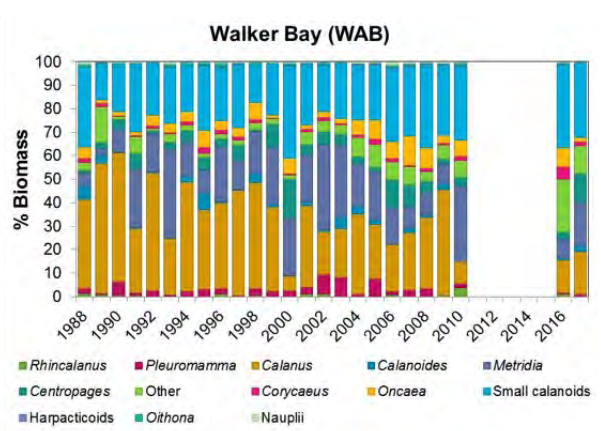


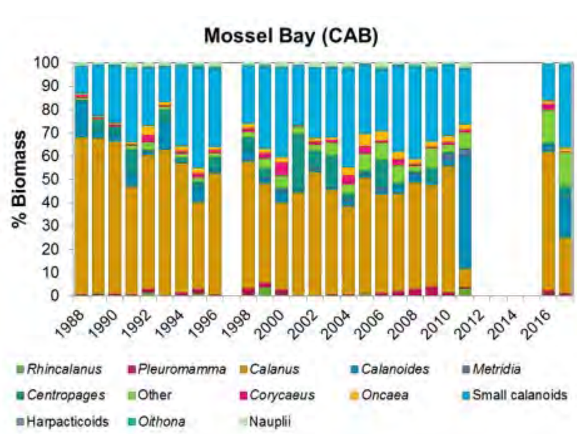
Map showing annual sampling locations (1988-2017)

Author: JA Huggett
Contributors: E Wright, S Setati









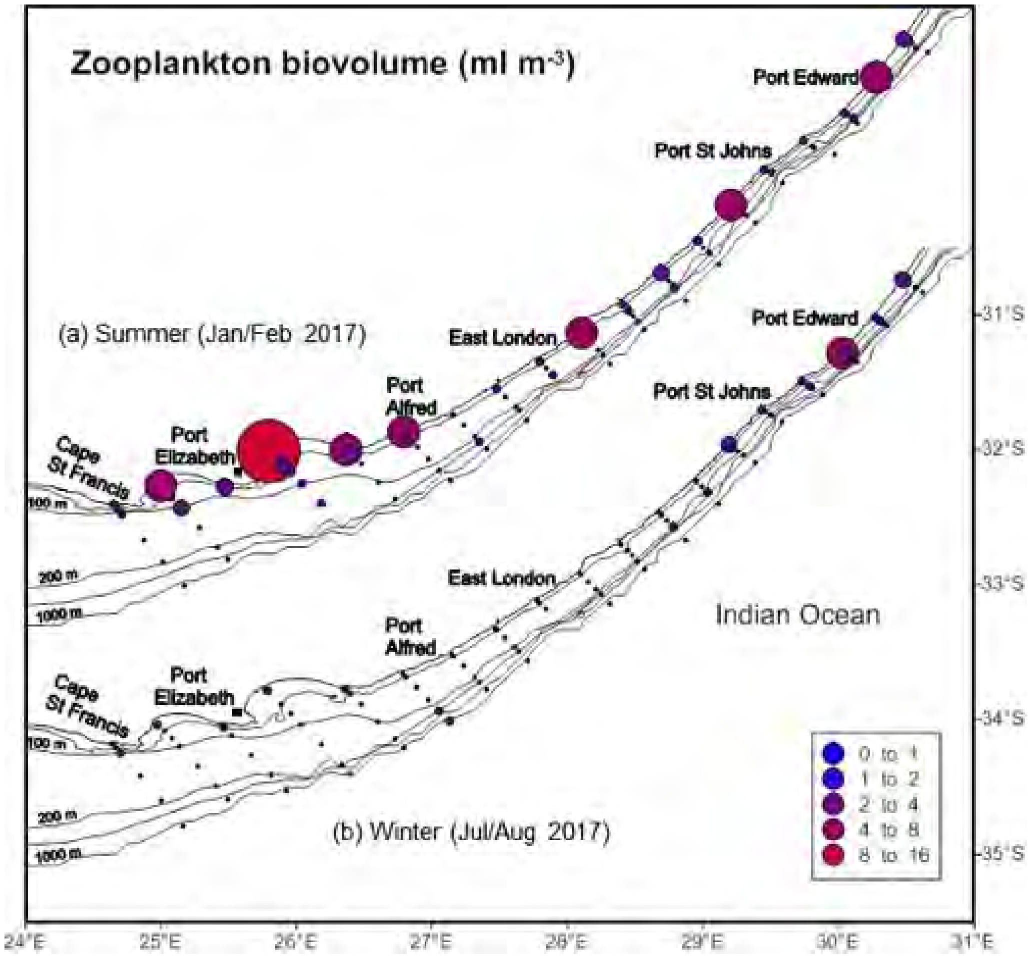
Species composition by size: large (bottom) to small (top)

6. SEASONAL (SUMMER AND WINTER) PATTERNS OF ZOOPLANKTON BIOMASS ON THE TRANSKEI SHELF DURING 2017

The Eastern Cape coast is one of the least studied sections of the South African continental shelf, particularly off the former Transkei, popularly known as the Wild Coast. Two multidisciplinary surveys were conducted here during summer (Jan/Feb 2017) and winter (Jul/Aug 2017) in order to improve our understanding of ecosystem functioning, in particular the influence of the Agulhas Current on ocean productivity and biodiversity. The zooplankton community in the upper 200 m was sampled using a vertically hauled Bongo net (mesh size: 200 µm).

Distribution of zooplankton biovolume (mL m^{-3}), a proxy for biomass measured using the 'quick-look', non-destructive method of settling volume in a graduated cylinder, indicates strong seasonal (summer vs winter) and cross-shelf differences (see Figure below). During summer, biovolume was largest (> 4 mL m^{-3}) inshore at the shallower (< 50 m) stations, particularly between Cape St Francis and Port Alfred, a region characterised by relatively cool (< 19°C) and chlorophyll-rich (2-6 mg m^{-3}) surface water during this survey. The largest biovolume (11.8 mL m^{-3}) was recorded in Algoa Bay, while patches of elevated biovolume (4-7 mL m^{-3}) were measured north of East London, downstream from Port St Johns off the Mthatha River Mouth, and north of Port Edward. Mean zooplankton biovolume during summer (1.3 mL m^{-3}) was approximately twice that measured during winter (0.7 mL m^{-3}), with a winter peak of 4.3 mL m^{-3} approximately 30 km south of Port Edward. Moderately elevated zooplankton biovolumes (1-4 mL m^{-3}) inshore in the northern sector coincided with moderate chlorophyll a concentrations (1-3 mg m^{-3}). Microscopic and size-based analyses of the zooplankton community are underway to examine patterns of biodiversity.

This work was co-funded by DEA and the African Coelacanth Ecosystem Programme (ACEP), a flagship programme of the DST and the NRF, in support of the Operation Phakisa proposed network of marine protected areas.



Author: JA Huggett
Contributors: H Kakora, Z Rasoloarijao(NMU), S Ockhuis (CPUT), K Batyi-Nkwenkwe, V Mabongo, S van der Merwe, L Ferguson (CPUT), J Edward (MFMR, Namibia), M Le Bihan (AMU, France), T Lamont

7. SEA TURTLES IN KWAZULU-NATAL AND THEIR ECOLOGICAL ROLE

Sea turtles are presumed to fulfil a range of different ecological functions, including: competitors on reef and sandy-bottom habitats, modifiers of habitats, predators of invertebrates, prey for some higher predators, vectors of nutrients, and a substrate for epibionts. Sea turtles were once abundant but global populations have declined. In South Africa, nesting populations of Loggerhead *Caretta caretta* and Leatherback Turtles *Dermochelys coriacea* have been listed as Vulnerable and Critically Endangered, respectively. Two other species found but hitherto poorly studied in South African waters are Green *Chelonia mydas* and Hawksbill Turtles *Eretmochelys imbricata*.

A project investigated the movement patterns and ecological roles of *C. mydas* and *E. imbricata* in South Africa, and contrasted with those of the better-known C. caretta. This was achieved through satellite tagging of *C. caretta* nesting in the iSimangaliso Wetland Park, and of *C. mydas* and *E. imbricata* that were caught using SCUBA. Diet was investigated by analysing stomach contents from individuals of each species that were caught in Kwa-Zulu Natal bather-protection nets and performing isotope analysis of skin tissue.

The satellite tracking information (Fig. 1) indicated that juvenile and sub-adult *C. mydas* and *E. imbricata* appear to be resident at iSimangaliso, spending most of their time on shallow inshore reefs. This was also true for adult female Loggerhead Turtles between nesting events during their breeding season. Stomach content analysis showed that *C. mydas* fed almost exclusively on algae (Fig. 2A), whereas *E. imbricata* fed on sponges, crustaceans and unidentified invertebrates (Fig. 2B) and *C. caretta* also showed a varied diet including crustaceans, molluscs, tube worms, fish and tunicates (Fig 2C). While there was dietary overlap, stable isotope analysis confirmed that the species occupied different trophic levels, supporting that they ultimately fulfil different functional roles.

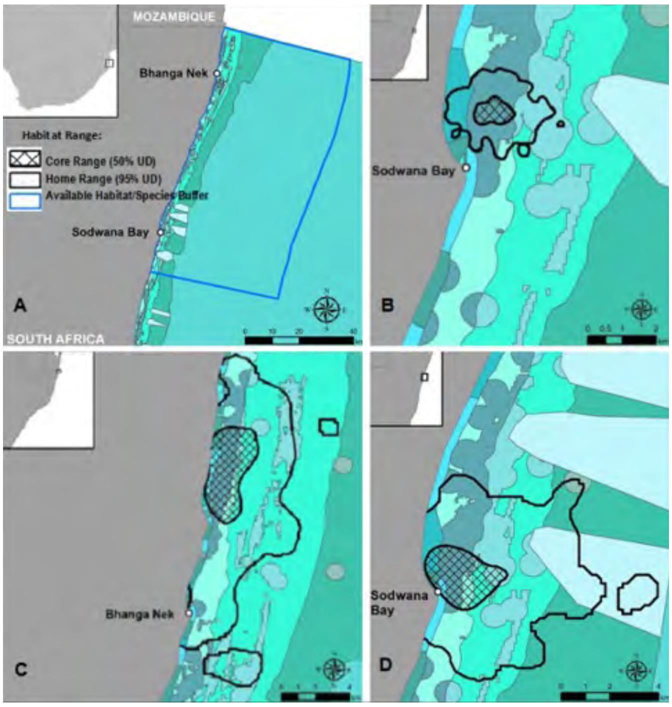


Figure 1: iSimangaliso Wetland Park (A), showing core and home ranges of individual sea turtles based on satellite tracks, specifically E. imbricata *(B),* C. caretta *(C) and* C. mydas *(D).*

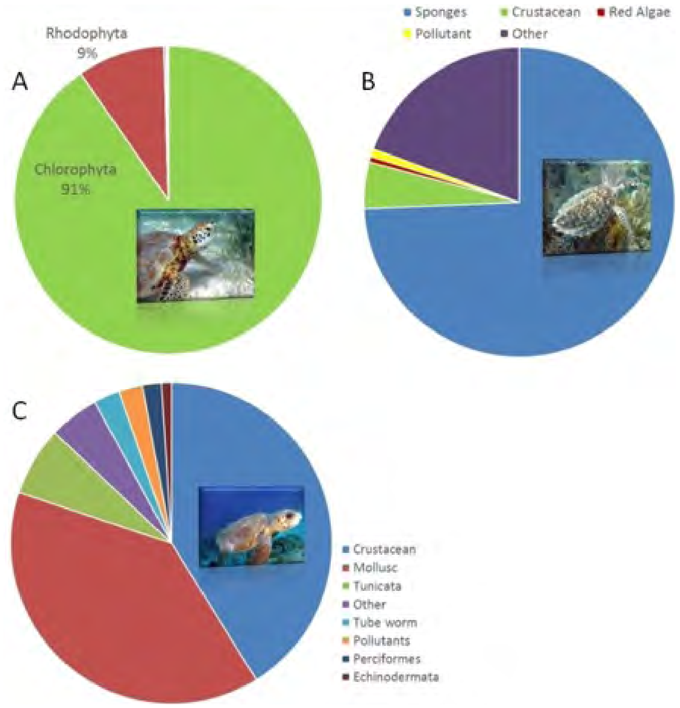


Figure 2: Dietary composition of three turtle species caught in the bather-protection nets in KwaZulu-Natal; (A) C. mydas *(n=14), (B)* E. imbricata *(n=2) and (C)* C. caretta *(n= 27).*

Authors: R Nel, R Rambaran (both NMU), SP Kirkman
Contributors: T Samaai, D Anders

8. MONITORING THE HEALTH OF LOGGERHEAD SEA TURTLES USING EPIBIONTS

Introduction

Sea turtles are long-lived migratory species that are sensitive to anthropogenic impacts. The condition of individuals can reflect the health of the ecosystems in which they live and as such can provide useful indices for monitoring. With the aim of developing a cost-effective indicator for turtle and ecosystem health, a joint study between DEA and the Nelson Mandela University assessed the potential for using turtle epibionts (organisms living on sea turtles) to infer the health of individual turtles.

Figure 1: Map of the northern coastline of iSimangaliso Wetland Park (Maputaland MPA) showing the high-density nesting area for Loggerhead Sea Turtles (yellow line) where samples were obtained during night patrols

Methods

Nesting Loggerhead Sea Turtles *(Caretta caretta)* were sampled at the iSimangaliso Wetland Park (Fig. 1) during the summer 2016/17 nesting season. Sampling consisted of taking measurements and photographs (Fig. 2) of turtles and collecting epibionts. Individuals were classified into one of four body condition categories (Poor, Average, Good, Very Good) based on injuries, skin deformities, neck circumference to length ratio and plastron shape. Epibionts from 48 turtles were identified (Fig. 3) and enumerated. Epibiont community composition, species richness and barnacle loading were compared between the body condition categories.

Figure 2: Examples of Loggerhead Sea Turtles encountered with variable epibiont communities and barnacle loading on their carapaces

Results

- Epibiont community composition was inversely related to body condition: abundance and species richness of epiobionts increased with decreasing body condition (Fig. 4).
- Barnacle epibionts showed the greatest variation between body condition categories, with significantly higher numbers found on turtles in poorer condition.

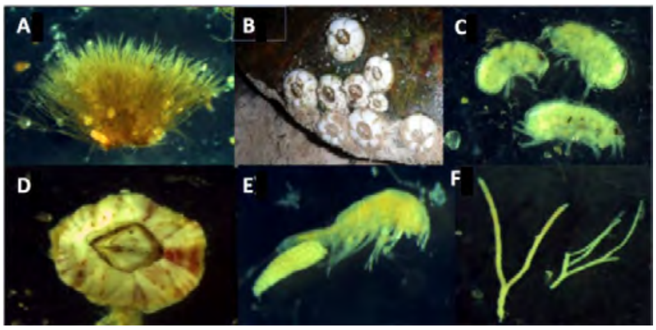


*Figure 3: The epibionts that were most commonly found on the study animals: (A) filamentous algae, (B) barnacles (*Chelonibia testudinaria*), (C) amphipods (*Lysianassa *sp.), (D) barnacles (*Balanus *spp.), (E) copepods, (F) coralline algae*

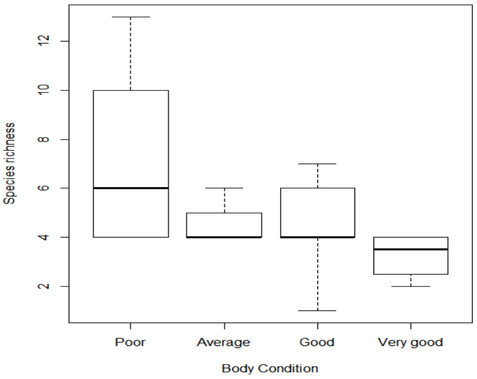


Figure 4: Boxplot of epibiont species richness categorized according to turtle body condition. Numbers indicate how many turtles were sampled per category. Solid black lines represent means, boxes the 25th and 75th quartile range, and whiskers the 95% confidence intervals.

Conclusions

- Epibionts are reliable indicators of body condition for nesting Loggerhead Sea Turtles in South Africa.
- This study succeeded in developing a cost-effective monitoring tool with the potential to be applied to other sea turtle species and ecosystems.

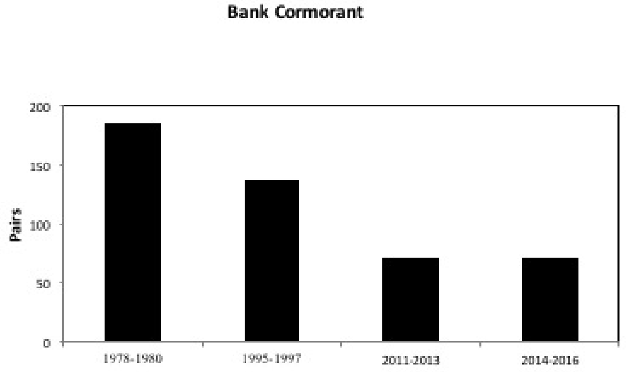
Authors: C Nolte (NMU), M Pfaff, R Nel (NMU)

9. SEABIRD POPULATIONS DECREASE IN SOUTH AFRICA'S NORTHERN CAPE PROVINCE

Breeding by seabirds has been recorded at 28 localities along the coast of South Africa's Northern Cape Province, which stretches from the mouth of the Orange River (28º 35'S) to the border with the Western Cape (31º 06'S), about 7 km south of the mouth of the dry Brak River (Fig. 1).

Figure 1: Localities where seabirds have bred coastally in South Africa's Northern Cape Province

Recent surveys, conducted similarly to earlier surveys, showed substantial decreases of all eight seabird species that have bred coastally in the Northern Cape. Numbers of four cormorant species, Kelp Gulls and Damara Terns estimated to have bred in different periods are illustrated in Figure 2.



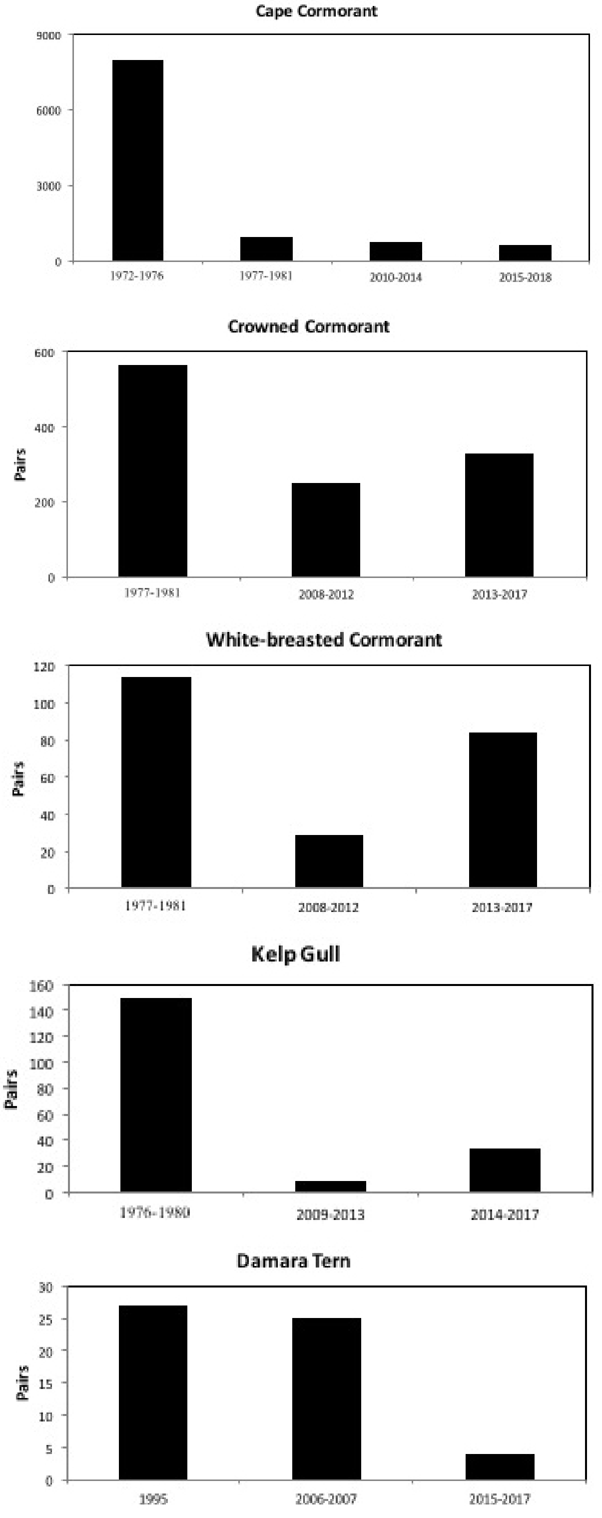


Figure 2: Numbers of Bank, Cape, Crowned and White-breasted Cormorants, Kelp Gulls and Damara Terns estimated to have bred coastally in the Northern Cape Province at different periods since the late 1970s/early 1980s

The number of Bank Cormorants breeding in the Northern Cape decreased by > 50% after the late 1970s/early 1980s. Three of the five colonies that were extant in that period are now extinct and a fourth has decreased. The only stable colony is at Boegoeberg (Fig. 3). The number of Cape Cormorants breeding in the province decreased by

> 90% since the mid-1970s. Crowned and White-breasted Cormorants and Kelp Gulls decreased after initial estimates of their abundance and then increased again, but not to their original levels. Some cormorants and gulls breed in a wide variety of environments, including on small boats lying idle in harbours (Fig. 4). A disadvantage of the latter is that they may lose their offspring if breeding is in progress when boats are required for use.

Figure 3: Bank Cormorants breeding at Boegoeberg stack in November 2017.

Figure 4: Small boats in Alexander Bay harbour may be used by some seabird species for breeding when they are not in use

It was estimated that 25–27 pairs of Damara Terns bred in the Northern Cape until 2007 (Braby 2011) but this decreased to just four pairs in the summer of 2017/18. Although further surveys are required to confirm the recent estimate, it is thought unlikely that more than ten pairs remain in the Northern Cape. The eggs of Damara Terns are laid in land surface and are cryptic so as to avoid detection by predators (Fig. 5).

In the late 1980s, about 700 pairs of Hartlaub's Gulls bred in the Orange River estuary. However, the number that now breeds in the Northern Cape is thought to be between 110 and 240 pairs and small dams are also used (Fig. 6). Thirteen pairs of Caspian Tern bred in or near the Orange River estuary in the early 1980s. However, although the species may still be seen in the estuary, there have been no subsequent records of Caspian Terns breeding in the Northern Cape.

Figure 4: Hartlaub's Gulls breeding at a small island in Simes Dam in November 2017

Figure 5: A Damara Tern egg at Oubeep Soutpan in November 2017

Likely drivers of the decreases include reduced availability of food and the loss of suitable breeding sites. Habitat has been lost through altering the Orange River estuary and modification of, or disturbance at, some pans and islands. The decreases have contributed to a worsening conservation status of several of the seabirds, some of which are endemic to southern Africa. In South Africa, the Damara Tern is regarded as Critically Endangered, both the Bank and the Cape Cormorant are Endangered, the Caspian Tern is Vulnerable and the Crowned Cormorant is Near Threatened (Taylor et al. 2015). The same classifications apply globally, except that the Damara Tern is Vulnerable and the Caspian Tern of Least Concern (BirdLife International 2017). In order to conserve remnant populations it will be necessary to prevent further loss of breeding habitat, restore some former habitats and provide suitable, alternative habitat.

BirdLife International. 2017. IUCN Red List for birds. Downloaded from http://www.birdlife.org on 09/12/2017.

Braby J. 2011. The biology and conservation of the Damara Tern in Namibia. PhD thesis, University of Cape Town.

Taylor MR, Wanless RM, Peacock F (eds). 2015. *The Eskom Red Data Book of Birds of South Africa, Lesotho and Swaziland*. BirdLife South Africa, Johannesburg.

Authors: RJM Crawford, AB Makhado, BM Dyer
Photographs: RJM Crawford

10. GANNETS (SULIDAE)

Africa's only gannet, the Cape Gannet (Fig. 1), is endemic to the Benguela upwelling ecosystem off south-western Africa.

Cape Gannet *Morus capensis*

2015 National Red List status: Vulnerable

2017 Global Red List status: Endangered

Figure 1: A Cape Gannet attending a small chick at Bird Island, Lambert's Bay

In South Africa the Cape Gannet breeds at three localities: Bird Island (Lambert's Bay) and Malgas Island in the Western Cape and Bird Island (Algoa Bay) in the Eastern Cape (Fig. 2).

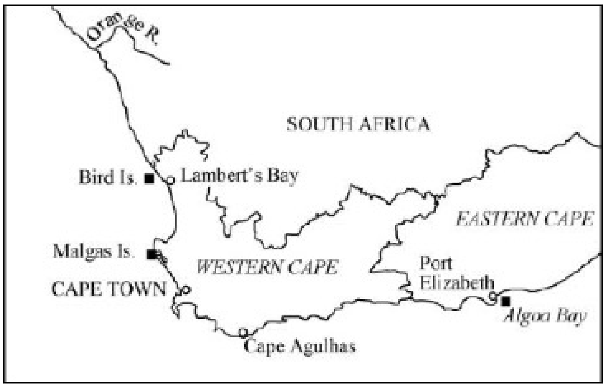


Figure 2: Map showing the locations of South Africa's three Cape Gannet colonies

Protected by:

Sea Birds and Seals Protection Act (No. 46 of 1973); Threatened or Protected Species regulations of the National Environmental Management: Biodiversity Act (No. 10 of 2004).

Conservation measures:

- All colonies are protected by CapeNature and SANParks.
- Long-line fishing permits include conditions to limit the by-catch of birds.
- Mortality inflicted by seals near colonies is controlled through removal of damage-causing animals.

Population trend:

The overall population declined from about 250,000 pairs in the 1950s and 1960s to 133,000 pairs in 2017. This was mainly the result of a decrease in Namibia's gannet population of > 90% following the collapse of the sardine resource there in the 1970s. Lipid-rich sardine and anchovy are favoured prey of the Cape Gannet.

Whereas Namibia held > 80% of the global Cape Gannet population in 1956, 90% of the population was in South Africa in 2017. Numbers in South Africa, after increasing between 1956 and 2000, subsequently decreased. Breaking it down by region, numbers in the Western Cape have decreased since 2000 while in the Eastern Cape the numbers have fluctuated about a stable level (Fig. 3). These changes accord with an eastward shift of mature sardine and anchovy off South Africa since the late 1990s, resulting in reduced availability of these prey species to the West Coast gannet colonies.

In 2017, the Cape Gannet was re-classified as Endangered by IUCN and the Algoa Bay colony held two thirds of the overall population. The main present threat to the species is a scarcity of prey off Namibia and western South Africa.

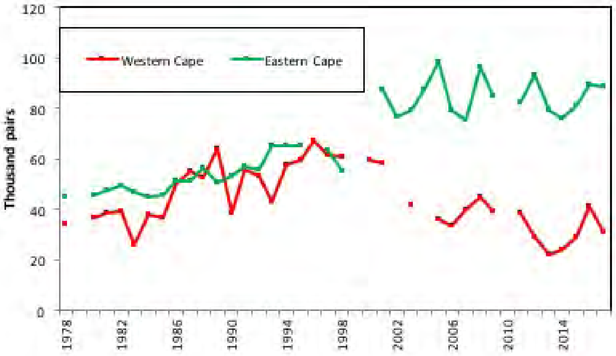


Figure 3: Numbers of Cape Gannets breeding in South Africa, 1978–2017

Further information:

Crawford RJM, Makhado AB, Whittington PA, Randall RM, Oosthuizen WH, Waller LJ. 2015. A changing distribution of seabirds in South Africa – the possible impact of climate and its consequences. *Frontiers in Ecology and Evolution 3: 10, 1–10.*

Authors: AB Makhado, BM Dyer, L Upfold, RJM Crawford,
Photograph: RJM Crawford

11. SWIFT (GREATER CRESTED) TERN *STERNA BERGII*

Global Red List status: Least concern

National Red List status: Least concern

The Swift Tern occurs around some coastlines of the south-east Atlantic, Indian and western Pacific oceans. The nominate race *S. b. bergii* is confined to the Benguela upwelling ecosystem off south-western Africa, where it breeds at 22 localities in Namibia and South Africa. Approximately 80% of the South African population breeds in the Western Cape during late summer and autumn, and the remainder breed in Algoa Bay in the Eastern Cape.

Conservation measures:

Applied:

Colonies at major islands are protected by CapeNature or SANParks.

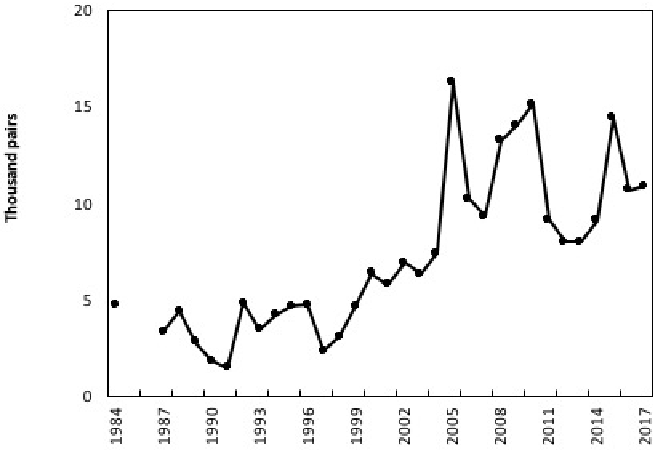
Population and trend:

Numbers of Swift Terns breeding in South Africa increased rapidly after the recent turn of the century. Less than 5,000 pairs bred annually during the period 1984–1999, whereas ca 10,000 pairs bred in most years from 2004–2017. After 2005, numbers in the north of the Western Cape decreased markedly and most birds now breed in the southwest sector of this province.

Several factors may have contributed to the increase of Swift Terns including good recruitment to the mature population and an increase in the proportion of mature birds breeding. Furthermore, the increase commenced at about the same time as a large increase in the combined biomass of sardine and anchovy, their main prey in South Africa.

The low fidelity that Swift Terns in southern Africa often show to breeding localities allowed the population to track shifts in the distributions of their main prey species, anchovy and sardine, since the late 1990s. Thus, many Swift Terns shifted their breeding from the north to the south of the Western Cape in response to the south- and eastward shifts of their prey. The population consequently avoided the large decreases incurred by two other seabird species on the west coast of South Africa, the African Penguin *Spheniscus demersus* and the Cape Cormorant *Phalacrocorax capensis*, which feed on the same prey but are much less able to shift their breeding localities.

A recent outbreak of avian influenza may affect the population, but the severity of this outbreak has not as yet been ascertained.



Trends in numbers of Swift Terns breeding in South Africa, 1984–2017.

Further information:

Crawford RJM. 2009. A recent increase of Swift Terns *Thalasseus bergii* off South Africa – the possible influence of an altered abundance and distribution of prey. *Progress in Oceanography* 83: 398–403.

Authors: AB Makhado, BM Dyer, L Upfold, RJM Crawford
Photograph: AB Makhado

12. AFRICAN PENGUIN *SPHENISCUS DEMERSUS*

Global Red List status: Endangered

National Red List status: Endangered

Endemic to Namibia and South Africa

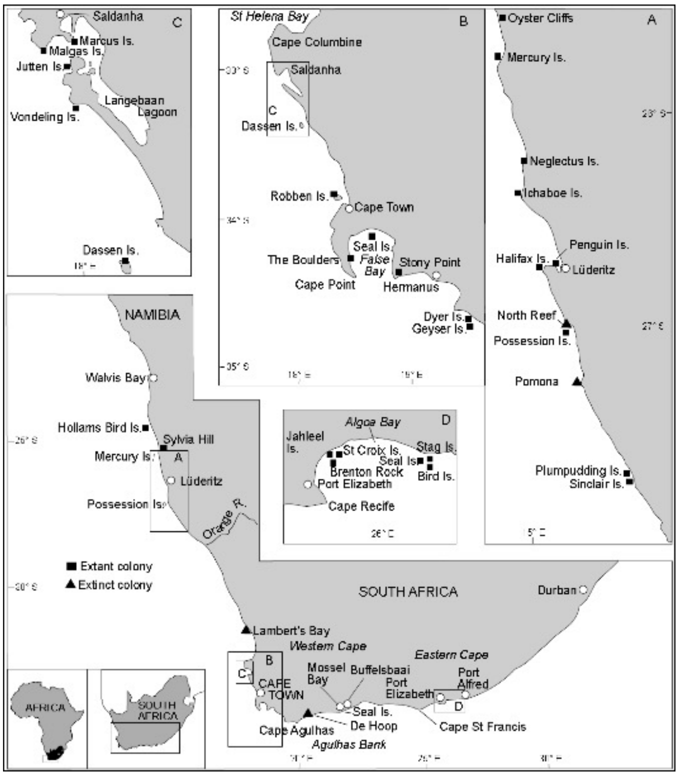


Figure 1: Breeding localities of the African Penguin in South Africa and Namibia.

Protected by:

Sea Birds and Seals Protection Act (No. 46 of 1973); Threatened or Protected Species regulations of the National Environmental Management: Biodiversity Act (No. 10 of 2004).

Management plan:

African Penguin Biodiversity Management Plan 2013.

Some conservation measures:

Applied:

- Most breeding localities (Fig. 1) are within national parks or nature reserves;
- Oiled and injured birds are rescued and rehabilitated;
- Orphaned chicks are reared and returned to wild;
- Disease control.

Proposed:

- Closing purse-seine fishing around major colonies;
- Establishing a new colony on the south coast closer to the present distribution of food;
- Improving breeding habitat through nest boxes;
- Limiting mortality inflicted by seals near colonies.

Population trend:

African Penguins continued to decline in South Africa from > 50,000 pairs in 2002 to *ca* 16,000 pairs in 2017, although the rate of decline has slowed in recent years (Fig. 2a). A large decrease in the Eastern Cape in the early 2000s (Fig. 2b) was followed by a collapse to the north of Cape Town during the mid-2000s (Fig. 2c) when adult survival fell. This was thought to be attributable to food scarcity because the distributions of main prey species (sardine and anchovy) shifted south- and eastwards. Numbers between Cape Point and Cape Agulhas have increased (Fig. 2d).

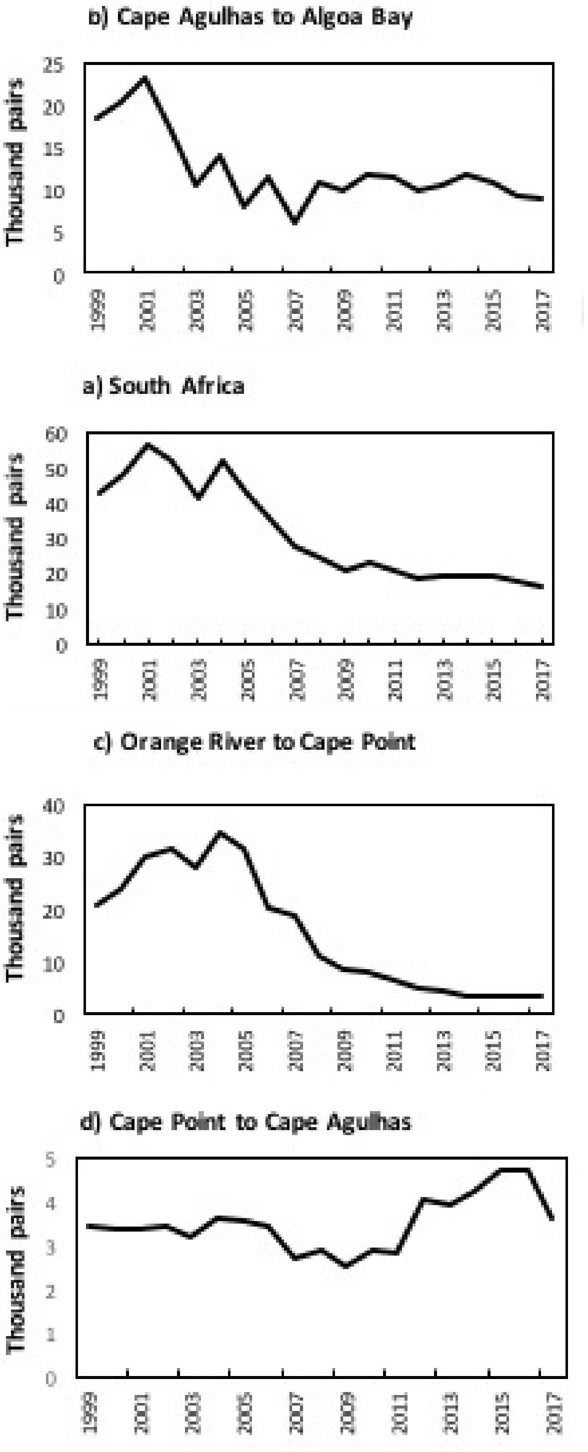


Figure 2: Trends in numbers of African Penguin breeding pairs for South Africa (a) and for three subareas in South Africa (b-d) for 1999–2017.

Authors: AB Makhado, RJM Crawford

13. THERMAL SENSITIVITY OF FLIGHTLESS MOTH CATER-PILLARS ON MARION ISLAND: IS HOTTER BETTER?

In Polar regions rapidly warming temperatures associated with global climatic changes are affecting both terrestrial and marine systems. This has implications for living organisms because their growth, survival and reproduction are highly dependent on regional temperature regimes. Investigating the physiological and behavioural responses of species in these regions is therefore essential for predicting, and planning for, climate change effects.

Figure 1: A nesting Wandering Albatross and the flightless moth caterpillar that occurs in nests

At sub-Antarctic Marion Island a unique relationship exists between the Wandering Albatross *Diomedea exulans* and caterpillars of the Flightless Moth *Pringleophaga marioni* inhabiting their nests (Fig. 1). *P. marioni* is a keystone species for ecosystem functioning when in the larval phase and it is hypothesized that nesting albatrosses may serve as thermal ecosystem engineers by providing conditions ideal for growth and survival of the caterpillars. We examined the responses of caterpillars to changing temperature regimes (nest conditions) and by doing so were able to envisage the implications of a warmer and drier island for the flightless moth.

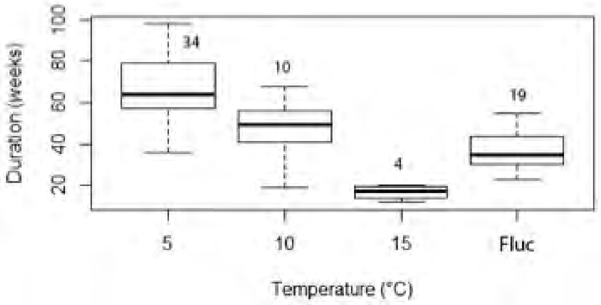


Figure 2: Box-whisker plots showing larval duration and survival under various temperature regimes including a fluctuating temperature regime (Fluc). The boxes represent the median and quartiles, the whiskers are the extremes, and sample sizes (number of caterpillars) are provided above each plot

Survival at very high temperatures was low (Fig. 2), but considering that temperatures in nests are not consistently high (Fig. 3), warm periods may provide a respite from cold spells. Caterpillars did not respond differentially to thermal acclimation (Fig. 4) indicating a lack of phenotypic plasticity, which is typical for Marion Island where environmental variability is unpredictable.

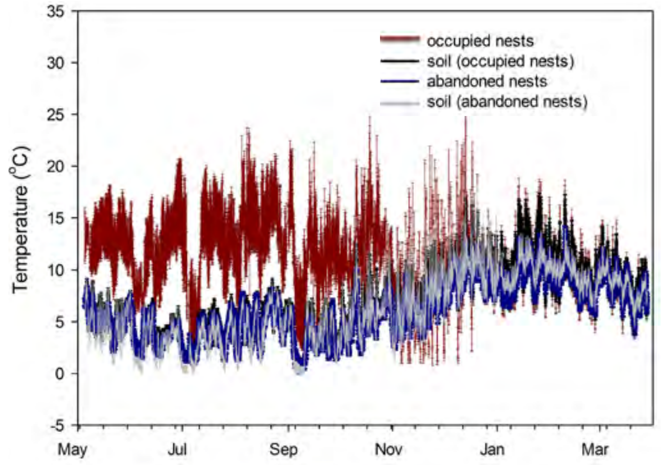


Figure 3: Temperatures in occupied nests and surrounding habitats

Thermal preference on a 0-30°C gradient was for low temperatures *ca.* 8°C (Fig. 4) and choice chamber trials also showed that there was a significant preference for cold rather than warm nest material.

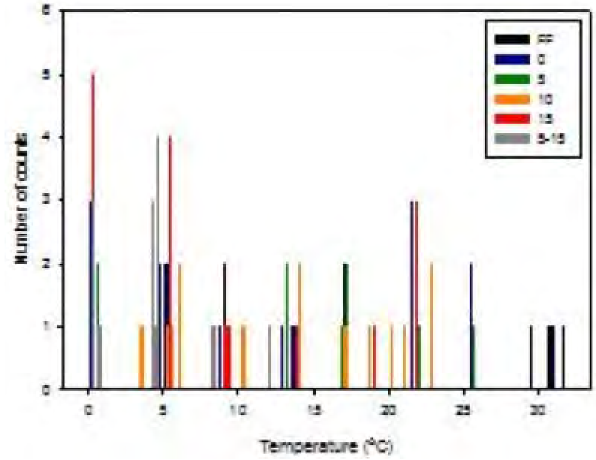


Figure 4: Thermal preference after acclimation at various temperatures depicted by colour bars (FF = field fresh)

The high abundance of caterpillars in nests suggests that these microhabitats are indeed a crucial resource for the *P. marioni* population. However, a low tolerance for warming and limited acclimation ability, in addition to reduced dispersal (because the adults are flightless), are risky attributes to hold, given future global change scenarios.

Author: T Haupt
Contributors: S Chown (MU, Australia),
B Sinclair (UWO, Canada)

14. MOVEMENT PATTERNS OF INDIAN OCEAN HUMPBACK DOLPHIN *SOUSA PLUMBEA* ALONG THE SOUTH AFRICAN COAST

The Indian Ocean Humpback Dolphin (Fig. 1) was up-listed to 'Endangered' in the recent South African National Red List Assessment (2016). Abundance estimates are available from a number of localized study sites, but information on movement patterns and population linkage between these sites is poor.

Figure 1: A group of Indian Ocean Humpback Dolphins.

A collaborative national research project, the SouSA Project, was established in 2016 to address this key knowledge gap. Twenty identification catalogues collected during the period 2000–2016 from 13 different locations (Fig. 2) were collated and compared. These included catalogues of the Knysna, Plettenberg Bay and Tsitsikamma areas, which were developed for a collaborative project between the Department of Environmental Affairs and Nelson Mandela University (D. Conry 2017, MSc thesis, Department of Zoology, Nelson Mandela University).

After data selection of photographs of 526 individuals from all locations, and then matching photographs between locations, 247 uniquely and well-marked Humpback Dolphins were identified (90 matches were found representing 61 individuals). From photographs of known individuals at multiple locations, movements along the coastline between locations could be determined. The distances of movement ranged between 30 km and 500 km with a median distance of 120 km. However, long-term site fidelity by individuals was also evident from the data. The lack of movement of individuals between the south and east coasts of the country supports the contention that the dolphins found on the south coast may constitute a single, isolated population at the western end of the species' global range.

The photo-identification data currently available suggest that national abundance of Indian Ocean Humpback Dolphins may be well below the previous estimate of 1,000 individuals, with numbers possibly closer to 500 (taking into account barely distinctive and unmarked individuals, and un-sampled areas of the coastline). Bearing in mind the poor conservation status of the species in the country, the development of an action plan for ensuring its long-term survival in South Africa is recommended. At the same time, increased research efforts are needed, particularly to allow for a more thorough assessment of population numbers and a better insight into the drivers of population limitation.

This study emphasizes the importance of collaboration when investigating threatened marine species that are highly mobile.

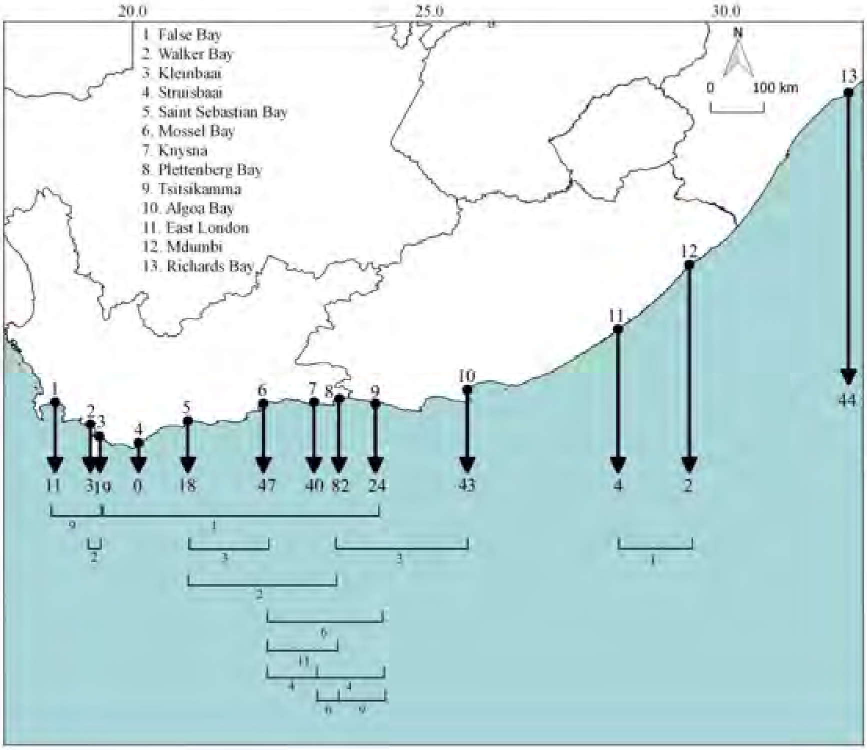


Figure 2: The south-eastern coastline of South Africa indicating the number of individuals identified in different locations after data selection (numbers below arrows) and the number of individuals moving between locations

Authors: E Vermeulen (MRI), SP Kirkman
Contributors: T Bouveroux, S Plön, V Cockcroft, D Conry, G Penry, P Pistorius, A Vargas-Fonseca (all NMU); S Atkins (EWT); W Chivell, S Hörbst, M Thornton (all DICT); E Gennari (OR); BS James, SH Elwen (both MRI)

15. PASSIVE ACOUSTIC MONITORING OF COASTAL DOLPHINS IN PLETTENBERG BAY

Coastal dolphins in South Africa are at risk of numerous threats. The Indian Ocean humpback dolphin (*Sousa plumbea*) was recently assessed to be "Endangered" at national level, and the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) as "Near-threatened". Continued research and monitoring of these species is needed to understanding and managing the main threats they face.

A study by the Department of Environmental Affairs and Nelson Mandela University assessed temporal patterns of coastal dolphins in the Plettenberg Bay area using Passive Acoustic Monitoring (PAM). Underwater acoustic recorders (hydrophones) were deployed near Robberg MPA on a sea-floor mooring at 20m depth using SCUBA (Fig. 1).

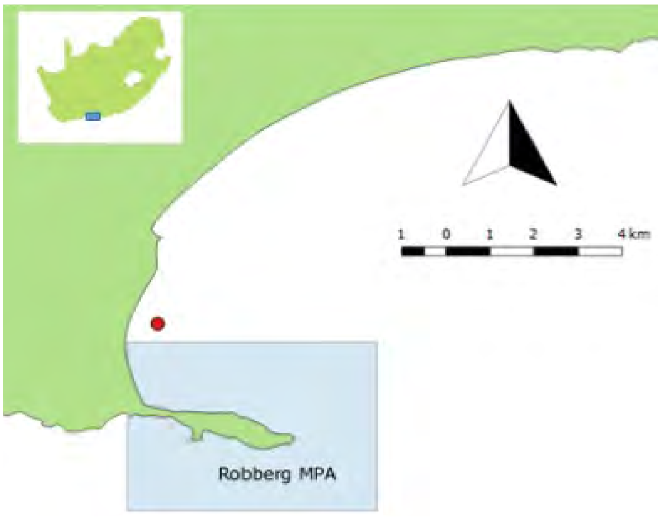


Figure 1: Map of the study area in Plettenberg Bay showing the boundary of Robberg Marine Protected Area (blue) and the location of the hydrophones (red dot). The position of the Plettenberg Bay region is indicated by the blue box on the inset map.

Acoustic recordings of dolphin vocalizations (echolocation clicks and whistles) were collected between 2015 and 2017. Automatic detector algorithms were used to process the acoustic recordings. An automatic detection protocol was then developed and its efficacy was assessed by determining whether it detected groups of dolphins that were observed during concurrent land-based observations. The occurrence patterns of the coastal dolphins were investigated based on the variation in detection rates of target vocalisations between different periods of the day.

The detector algorithms that were employed achieved > 80% true detection rates and < 5% false alarm rates (Fig. 2). Their performance was adversely influenced by the low sampling frequency; to optimize performance a high sampling frequency is essential.

The coastal dolphins frequented the bay during both daytime and night-time, with apparent high activity between midday and dawn (Fig. 3). Group size and behaviour showed an effect on acoustic detectability of dolphins. It was generally the larger foraging groups that were detected both visually and acoustically, whereas smaller groups (associated with other behaviours such as travelling) were more likely to be only visually and not acoustically detected (Fig. 4).

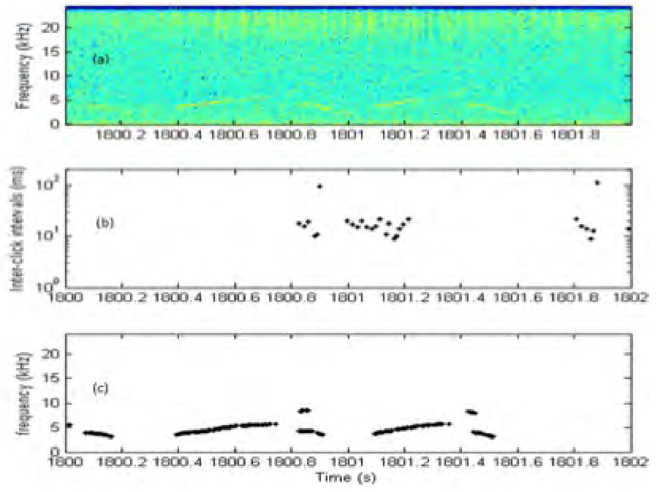


Figure 2: Example of detection results: (a) full spectrogram, (b) click detection, and (c) tonal sound detection.

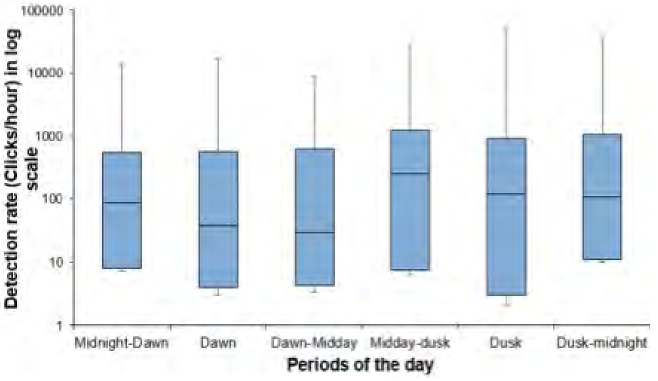


Figure 3: Box-whisker plots representing the mean detection rates of coastal dolphins based on echolocation clicks for six diurnal periods. The upper and lower lines of the box represent the quartiles and the whiskers the range of detection rates.

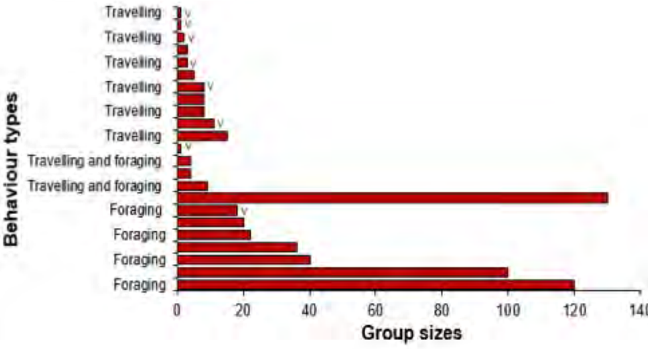


Figure 4: Prevalent behaviour types displayed by visually detected groups of dolphins. Groups that are marked "V" were detected only visually, the rest were detected both visually and acoustically.

Authors: K Hlati, SP Kirkman,
Contributors: D Anders, A Vargas–Fonseca (NMU),
P Pistorius (NMU), H Lin (AS, Taiwan);
G Latha, MM Mahanty (both NIOT, India)

16. TWENTY ONE YEARS OF WHALE STRANDING DATA FOR SOUTH AFRICA'S SOUTH-WESTERN COAST (1997-2017)

Archaeological evidence suggests that early inhabitants of the South African coast depended on stranded whales as a source of food and building material (Fig. 1). In modern times, whale strandings, especially mass strandings, have elicited significant media attention and public interest locally. This is affected by the charismatic status of whales and the emotional attraction that many people feel towards them.

Figure 1: Early hunters/gatherers of the Cape coast (Artwork: Margo Branch)

DEA and other stakeholders have intensified their efforts to attend to stranded whales (live or dead). The intentions for this include rescue of live animals where feasible, prevention of undue suffering by moribund animals, and collection of biological data – strandings are key sources of data for many species, especially since South Africa has adopted a non-lethal sampling policy for marine mammals. Stranding responses are coordinated per sections of coastline through a stranding network established in 2009; DEA responds to stranding incidents along the south-western coast of South Africa (Fig. 2).

Figure 2: Locations of reported stranding incidents along the south-western coast of South Africa

On average, five whale strandings were recorded per year between 1997 and 2006. This tripled to 16 per year during 2007-2016 and then further doubled to 33 in 2017 (Fig. 3).

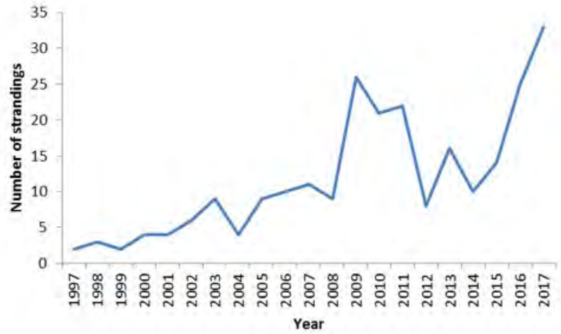


Figure 3: The trend in whale strandings on South Africa's south-western coast between 1997 and 2017

Large migratory whales such as Southern Right *Eubalaena australis* and Humpback *Megaptera novaeangliae* Whales made up 33% of all strandings (Fig. 4). Numbers of False Killer Whale *Pseudorca crassidens* were inflated by two mass strandings, in 2009 and 2013. Of the 18 species recorded, three are classified as 'Vulnerable' and one as 'Endangered' in terms of the most recent national Mammal Red List (2016).

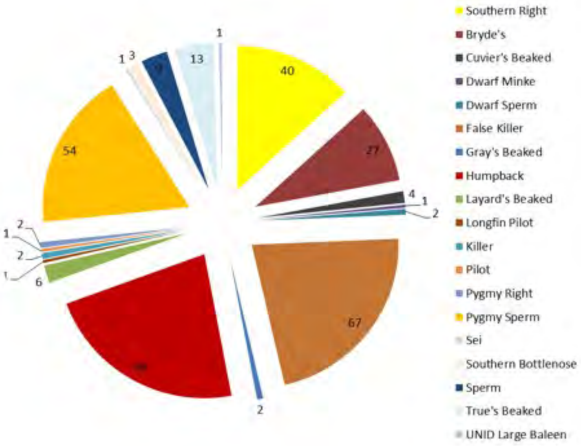


Figure 4: Numbers of stranded individuals per species found on South Africa's south-western coast between 1997 and 2017

Recovering populations of *E. australis* and *M. novaeangliae* may have contributed to the increase in whale strandings that was evident over the study period. So too may increasing human population numbers and human activities such as industrial fishing, shipping and seismic surveys that may affect whale stranding and mortality. However, while determining the reason for stranding is a key objective of stranding responses, the cause is often difficult to pinpoint except in obvious cases, e.g. ship strikes or entanglement in fishing gear.

Authors: D Kotze, S McCue, M Seakamela,
S Swanson (FBWSA), M Meÿer (formerly DEA)

17. A FRAMEWORK FOR EVALUATING EFFECTIVENESS OF MARINE PROTECTED AREAS IN SOUTH AFRICA

Effectiveness of Marine Protected Areas (MPAs) is ultimately determined by how well they deliver on their goals and objectives. However, South Africa (SA) currently lacks an appropriate framework for assessing MPA effectiveness. Specifically:

- There is a lack of an overarching framework of goals and objectives for MPAs;
- At MPA level, objectives are often too generic, or are not well balanced between categories of objectives (Fig. 1);
- Programmes are often lacking to determine if an MPA is performing useful functions.

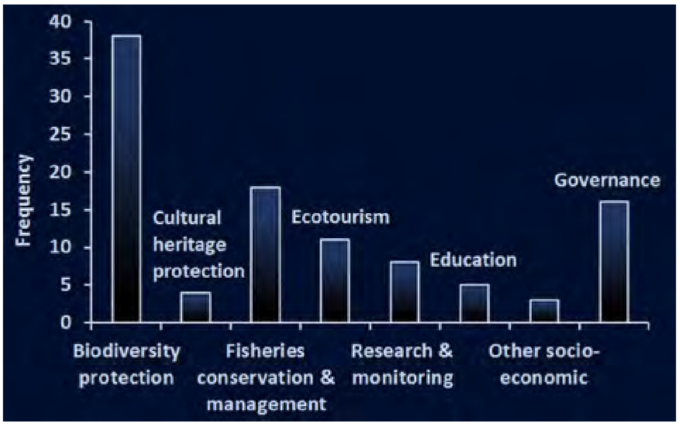


Figure 1: Frequency of occurrence by category of objectives listed for all MPAs in SA

In addition, the lack of an integrated, more human-centred approach in MPA processes has been criticised. Specifically:

- Many MPAs were declared without proper consultation;
- This has contributed to a lack of acceptance by many;
- There are implications for effectiveness, e.g. a lack of compliance.

Thus, a DEA-WWF project aims to:

1. Develop an appropriate framework to evaluate MPA effectiveness;
2. Bridge social-ecological divides with greater involvement by stakeholders, including communities.

The project has four phases. Phase 1 involved revisiting MPA goals and objectives through a literature review and two national workshops (Pine Lodge, Port Elizabeth, 27 October 2016; Cape Research Centre, Tokai, 14-15 March 2017). Draft overarching goals, objectives and indicators of MPA effectiveness were determined for three main categories: Ecological/Protection (biodiversity protection, fisheries conservation), Socio-Economic (ecotourism, cultural, education, research and monitoring, sustainable utilisation and other socio-economic benefits) and Governance (not considered further in this project).

Overarching Ecological/Protection goals included:

1. Protection of habitat types and ecosystem integrity ensured;
2. Protection of species or populations of conservation concern assisted;
3. Ecological viability of marine living resources ensured.

Overarching Socio-Economic goals included:

1. Food security enhanced or maintained (Fig. 2);
2. Livelihoods enhanced;
3. Non-monetary societal benefits enhanced or maintained;
4. Benefits and opportunities equitably distributed;
5. Undisturbed sites set aside for monitoring and research (Fig. 3);
6. Environmental education, awareness and knowledge enhanced.

Phase 2 of the project (currently underway) is concerned with developing a robust evaluation technique for MPA effectiveness. This will be refined and tested at individual MPA level and at national level (Phase 3). The final phase (Phase 4) will provide advice for monitoring activities (Fig. 3) to allow for tracking and comparing effectiveness of MPAs.

Figure 2: Harvesting for sustenance in an MPA

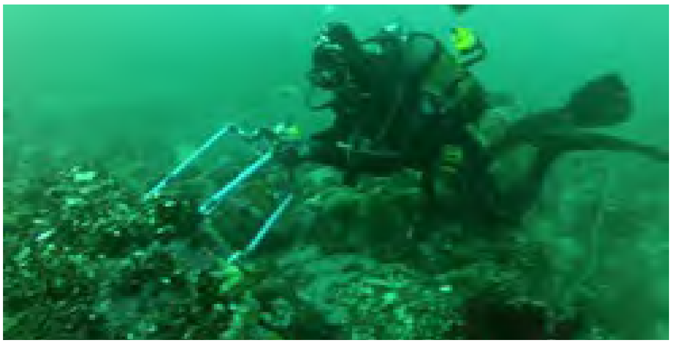


Figure 3: Collecting baseline biodiversity data in an MPA

Author: SP Kirkman
Contributors: S Peterson, J Duncan, R Adams (all WWF); G Branch (UCT); M Pfaff

18. MARINE PROTECTED AREAS AS A PLATFORM FOR MONITORING REEF COMMUNITIES IN SOUTH AFRICA

To be able to monitor the impacts of pressures on the environment, baseline assessments of ecosystems in their 'pristine' state are essential. In the ocean, reefs are exemplar systems for monitoring, but in South Africa baseline data are largely lacking for reef ecosystems. A contributing factor is their inaccessibility – with SCUBA mostly limited to depths of <30m, reef communities of deeper reaches remain largely unexplored.

Figure 1: The DEA team conducting jump camera surveys

DEA has initiated research and long-term monitoring on reefs in marine protected areas (MPAs), with baseline assessments in the Table Mountain National Park (TMNP) MPA commencing in 2016. By conducting monitoring and research in MPAs, we aim to:

- Provide a better description of the full range of fauna and/or whole ecosystems. Ecological monitoring in MPAs has largely targeted focal species (of economical importance, threatened, protected, or so-called 'charismatic'). Indices of non-focal species, community and function have largely been disregarded.
- Determine the drivers of spatial variability, e.g. depth, temperature, etc.
- Conduct long-term monitoring to detect temporal changes. MPAs are exposed to less anthropogenic activities, making them almost natural laboratories in which we can monitor temporal changes in communities as a result of 'natural' processes.

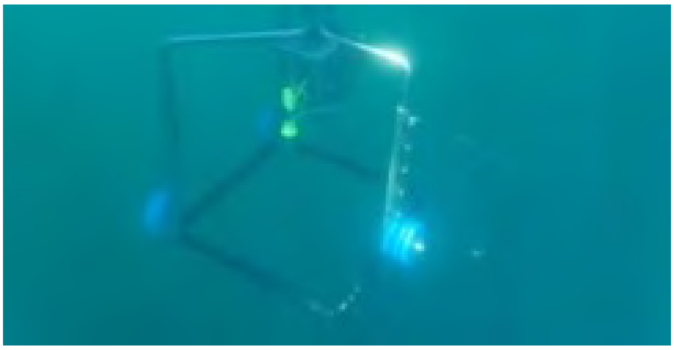


Figure 2: The jump camera system

The DEA reef monitoring programme utilizes underwater imagery equipment (Figs 1 and 2), in use worldwide by researchers to survey the marine environment. These non-destructive tools are highly effective for conducting baseline assessments using standardized protocols.

Author: T Haupt;
Contributors: L Janson, L Snyders, D Anders, M Worship, I Weideman, R Payne, L Williams, D Kotze, S McCue, SP Kirkman, T Samaai

Figure 3: A grid system covering an area of granite reef in the TMNP MPA

The reefs are surveyed remotely using a jump camera lowered from a rubber boat (Fig. 1). This system allows for exploration of reefs from 15 m to 100 m by dropping the camera at fixed co-ordinate points along a grid system (Fig. 3).

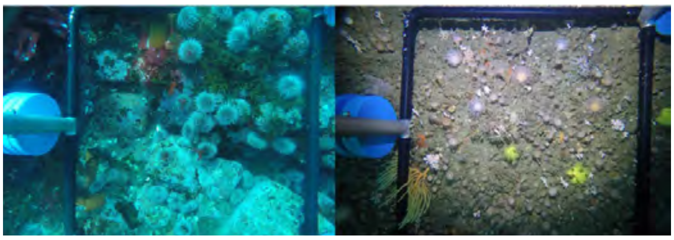


Figure 4: Snapshots of reef invertebrates at 14 m and 70 m

The occurrence of reef invertebrate phyla varies significantly with depth (Anosim; $R = 0.69$, $p = 0.002$). Deeper reaches (61-100 m) are comprised of a broad array of sponges, bryozoans, ascidians, corals and echinoderms. Different forms of sponges occur in the mesophotic zone (31-60 m) along with coralline algae, whereas ascidians and seaweeds dominate the shallower reaches (0-30 m) (Figs 4 and 5).

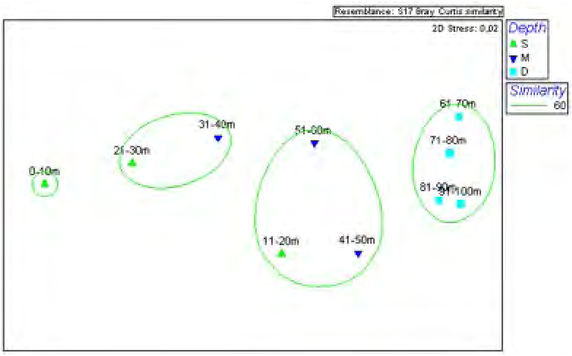


Figure 5: A Bray-Curtis plot showing the similarity of reef invertebrate communities between shallow (S), mesophotic (M) and deep (D) reef zones

Apart from providing the platform for long-term monitoring, baseline assessments of the full range of biological diversity that MPAs are meant to conserve and protect may contribute to initiatives such as marine spatial planning and MPA effectiveness.

19. NATIONAL ESTUARINE ASSESSMENTS AND MONITORING

Estuaries deliver important ecosystem services including carbon sequestration, flood regulation, storm protection, nursery habitats for fish and invertebrates, and provision of food, fuel and building resources. However, estuarine ecosystems face a number of anthropogenic threats, some of the most severe being flow modification, pollution, sedimentation, exploitation of living resources and habitat destruction.

There are approximately 300 estuaries in South Africa and various institutions are mandated to assess and monitor their ecological state. Monitoring programmes should ideally focus on various ecosystem components, but due to the lack of funds and human capacity most initiatives are limited to the collection of basic data (Fig. 1, Tier 1).

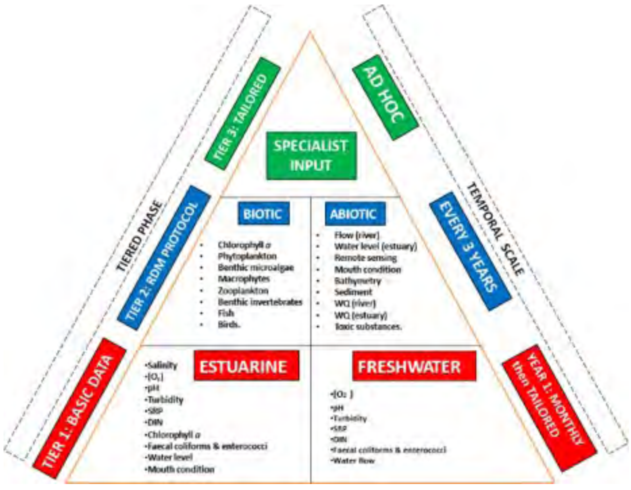


Figure 1: The three tiers of National Estuarine Monitoring Programmes for South Africa (Cilliers and Adams, 2016)

The last National Biodiversity Assessment in 2011 highlighted an urgent need to assess estuarine benthic invertebrates as indicators of ecosystem health. A comprehensive dataset of benthic invertebrates was collated at a national scale almost two decades ago, but subsequently there has been little effort to assess this important component of estuarine ecosystems.

In 2016, DEA initiated a collaborative project with the Department of Agriculture, Forestry and Fisheries (DAFF) to complement an existing monitoring programme that focuses on estuarine fish with invertebrate sampling. Since then, two estuaries have been monitored: the Kei estuary in the Eastern Cape (Fig. 2) and the Orange River estuary in the Northern Cape (Fig. 3).

Figure 2: Sites where benthic invertebrates have been monitored in the Kei estuary, Eastern Cape

Figure 3: Sites where benthic invertebrates have been monitored in the Orange River estuary, Northern Cape

State of the Kei estuary:

This Eastern Cape estuary is characterised by relatively low invertebrate diversity. Few phyla are present (Mollusca, Crustacea and Annelida) and most of the species found are known indicators of high sediment loads (Fig. 4), suggesting that this system is in a degraded state.

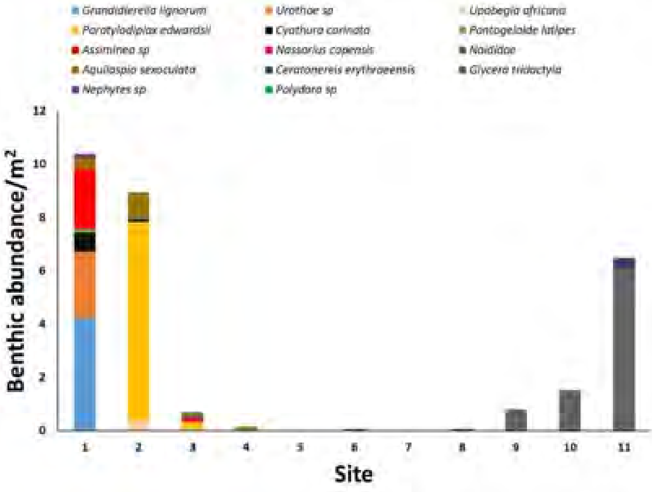


Figure 4: Kei estuary benthic invertebrates per sampling site

State of the Orange River estuary:

This estuary is characterised by relatively low water levels due to the current drought, therefore some of the sites are anoxic. As a result freshwater invertebrates dominate in the estuary.

Cilliers GJ, Adams JB. 2016. Development and implementation of programme for South African estuaries. *Water SA* 42: 279–290.

Author: J Nhleko
Contributor: S Lamberth (DAFF)

20. THE COMPOUNDED EFFECTS OF HARVESTING AND INVASIVE SPECIES ON INTERTIDAL ROCKY SHORE ECOSYSTEMS

Harvesting on intertidal rocky shores of the Cape Peninsula dates back to pre-colonial times. In the present day, because of intensifying human population pressure on coasts, it is essential to understand the effects of harvesting on ecosystem structure and functioning. This will enable estimation of sustainable harvesting levels, particularly for controlled-use zones of marine protected areas (MPAs). This study addressed the impacts of harvesting in the Table Mountain National Park MPA by comparing community structure between three different harvesting regimes:

- Heavily harvested (Kommetjie Mainland)
- Lightly harvested (Kommetjie Island)
- Protected (Scarborough Reserve)

In addition, the compounding effects of the invasive mussel *Mytilus galloprovincialis*, which was introduced to South Africa in the 1970s, was assessed by comparing current with past survey data:

- 1970 – before invasion of *M. galloprovincialis*
- 2017 – after it had become a dominant species

Key results

The cover of grazers decreased with an increase in harvesting level (Fig. 1A); simultaneously, the cover of algae increased (Fig. 1B).

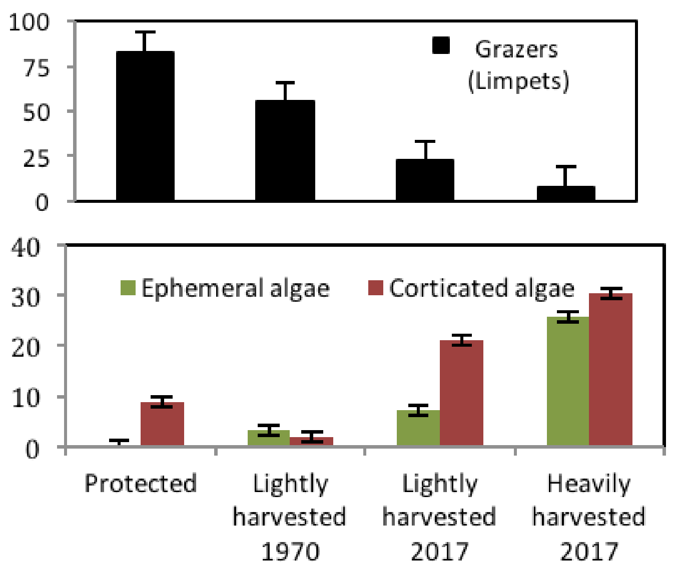


Figure 1: Effects of harvesting level and survey period on the cover of (A) grazers and (B) algae. Error bars represent standard errors

With the invasion of *M. galloprovincialis*, community structure in the intertidal shifted from a limpet-dominated to an algae-dominated system (Fig. 2).

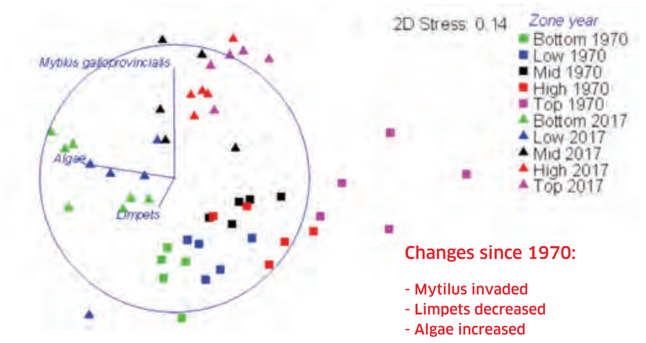


Figure 2: Multiple Dimensional Scaling plot showing a shift in intertidal community structure since 1970. Symbols represent different quadrat samples and colours the different intertidal zones. More similar communities are plotted closer to each other and dissimilar communities are far apart.

Figure 3: Photographic evidence of changes in community structure due to (A) harvesting and (B) invasion of M. galloprovincialis

Summary and conclusions

- ∆ Harvesting resulted in 3-10 times lower grazer cover (and densities) compared to protected sites, and community transformation towards the domination of algae.
- ∆ The invasive mussel *M. galloprovincialis* has displaced limpets, which further compounds the domination of algae.
- ∆ Harvesting in controlled zones of the Table Mountain MPA is currently exceeding sustainable levels.
- ∆ Experiments need to be conducted to determine sustainable levels of harvesting in this MPA.

Authors: N Baliwe (UCT, SanParks), M Pfaff, G Branch (UCT)

21. IMPACTS OF HARVESTING ON ROCKY SHORE COMMUNITIES OF THE DWESA-CWEBE MARINE PROTECTED AREA

Following 25 years of conflict between local communities and conservation agencies, the Dwesa-Cwebe Marine Protected Area (MPA) was re-zoned in December 2015 to allow for controlled levels of subsistence harvesting on selected rocky shore ledges inside the MPA. To assess the impacts of harvesting on biodiversity, the DEA Rocky Shore Monitoring team conducted baseline surveys at two sites (Fig. 1) before harvesting commenced, and follow-up surveys after a year of harvesting.

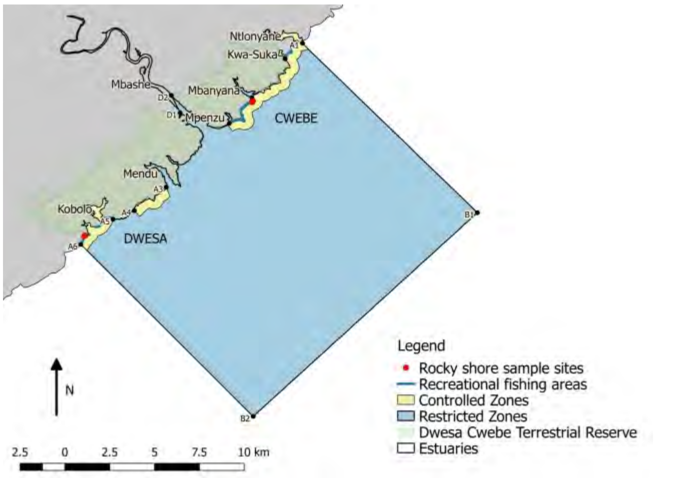


Figure 1: Map of the Dwesa-Cwebe MPA showing the recent re-zonation, which permits subsistence harvesting in 'Controlled Zones'

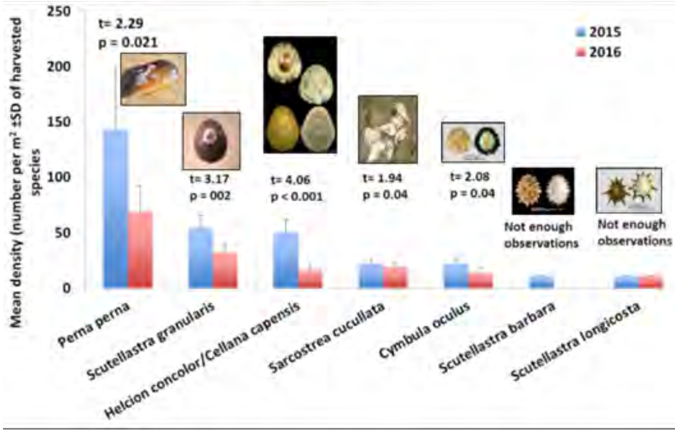


Figure 3: The densities of key harvested species declined between 2015 and 2016, following a year of controlled harvesting

Changes in the densities of harvested species and their effects on rocky shore communities were determined from repeated photographs along permanently fixed transects (Fig. 2).

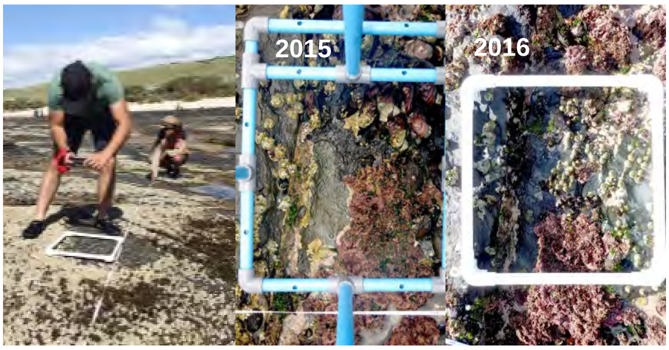


Figure 2: Photographs taken along permanent transects were used to compare densities of harvested species between no-take (2015) and controlled harvesting areas (2016)

Results

- Densities of harvested species declined significantly within one year of controlled harvesting (Fig. 3).
- Community structure in mid- and low zones shifted significantly between 2015 and 2016 (Fig. 4).

Conclusions

While the results of the comparisons were remarkably consistent, it is not certain that the observed changes in community structure and species densities can be attributed only to harvesting; annual variation, fluctuations in recruitment and environmental parameters may also play a role. Further monitoring, including at control sites outside the MPA, is critical to validate these trends and ensure that current controlled harvesting levels are sustainable.

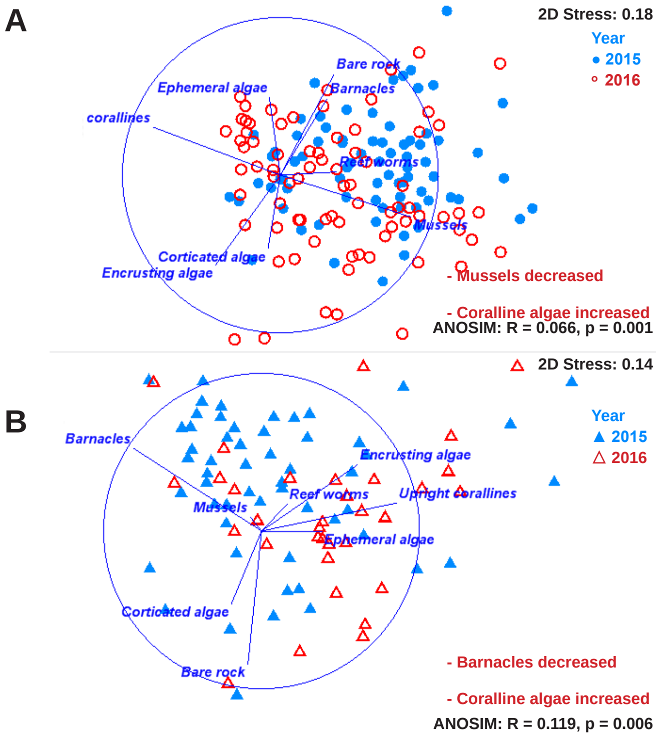


Figure 4: Multiple Dimensional Scaling plot showing changes in community structure on the low shore (A) and mid-shore (B) between 2015 and 2016

Authors: M Pfaff, M van der Bank (ECPTA, SANBI), I Malick (DEA, SAEON), T Samaai

22. INTEGRATED ECOSYSTEM PROGRAMME: SOUTHERN BENGUELA (IEP: SB)

The west coast of South Africa has been the focus of much environmental research attention over the decades with DEA: O&C being the custodian of several long-term datasets. These data may be used to assess environmental change, stability, resilience and health. The continued collection of such information for this purpose is termed monitoring.

Several concerns have led many governments to introduce an ecosystem approach to monitoring: (1) existing initiatives may be limited in scope, in that they depend on a small number of indicators, failing to consider the ecosystem complexity, (2) the objectives and goals of some are vague and intangible, and (3) some initiatives lack a clearly defined link between complex science and management relevance.

The Integrated Ecosystem Programme: Southern Benguela (IEP: SB) was initiated by DEA: O&C in 2013 as an ecosystem end-to-end monitoring programme, to investigate the ecosystem from the smallest to the largest factor. Based on a coordinated observing system, using proven technology, historical datasets and by creating new projects to bridge the information gaps, the IEP: SB aims:

1. To measure Essential Ocean Variables (EOVs): existing and new data will be used to characterise the natural variability of the southern Benguela, through the development of indices to assess environmental change, stability, resilience and/or health, with the ultimate aim of translating potentially complex science into clear management indices.

2. To validate existing data for use in these indices. All data are to be processed, validated and freely distributed through DEA's Marine Information Management System (MIMS, www.ocean.gov.za).

3. To innovate: where applicable, implement novel, reliable, rigorous yet practical and less time-consuming methods and technologies.

4. To build capacity and train.

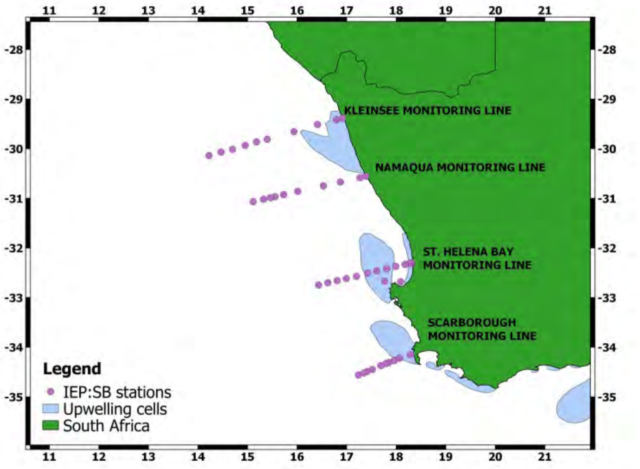


Figure 1: Monitoring stations off the west coast of South Africa. The 1st line is south of the Namibian border and starts off Kleinsee (KML), the 2nd line runs over Childs Bank and starts off Namaqualand (NML), the 3rd line is in St Helena Bay (SHBML) and starts off Elands Bay, and the southernmost line is off Scarborough (SML).

Table 1: Monitoring projects within the IEP: SB

Project	EOVs monitored/ being developed	Long-term or New
Hydrography	salinity, temperature	Long-term
Currents	wave direction and speed	Long-term
Chemistry	oxygen, chlorophyll, nutrients, pH, inorganic carbon, pCO_2	Long-term & New
Microbes	biomass/abundance and community structure	New
Primary Production	primary production rates	New
Phytoplankton	biomass/abundance, size structure and community structure	New
Microzooplankton	biomass/abundance, size structure and community structure	New
Mesozooplankton	biomass/abundance, size structure and community structure	Long-term
Benthos	biomass/abundance and community structure	New
Seabirds	biomass/abundance	New
Whales	biomass/abundance	New

Why do we monitor particular factors?

The suite of projects/EOVs was chosen because the information generated from them is relevant to the effective management of the West Coast.

Temperature: is a vital component of the climate system; influences exchanges of energy and gases between the ocean and atmosphere; provides the living medium for ocean life.

Salinity: can contribute to monitoring the water cycle; together with surface temperature, can be used as a measure of ocean warming.

Currents: are responsible for significant surface transport of heat, salt, micro-plastics and pollutants. Surface currents are a major player in climate due to weather fluctuations.

Oxygen: is critical to understand the large (mostly) decreasing trends in the concentrations of dissolved oxygen in the ocean over the last few decades. Oceanic oxygen is an indicator of climate change.

Chlorophyll: is found within the phytoplankton (floating plants). It is responsible for photosynthesis, the critical process in which the energy from sunlight is used to produce life-sustaining oxygen.

Nutrients: are the essential chemicals to sustain life in the oceans.

pH: with the increasing uptake of anthropogenic CO_2 into the oceans, a decrease in pH is important to consider at this time. pH is thus a simple index that can be used to assess the ecosystem health of an area.

pCO_2 and inorganic carbon: seawater has a high capacity for absorbing carbon. The ocean influences the rate of accumulation of carbon in the atmosphere, and thus slows the rate of global warming.

Microbes: micro-organisms exist in all habitats, use a variety of energy sources and rapidly adapt to environment changes. They are considered to be the ocean's 'canary in the coal mine' as they are a very good indicator of immediate environmental change.

Primary production: this is the 'biological pump', a process driven by the organisms in the ocean that moves CO_2 to ocean depths, thus regulating the atmospheric concentration of this greenhouse gas. It is also a measure of how fertile the ocean is, with regions of higher primary production potentially supporting more ocean life.

Phytoplankton: their abundance and species composition can affect fishery catch potential, patterns of harmful algal bloom occurrence and cause shifts in marine habitats. These services are the foundation for resilient coastal communities and for the 'blue economy'.

Microzooplankton: are highly sensitive to ecosystem changes both at the bottom and top of the system. They are important in recycling the essential chemicals in the ocean.

Mesozooplankton: is a commonly used indicator to evaluate fisheries potential and ecosystem health. In turn, mesozooplankton diversity is sensitive to environmental pressures such as climate change, including ocean acidification, warming and changes in oxygen.

Benthos: the sensitivity of these organisms, which live on the ocean floor, to changes in environmental quality renders them a good ecosystem indicator.

Marine seabirds and marine mammals: are long-lived organisms, and are thus particularly vulnerable to human impacts such as fisheries and climate change, providing longer-term indicators of ecosystem health. Also, by virtue of their position high in the foodweb, they are susceptible to toxins and contaminants that accumulate up the foodchain. Seabirds and mammals are protected by national and international regulation, needing such protection to prevent extinction (e.g. Red List of Threatened Species, CITES). As such, the high profile of these marine species can be used to engage and educate stakeholders and the public on ocean health and other issues.

What have we achieved so far?

The ultimate outcome of the IEP: SB is to have a suite of indices that will be used to inform management decisions.

All projects under the IEP: SB are in various stages of indices development. Results from some of the more advanced projects are provided below.

OCEAN CHEMISTRY: PH MEASUREMENTS AND OCEAN ACIDIFICATION

Oceanic uptake of anthropogenic CO_2 is changing the ocean's chemistry, leading to more acidic conditions (lower pH) and lower chemical saturation states (Ω) for the calcium carbonate ($CaCO_3$) minerals formed by many marine species. Increased ocean acidification will have massive implications for marine ecosystem health and functions. If seawater becomes undersaturated with respect to $CaCO_3$ ($\Omega < 1$), the shells and skeletons of organisms such as corals, pteropods, molluscs and foraminiferans can begin to dissolve. A pH of 7.7 indicates the onset of stress on calcifying organisms.

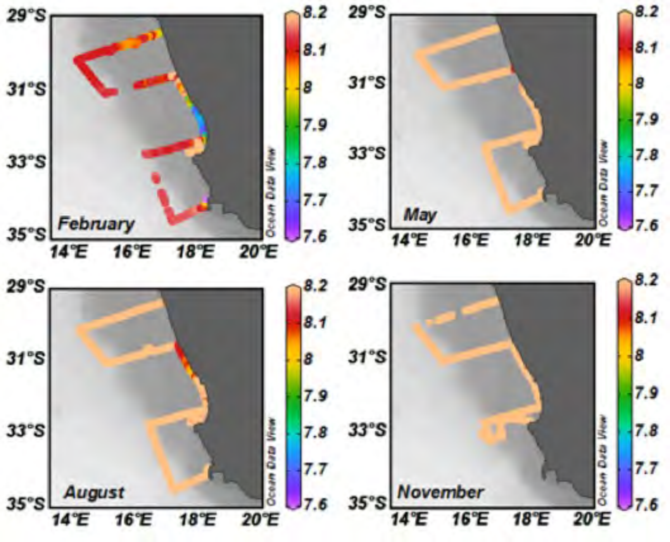


Figure 2: Maps showing surface pH distribution off the west coast of SA in 2017

Table 2: Calculated pH values for the sampling area during 2017

Season	Nearshore		Midshelf and Offshore	
	Mean ± SD	Range	Mean ± SD	Range
Summer (February)	8.08 ± 0.15	7.61 – 8.32	8.08 ± 0.15	7.51 – 8.56
Autumn (May)	8.33 ± 0.23	7.97 – 8.85	8.47 ± 0.14	7.98 – 8.89
Winter (August)	8.28 ± 0.13	7.91 – 8.45	8.34 ± 0.01	7.91 – 8.47
Spring (November)	8.75 ± 0.11	8.41 – 8.96	8.74 ± 0.10	8.38 – 8.96

Lowest pH (most acidic) conditions in the nearshore environment were recorded during late summer (February), with minimum levels approaching 7.6 (Table 2). The midshelf to offshore environment also indicated lowest pH values during late summer, although the minimum value approaching 7.5 was found on a nearshore transect. Areas with a pH stress threshold of 7.7 for calcifying organisms were located nearshore at Kleinsee, north of St Helena Bay and at Scarborough (Figs 2 and 3). All other areas had a surface pH approaching 8.1 during summer, which is not considered to pose a threat to calcifying organisms.

Autumn through to spring showed pH levels above 8, with higher mean values in the midshelf to offshore environment than in the nearshore zone (Table 2). The lowest dips in pH were measured nearshore at Kleinsee and Namaqua during May and August (Figs 2 and 3) with the lowest pH approaching 7.9, which is above the threshold to cause concern to organisms.

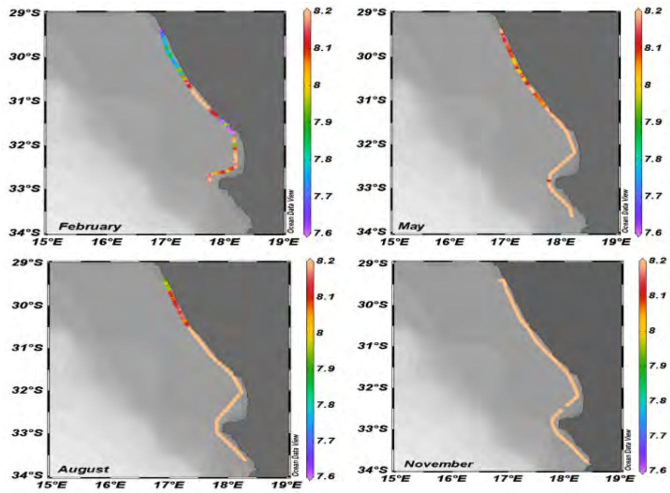


Figure 3: pH distribution in the nearshore zone during 2017 en route to the start of the surveys

Status of bottom water pH from September 2013 to August 2017:

In the southern Benguela Upwelling System, the lowest pH values are observed in the bottom waters of inshore stations, corresponding with areas where upwelling occurs and phytoplankton productivity in the overlaying water is the highest. The pH values of these inshore bottom waters have been monitored since spring 2013 (Fig. 4). Water samples were analysed for their total dissolved inorganic carbon and alkalinity content, to establish accurate pH values.

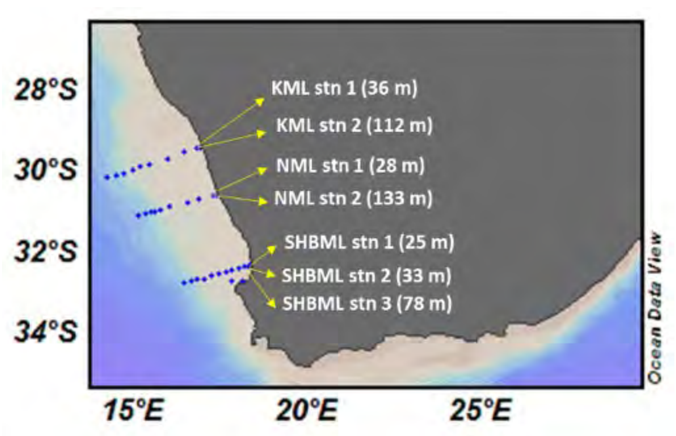


Figure 4: Map showing location of inshore stations where pH of bottom water was monitored

Very poor seawater conditions with low pH were found to occur in the nearshore environment along the KML, NML and SHBML throughout the year (Fig. 5). Lowest pH conditions were observed in 2015 and 2017. The occurrence inshore of low pH values in bottom water poses a threat to shells and skeletons of economically important marine organisms, such as abalone, prawns, mussels and oysters.

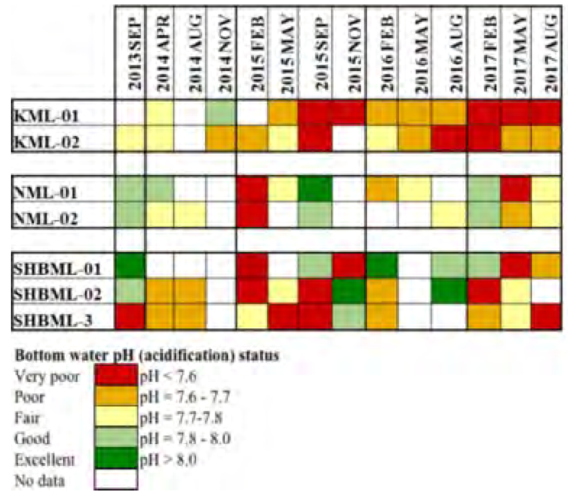


Figure 5: Annual variability in pH of inshore bottom water

MICROBIAL ABUNDANCE AND DIVERSITY

Microbes comprise both prokaryotes (single-celled organisms such as bacteria that lack a membrane-bound nucleus or other organelles) and eukaryotes (organisms with a well-defined nucleus and organelles). Microbes make up more than 90% of the ocean's biomass. These unicellular organisms are responsible for the ocean's primary production, nutrient and element cycling, and play key roles in regulating global climate, being the first to respond to a changing environment. Despite providing invaluable ecosystem services, marine microbial diversity and function are still poorly understood. The advent of modern technologies that speed up the identification and enumeration of microbes provides opportunities to address this overlooked foundation of marine life.

Picoplankton refers to planktonic (drifting) organisms less than 2 µm in diameter. This includes the prokaryotes *Synechococcus* and *Prochlorococcus*, which are small cyanobacteria and the most abundant photosynthetic organisms on earth, as well as picoeukaryotes. As part of the IEP: SB, microbes were sampled throughout the southern Benguela upwelling region during May, September, November 2015 and February, May, August, November 2016. DEA's flow cytometer was used to identify and count two groups of picophytoplankton (Fig. 6):

- *Synechococcus* spp. (size: ~0.9 µm)
- picoeukaryotes (size: ~ 0.95 µm)

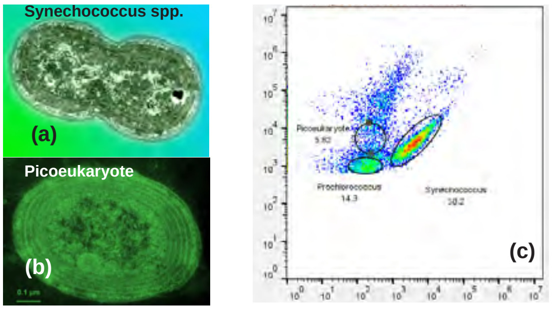


Figure 6: (a) Synechococcus *spp., (b) picoeukaryotes and (c) distinguishing microbial groups on a flow cytometer where the x-axis is phycoerythrin and the y-axis is chlorophyll*

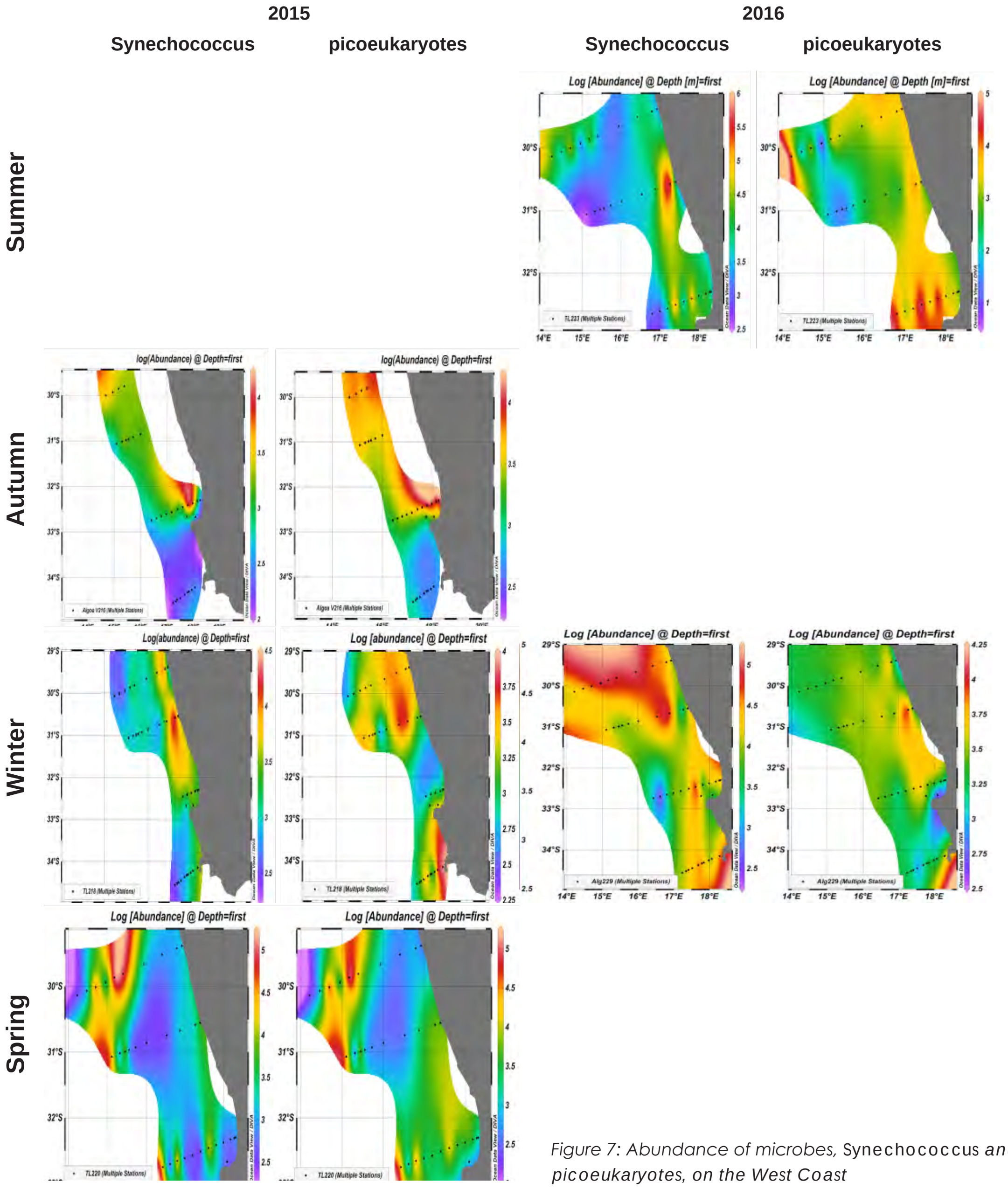


Figure 7: Abundance of microbes, Synechococcus *and picoeukaryotes, on the West Coast*

Measurements made during 2015 and 2016 (Fig. 7) indicate both temporal and spatial variability in abundance and distribution of the two groups. *Synechococcus* and picoeukaryotes seem to coexist in some months but not in others. PRIMER analysis indicated salinity and temperature were important drivers for both communities. Once fully processed, nutrient data will contribute to further understanding of these patterns.

In addition to abundance, microbial diversity was investigated using New Generation RNA/DNA sequencing along the SHBML (Fig. 8) during 2016. Biodiversity (the number of different organisms in an area) underpins the capacity of ecosystems to provide services valued by society and, consequently, is considered to be a 'master indicator' of ecosystem health. Both prokaryote and eukaryote diversity were investigated.

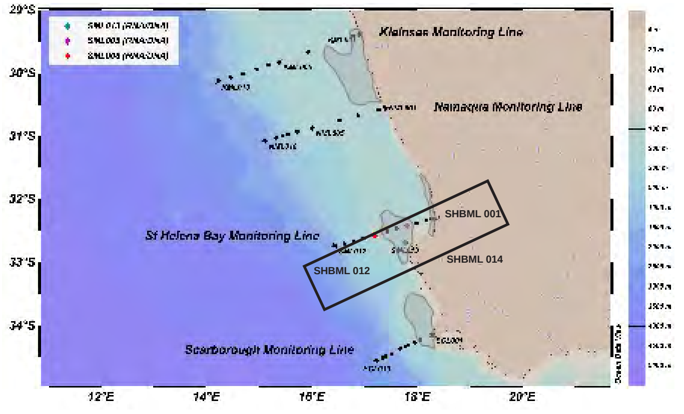


Figure 8: Sampling stations for genetic analysis of microbes

Upwelling waters had higher prokaryote species diversity than non-upwelling water (Fig. 10). These waters were dominated by the alphaproteobacteria, and by *Roseobacter* spp. in particular. These are aerobic anoxygenic phototrophs (AAPs), which means that, unlike most plants, the process of photosynthesis in this organism does not produce oxygen. Reported abundances of AAPs range from 1% to 25% of bacterial biomass and are thought to have an advantage in oligotrophic conditions (more light). More recent studies suggest that AAPs thrive better in more eutrophic environments. It has also been demonstrated that after upwelling and subsequent phytoplankton blooms, AAPs can grow well using nutrients from deep cold water and abundant light in surface waters. However, *Roseobacter* spp. are also facultative photoheterotrophs - bacteria that usually grow anaerobically in light but can also grow aerobically in the dark, i.e. grow and conduct photosynthesis in the presence of oxygen, using light only as an additional energy source. Comprising 20% of our samples, the ecological role of this group in the southern Benguela remains to be fully understood.

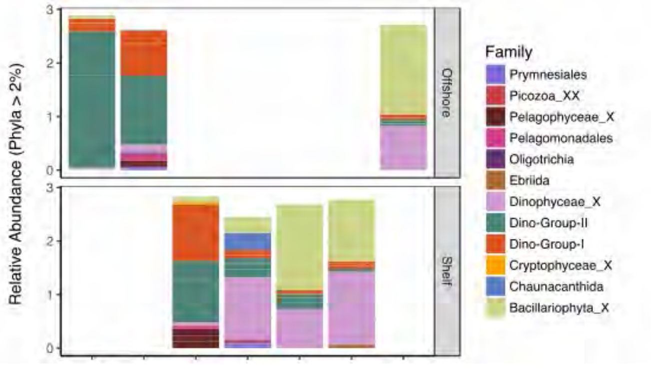


Figure 9: Results from genetic analysis of eukaryotes: samples for February: A. station 8 F_{max}, B. station 8 surface, C. station 5 F_{max}, D. station 5 surface; samples for November: E. station 5 F_{max}, F. station 5 surface, G. station 8 surface; prokaryote results for this time period are not shown here.

SAR11, a slow growing prokaryote known to indicate nutrient-depleted environments, dominated the non-upwelling water (Fig. 10). Large numbers of ammonium-oxidizing bacteria were also present, which are essential for the first step of nitrification. Further investigation into these organisms is required to fully understand their role in the nitrogen cycle. Eukaryotes were dominated by parasitic dinoflagellates suggesting that the biological pump is being stimulated in a different manner than we originally thought (parasitism *versus* grazing; Fig. 9). Aged upwelled water was dominated by diatoms. More research needs to be done to clarify the roles of these groups of eukaryotes.

This is the first study of spatio-temporal variability of picophytoplankton in the southern Benguela Upwelling region. The results therefore provide a novel and significant contribution to marine science in South Africa.

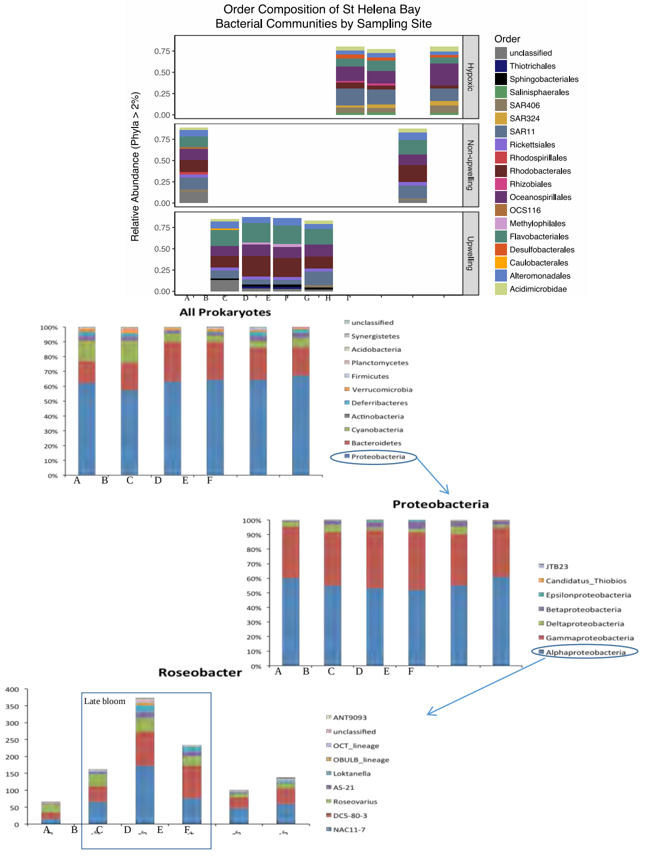


Figure 10: Results from genetic analysis of prokaryotes: samples for May: A. station 7 surface, B. station 5 surface, C. station 3 surface, D. station 3 F_{max}; samples for September: E. Station 13 surface, F. station 5 surface, G. station 13 bottom, H. station 13 bottom, I. station 5 bottom.

PHYTOPLANKTON: ESTABLISHING A BASELINE CHARACTERISATION

Phytoplankton are similar to terrestrial plants in that they contain chlorophyll and require sunlight and nutrients in order to live and produce oxygen as a by-product. Together with microbes, phytoplankton produces half the world's oxygen, sustaining life in the oceans, and affecting all life on Earth. Most phytoplankton float in the upper part of the ocean, where sunlight is available. The size groups are picoplankton (0.2–2 µm), which includes heterotrophic bacteria, nanoplankton (2–20 µm) and microplankton (20–200 µm).

The two main groups of phytoplankton are dinoflagellates and diatoms (Fig. 11). Dinoflagellates use a whip-like tail, or flagellum, to move through the water and their bodies are covered with complex shells. Diatoms also have shells, but they are made of a different substance and their structure is rigid and composed of interlocking parts. Diatoms do not rely on flagella to move through the water but instead rely on ocean currents to travel through the water.

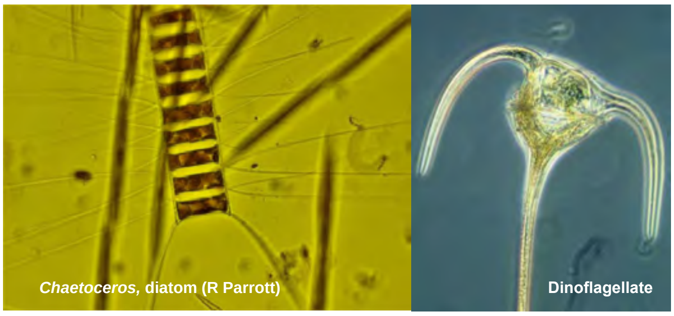


Figure 11: Examples of a diatom and a dinoflagellate

In a balanced ecosystem, phytoplankton provide food for a wide range of animals including whales, shrimp, snails, and jellyfish. When too many nutrients are available, phytoplankton may grow out of control and certain species may form Harmful Algal Blooms (HABs). These blooms can produce extremely toxic compounds that have harmful effects on fish, shellfish, birds, mammals, and even humans.

Table 3: Parameters used for the baseline characterisation of phytoplankton (defined by literature and other government monitoring programmes)

Parameter	Definition	Status of development
Abundance	The number of phytoplankton present	Method developed for DEA:O&C
Biomass	The amount of phytoplankton present	Method developed for DEA:O&C
Community structure	The groups or species present and their relative proportions	In progress
Diatom:Dinoflagellate ratio index	Currently a test indicator under the EU; the average Dia/Dino ratio has a threshold value of 0.5	Requires more data assimilation for the southern Benguela
Phytoplankton Index of Biological Integrity (P-IBI)	Management tool to assess phytoplankton status using various phytoplankton data relative to nutrient, light and other relevant physical and chemical parameters	Requires more data assimilation for the southern Benguela

A pilot study was conducted in 2016 to experimentally determine the best at-sea practices with respect to collection and storage of samples. Full seasonal collection began in 2017 following the new protocol of preservation with 1% formalin and storage at -20°C until analysis using a flow cytometer. Analysis has started to determine each of the phytoplankton parameters that will be used to create a P-IBI (Table 3). It is shown in Figure 12 that the total abundance of phytoplankton in late autumn is highest offshore along KML both at the surface and the depth of maximum fluorescence (F_{max}). Whilst many studies have measured proxies of phytoplankton abundance and biomass such as chl-*a* and carbon content, or of diversity such as pigment composition, this project seeks to measure actual cell abundance and species composition. In partnership with the Department of Agriculture, Forestry and Fisheries (DAFF), phytoplankton culture samples were analysed creating templates of pigment signatures on a flow cytometer for a single species. These can then be used to determine community structure and the diatom:dinoflagellate ratio index (Table 3). Shown here is the first signature created, for the diatom *Chaetoceros* (Fig. 13). Such signatures allow the determination of the proportion of each species in the sample, and can even be applied retrospectively to existing flow cytometer data.

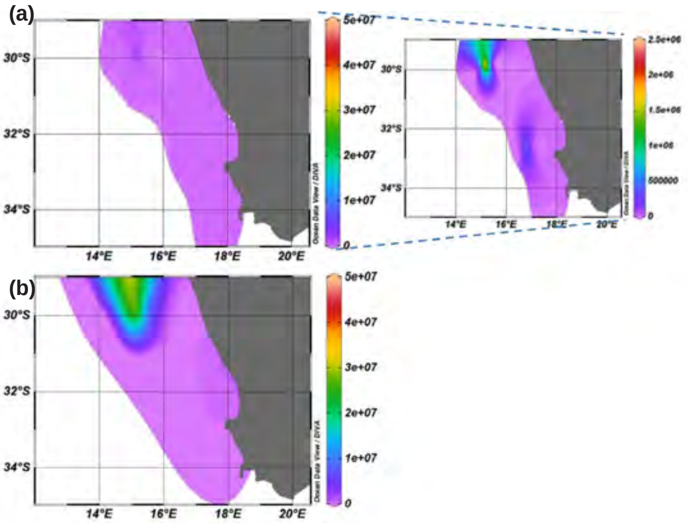


Figure 12: Total phytoplankton abundance (no. m⁻³) during late autumn (May 2016) for (a) the surface, with enhanced scale to the right, and (b) F_{max} (area of the ocean with the highest amount of fluorescence, a proxy of phytoplankton biomass)

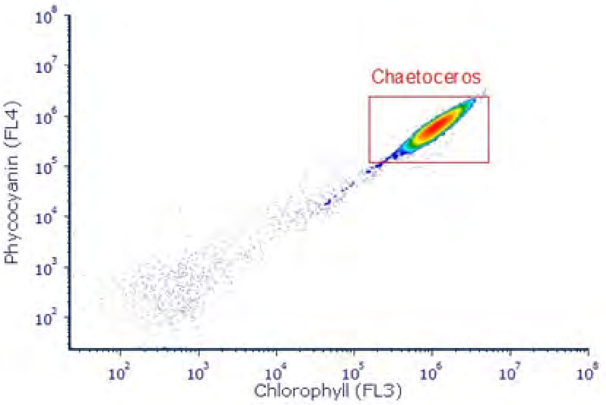


Figure 13: Diatom Chaetoceros *'signature' from flow cytometry*

PRIMARY PRODUCTION

Primary production is the synthesis of organic matter from atmospheric or aqueous carbon dioxide (CO_2). In marine systems, this process of 'carbon fixation' occurs principally through photosynthesis by phytoplankton. The eventual fate of phytoplankton biomass is removal to the ocean interior, either via passive sinking or as the by-product of grazing by higher trophic levels. This mechanism, termed the ocean's 'biological pump', results in the sequestration of CO_2 at depth, thereby contributing to the regulation of the atmospheric concentration of this greenhouse gas. In addition to its importance for the global carbon cycle, primary production underpins global ocean fertility, with regions of higher primary production supporting richer foodwebs.

The most productive regions in the ocean are associated with eastern boundary currents where the upwelling of cold, nutrient-rich waters from depth stimulates high levels of primary production in the 'euphotic zone' (i.e. the sunlit upper ocean down to the depth at which light reaches 1% of its surface value). These upwelling regions comprise approximately 1% of the global ocean surface area, but account for >20% of the world's marine fish catch due to the high biomass that occurs at lower trophic levels (i.e. primary producers). The west coast of southern Africa supports one of the four major eastern boundary current systems, the Benguela Current ecosystem.

Measurement of a range of metrics was initiated in 2017 (Table 4). This work will yield a full seasonal cycle of data on nutrient (nitrate, nitrite, phosphate, silicate) concentrations, ammonium concentrations, rates of primary production (carbon biomass produced), rates of export production (CO_2 sequestered), rates of nutrient consumption and regeneration (ecosystem fertility), and the first information from this region on the fluxes and concentration of N_2O, a powerful greenhouse gas.

Figure 14 shows the May 2016 proof-of-concept sampling results. Net primary production (NPP) and nitrate- and ammonium uptake (i.e. new and regenerated production) were measured throughout the euphotic zone at six stations across the four monitoring lines. While NPP was highest inshore and declined with distance from the coast, a greater proportion was potentially exportable from offshore surface waters, as indicated by higher rates of new production, specifically nitrate uptake at these stations. Inshore, phytoplankton growth was predominantly supported by ammonium, despite the high ambient nitrate concentrations, with nitrate consumption apparently inhibited by the elevated levels of ammonium. Averaging the daily rates of euphotic zone NPP measured in this study (2.1 g C m^{-2} day^{-1}) with previous summertime estimates (3.5 g C m^{-2} day^{-1}) suggests an annual average rate of NPP for the southern Benguela upwelling system between the coast and 1,000 m isobath of ~1,015 g C m^{-2} y^{-1}. This is lower than has been proposed previously, but a seasonally resolved dataset is required to validate this.

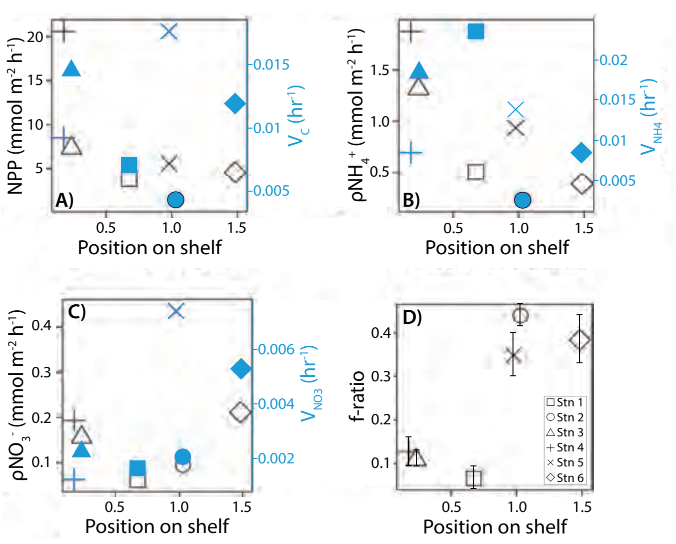


Figure 14: A) NPP and the specific carbon fixation rate (V_C), B) ρNH_4^+ and the specific NH_4^+ uptake rate (V_{NH4}), C) $_\rho NO^{3-}$ and the specific NO_3^- uptake rate (V_{NO3}) and D) the f-ratio (an indication of the strength of the biological pump) at the PP IEP stations. Open black symbols indicate the transport rates (primary y-axis) and solid blue symbols show the specific uptake rates (secondary y-axis). Shelf position was calculated by dividing the distance of each station from shore by the width of the continental shelf at the station latitude; higher shelf positions indicate stations further offshore.

Table 4: Primary production (PP) stations and the parameters sampled per station during IEP: SB cruises of 2017

Station	NPP	N uptake	Nitrification	Nutrients	Ammonium	Nitrate isotopes	DG and N_2O
KML05	Feb, May, Aug, Nov	Feb, May, Aug, Nov	May, Aug, Nov				
NML04	Feb, May, Aug, Nov	Feb, May, Aug, Nov	May, Aug, Nov				
SHBML01	Feb, May, Aug, Nov	Feb, May, Aug, Nov	May, Aug, Nov				
SHBML14	Feb, May, Aug, Nov	Feb, May, Aug, Nov	May, Aug, Nov				
SHBML12	Feb, May, Aug, Nov	Feb, May, Aug, Nov	May, Aug				
SML09	Feb, May, Aug	Feb, May, Aug	May, Aug				
All SHBML stns							Feb, Aug
All stations*				Feb, May, Aug, Nov	Feb, May, Aug, Nov	Feb, May, Aug, Nov	

**Note that in Nov, the SML was not sampled due to inclement weather*

ZOOPLANKTON

Plankton refers to the small organisms in a water body that cannot actively swim against a current, but float and drift in the water. The animals in this drifting group are referred to as zooplankton. Presented here is work on mesozooplankton, animals of 200–2,000 µm (0.2–2 mm) in size.

Data collected from the SHBML (see Fig. 8) over the past 17 years (2000-2016) are presented here for the following locations: inshore, midshelf to offshore, and the area with permanent low-oxygen bottom water. Each mesozooplankton sample was carefully poured into a graduated glass measuring cylinder and allowed to settle for 24 hours, after which the exact volume in cubic centimetres is recorded. This is the settled volume and a simple, albeit crude, estimate of the amount of zooplankton biomass in the water. Mesozooplankton are food for many animals such as larger crustaceans, squid, fish, and whales and as such play a significant role in the ecosystem. Mesozooplankton biomass accordingly provides an index of how much food is available to the upper levels of the ecosystem. For the SHBML time-series, mesozooplankton biomass was highest inshore, declining significantly over the midshelf to offshore region (Fig. 15). While the low-oxygen stations might be considered vulnerable to a drop in biomass due to limited oxygen availability, they do not display a low biomass of mesozooplankton.

A group of small crustaceans (animals with a chitinous exoskeleton) typically between 1–3 mm in adult length, called copepods, are usually the dominant members of the mesozooplankton. Copepod abundance along the SHBML shows a similar pattern to zooplankton biomass: high inshore and low offshore values. This suggests copepods may be the dominant group, except at station 1 (Fig. 15). This most-inshore station displays very high biomass, a pattern not mimicked in terms of copepod abundance, suggesting dominance of either a different zooplankton group, or smaller copepods (e.g. *Oithona*, see next section) compared to stations further offshore. These data will have to be more fully analysed to determine species dominance and under what conditions this may vary.

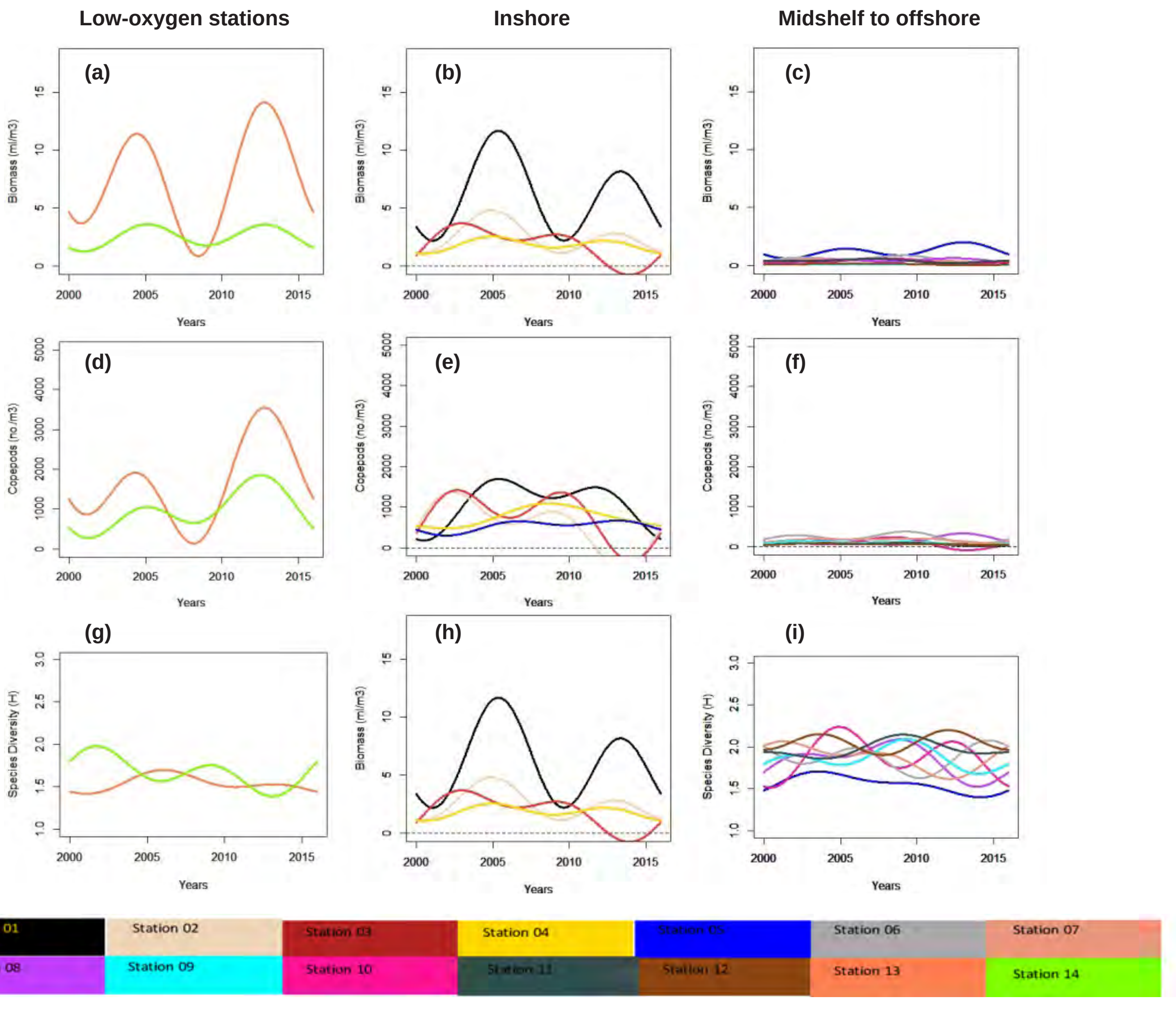


Figure 15: Functional data analysis was used to determine the following patterns: biomass of mesozooplankton along SHBML at (a) low-oxygen stations 13 and 14, (b) inshore stations 1 – 4, (c) midshelf to offshore stations 5 – 12; copepod abundance along SHBML at (d) low-oxygen stations 13 and 14, (e) inshore stations 1 – 4, (f) midshelf to offshore stations 5 – 12; species diversity of mesozooplankton along SHBML at (g) low-oxygen stations 13 and 14, (h) inshore stations 1 – 4 and (i) midshelf to offshore stations 5 – 12. See Fig. 8 for map with station numbering.

As mentioned above, diversity is seen as the master indicator of ecosystem health. Due to the position of mesozooplankton in the ecosystem influencing and being influenced by both top-down (being eaten) and bottom-up (environmental) factors, it is extremely important to monitor changes in their diversity. Species diversity has two separate components: the number of species present and their relative abundances. The Shannon-Wiener index *(H)* was used here to measure diversity. Values of this diversity index for plankton communities typically fall between 1.5 (low) and 3.5 (high). The species diversity along the SHBML (Fig. 15) is low but this is typical of upwelling systems. Inshore and low-oxygen stations are less diverse than midshelf to offshore areas. Diversity at stations 1 – 3, on occasion, dips below 1.5, which may be indicative of a severe environmental change. Further analyses are required to elucidate the influence of environmental forcing on species diversity.

One of the smallest copepods to occur off the west coast is *Oithona*. This genus occurs in the same pattern as the general copepod group with an inshore high and midshelf to offshore low abundance (Fig. 16). This is an organism known to be a cold-water species and has been used as an indicator of ocean warming, i.e. if the water gets to a certain temperature the numbers of *Oithona* decrease because of the cold temperature range that is best suited for their survival (optimal range).

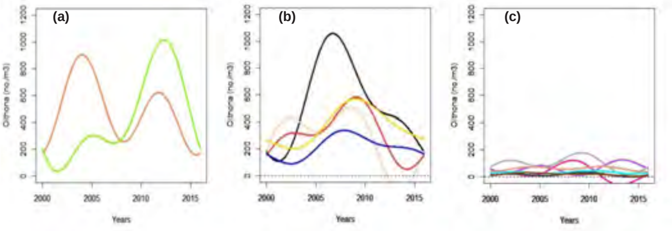


Figure 16: Functional data analysis was used to determine the abundance of Oithona *along SHBML at (a) low-oxygen stations 13 and 14, (b) inshore stations 1 – 4, (c) midshelf to offshore stations 5 – 12.*

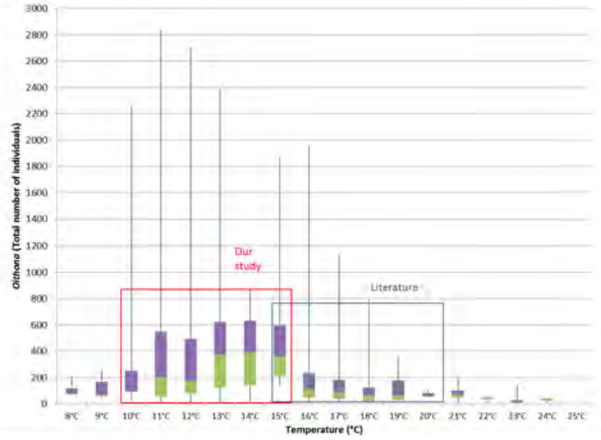


Figure 17: Boxplot showing the abundance of Oithona *vs sea surface temperature (SST) with the red box showing the optimal range of* Oithona *off the west coast of South Africa and the blue box showing the optimal range of* Oithona *(from the literature).*

Using 574 data points, the total and average abundances of *Oithona* were plotted against SST (range: 8 - 25°C; Figs 17 and 18). In previous studies elsewhere, temperatures measured were not as cold as in the Benguela. High abundances of *Oithona* in these areas are being used as an indicator of water <20°C but water temperatures there were ≥15°C. Our study shows similar results with higher abundance of *Oithona* in water temperatures of 15 - 21°C compared to >22°C but our optimal range is 9 - 15°C showing that *Oithona* is truly a cold-water species.

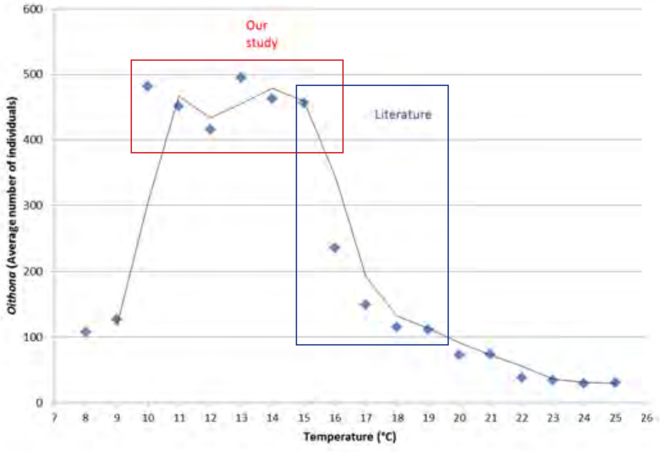


Figure 18: Average abundance of Oithona *vs sea surface temperature (SST) with a moving average trendline; the red box shows the optimal range of* Oithona *off the west coast of South Africa and the blue box shows the optimal range of* Oithona *(from the literature).*

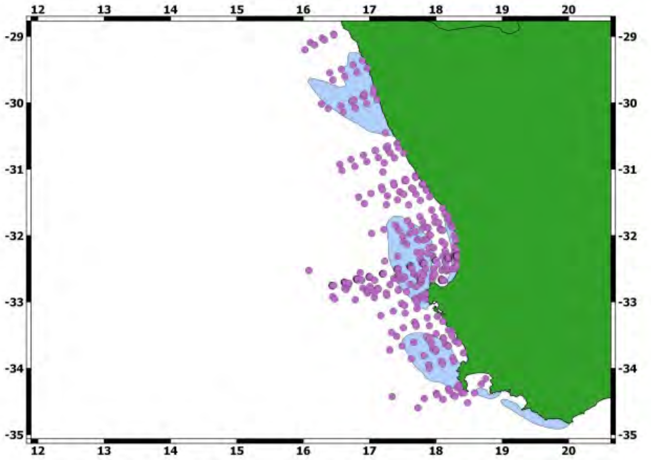


Figure 19: A subset of West Coast data used to determine the relationship between Oithona *and SST*

As an indicator (proxy) of water temperature the abundance of *Oithona* can be monitored with a decline or increase in this species possibly signalling an increase or decrease, respectively, in water temperature. To determine if this assumption holds true, a subset of West Coast data (1996 – 2012; Fig. 19) was used to explore the relationship between abundance of *Oithona* (as a proxy of water temperature) and the actual water temperature for each year.

Figure 20 shows the relationship between annual average water temperature and abundance of *Oithona*. SST ranged between 8°C and 21°C with an overall average of 14.6°C±2.0252°C. These temperatures are within the optimum range of the cold- water *Oithona* and are typical of the southern Benguela. *Oithona* abundance ranged from 1 to 2833 individuals per annum with an average of

378.4±463.4. Such a large standard deviation is indicative of high variability, but the overall trend indicates a slight increase in water temperature over the time-series with an associated decrease in *Oithona* abundance. This inverse relationship suggests it may be possible to use *Oithona* abundance as an indicator of ocean temperature variability (warming/cooling) in the southern Benguela.

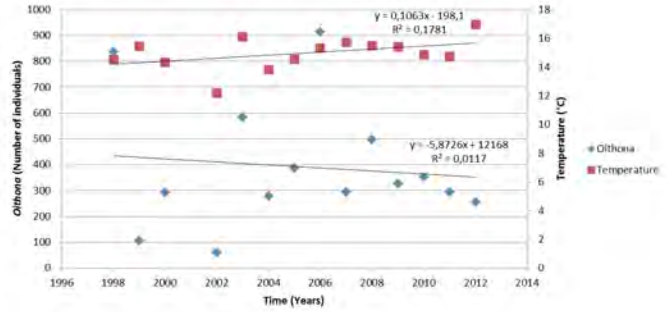


Figure 20: Average abundance of Oithona *vs sea surface temperature (SST) off the west coast of South Africa, from 1996 to 2012, using linear trends*

SEABIRDS

While chemistry and plankton indices are useful to indicate short-term environmental change, larger animals like seabirds and whales show changes over a longer time scale. Much of the documented information is from island-based records, with no baseline information about at-sea abundance and distribution of these species.

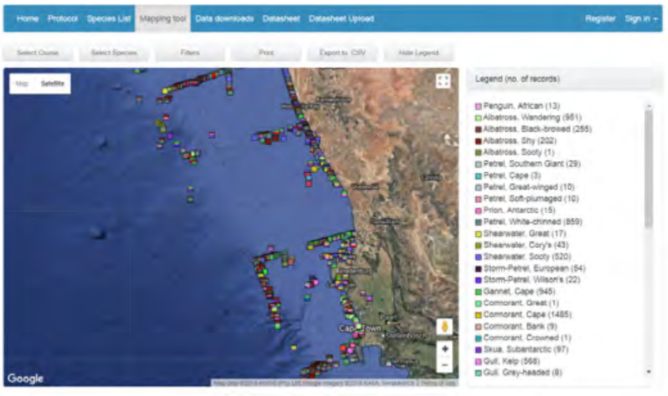


Figure 21: Open-source online tool showing IEP: SB seabird at-sea data; data are freely accessible from http://seabirds.saeon.ac.za/

The Atlas of Seabirds at Sea (AS@S) is a collaboration between BirdLife South Africa, the South African Environmental Observation Network (SAEON) and DEA: O&C, which makes significant vessel time, including the IEP:SB, available to seabird observers. AS@S uses 'citizen scientists' to collect baseline information on seabird at-sea distribution and abundance. The data are collected according to a standard protocol and uploaded via a website to be immediately incorporated into the AS@S database. The database is open-access and is fast becoming a valuable resource for understanding the abundance, seasonality and distribution of seabirds at sea, and for examining how these have changed through recent decades (Fig. 21). Several conservation applications of the AS@S data are envisaged, such as aiding in defining marine spatial planning, 'ocean hotspots' (where seabirds congregate in high numbers) and identifying important areas for highly threatened species.

Table 5: Available data for the at-sea distribution of seabirds for the southern Benguela

Species	2015	2016	2017
Albatross, Atlantic Yellow-nosed	23	8	22
Albatross, Indian Yellow-nosed	1	10	0
Albatross, Black-browed	7	85	159
Albatross, Shy	0	51	136
Albatross, Sooty	0	0	1
Albatross, Unidentified	0	0	10
Cormorant, Cape	1335	1065	359
Cormorant, Crowned	0	0	1
Cormorant, Great	1	0	0
Cormorant, White-breasted	0	4	0
Cormorant, Unidentified	13	0	0
Gannet, Cape	470	270	573
Gull, Grey-headed	0	1	7
Gull, Hartlaub's	0	52	48
Gull, Kelp	261	162	320
Gull, Sabine's	0	0	5
Gull, Unidentified	9	0	1
Pelican, Great White	0	0	6
Penguin, African	7	8	4
Petrel, Great-winged	2	1	4
Petrel, Northern Giant	0	1	13
Petrel, Pintado/Cape	2	24	25
Petrel, Soft-plumaged	0	5	5
Petrel, Unidentified Giant	0	0	15
Prion, Antarctic	0	15	0
Petrel, White-chinned	7	242	578
Seabird, Unidentified	1	0	2
Shearwater, Fleshfooted	0	1	0
Shearwater, Cory's	0	2	41
Shearwater, Great	14	0	3
Shearwater, Manx	0	0	2
Shearwater, Sooty	0	155	352
Shearwater, Unidentified	0	0	2
Skua, Subantarctic	0	50	29
Storm-Petrel, European	0	54	0
Storm-Petrel, Wilson's	0	8	14
Tern, Arctic	0	25	0
Tern, Antarctic	0	7	4
Tern, Common	0	0	262
Tern, Greater Crested	0	0	95
Tern, Swift	42	0	0
Tern, Unidentified	943	5	20
Tern, Unidentified - Common/ Antarctic/Arctic	0	106	0
	3138	**2417**	**3118**

Flying and sitting birds were identified and recorded within 10 minute-length transects from the bridge, only while the vessel was in motion (± 10 knots). Date, time, weather conditions and beginning and end GPS points were recorded. The count area was determined using the angles of observation (90°) and distance from the ship (between 50 m and 300 m) for each transect. Each bird encountered, excluding 'ship-followers' or birds that appeared attracted to the vessel, was identified and recorded. All the records were made during the day.

In total 3,138; 2,417; and 3,118 seabirds, either flying or sitting on the water, were observed respectively during 2015, 2016 and 2017 (Table 5). The observations showed that in all three years seabird species were dominated by flocks of Cape Cormorants, which could often be seen catching fish in the water below a flock of hovering Terns, the second dominant species in 2015. This was followed by Cape Gannets that appeared in greater or lesser abundance each year (Table 5).

Several species of albatrosses and petrels were also identified foraging alongside the ship, i.e. Atlantic and Indian Yellow-nosed, Black-bowed, Shy, and Wandering Albatrosses albeit in negligible numbers. These species are known to breed in the sub-Antarctic region, and although their contribution was minimal compared to the resident birds, it is important to note their presence. White-chinned Petrels were also recorded in low numbers in 2015 but with higher numbers in 2016 and 2017, 242 and 578 respectively.

Kelp Gulls often followed the ship and 8%, 6% and 10% were observed in 2015, 2016 and 2017 respectively. Furthermore, Sub-Antarctic Skuas (2% and 0.9 %) were also seen following the ship in 2016 and 2017 respectively. The only penguin species observed was the African Penguin, which occurred in all years although in low numbers. The African Penguin is currently listed as Endangered on The Red List of Birds and no longer has a colony on the west coast of South Africa.

Other species recorded were Swift Tern, Great Shearwater, Sabine's Gull and Sacred Ibis, while White-chinned Petrels and African Penguins were seen in 2014. Cape Cormorants were mostly recorded at different times of the day and were seen flying from inshore to the offshore region in large numbers in the early morning, returning to their roosts in the late afternoon.

MARINE MAMMALS

At-sea distribution of cetaceans as determined from the IEP: SB cetacean observation data indicates a predominantly coastal distribution (Fig. 22). This is consistent with data collected by DEA during dedicated cetacean cruises. However, cetacean data collected further offshore during the IEP cruises yielded distribution data usually not collected during dedicated cruises.

Of great significance is the information collected on the Humpback Whale. These long-lived, internationally protected animals were thought to be in our waters only during their migration period, i.e. for a few months of the year. However, through the IEP: SB it has been shown that Humpback Whales occur throughout the year (Table 6) and possibly in two groups, viz. a northern and a southern group. This information will aid conservation and management strategies both nationally and internationally.

Figure 22: At-sea distribution of whales during IEP: SB cruises in 2017; Red=May; Green= August; Yellow=November

Eight species of Cetacea were recorded since this project was initiated (Table 6). Of these, the Long-finned Pilot Whale, a large oceanic species of dolphin, is rarely spotted coastally. This species was sighted and photographed during the May 2017 cruise. Its conservation status is classified nationally as 'Least Concern' in The Red List of Mammals of South Africa (Endangered Wildlife Trust, 2017). With little research effort on this species, the IEP: SB coverage provided a much needed data point of a live specimen. The species is data deficient in South African waters, mainly due to their offshore distribution.

Table 6: Baseline information on the number of different whales off the west coast of South Africa

Species	May Estimate	August Estimate	November Estimate
Humpback whale	241	69	48
Dusky Dolphin	75	3	
Southern Right Whale	75	3	
Heaviside's Dolphin		61	
Common dolphin (long beak)	1	4	
Minke whale		1	
Sperm whale		2	
Pilot whale (long finned)	1		
Unidentified Dolphin	160		
Unidentified Whale	116	35	1
TOTAL	**669**	**178**	**49**

In which way have we innovated?

Part of the IEP: SB initiative is to ensure the provision of reliable data with a quick turnaround for converting data into information. This has involved the use of different, and sometimes new, techniques (Table 7).

Table 7: Technical innovation on the IEP: SB

Variable	Technique	Outcome
Hydrography	Buoys: structures placed underwater by dive team (Fig. 23)	Increased frequency of data = more accurate information generated
Chemistry	underway pCO2: instrument connected to the ship to collect continuous data	Increased frequency of data = more accurate information generated; gathering of information not previously collected by DEA: O&C.
Microbes	Genetics and flow cytometer: uses light to analyse samples	Allows gathering of information previously not collected by DEA: O&C routinely.
Phytoplankton	Collection, preservation and analysis methods revised; flow cytometer	Ensures sample integrity; shortened turnaround time for information from 2 years to ~ 3 months post-cruise.
Primary Production	Stable isotope analysis: biogeochemical technique	Allows gathering of information not previously collected by DEA: O&C.
Micro-zooplankton	Collection, preservation and analysis methods revised; FlowCam: instrument using images to analyse sample.	Ensures sample integrity; shortened turnaround time for information from 2 years to ~ 6 months post-cruise.
Meso-zooplankton	ZooScan: instrument using images to analyse sample	Shortened turnaround time for information from 2 years to ~ 1.5 months post-cruise.
Benthos	SkiMonkey: camera system taking images/videos of the ocean floor	Allows gathering of information not previously collected by DEA: O&C.

Figure 23: DEA: O&C dive team aboard DEA's research vessel Algoa *deploying moorings for the research buoys to be attached (SHBML, November 2017)*

Conclusion, and the way forward

The growing baseline information gathered during the IEP: SB shows that the southern Benguela displays differences, between north and south, inshore and offshore, and seasonally. This is not novel, but tangibly defining these differences is what our baseline studies are aiming to do. Baseline information is vital for developing appropriate yet simple indices for operational environmental monitoring.

With the preliminary information gathered we have learnt that while the southern Benguela is highly productive it may not be sequestering as much carbon as it has the potential to do so. This requires further investigation as it is the main mechanism off the South African coast to remove this greenhouse gas (CO2) from the atmosphere. Low pH and plankton species diversity are of concern in the inshore areas and should be monitored operationally as this may affect coastal resilience and livelihoods. Our estimates of diversity could supplement current national estimates to incorporate the very small yet important ecosystem-structuring organisms. Our data also show that these small organisms live in specific areas. Due to their role in creating a healthy, functioning ecosystem their presence needs to be taken into account when defining ecologically important areas.

Over the next two years, using all information generated, we will develop an end-to-end ecosystem baseline framework of the southern Benguela. Integrated indices will be defined that contribute to this framework and can be used to monitor environmental change, health, resilience and stability, thereby contributing information to management-defined priorities.

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23. RESEARCH VESSELS RV *ALGOA* AND MV *SA AGULHAS II*: OPERATIONS, MANAGEMENT AND SCHEDULE DURING FINANCIAL YEAR 2017/18

The DEA has two research vessels that are managed under the Branch: Oceans and Coasts, namely MV *SA Agulhas II* and RV *Algoa*. Both vessels have equally important but different purposes.

The MV *SA Agulhas II* (Fig. 1), commissioned in 2012, is used for both logistics and research purposes. This vessel provides logistical support during the annual relief and supply voyages to South Africa's remote research bases situated at the Sub-Antarctic Islands Marion and Gough, and its Antarctic research station SANAE-IV. During these voyages the MV *SA Agulhas II* delivers the overwintering teams as well as their supplies for a year. Participants in these take-over voyages include research scientists and technicians (both land- and ship-based), engineers, cooks, construction workers, etc. who form a support team for the overwintering team. Furthermore, during take-over cruises, the ship-based scientists onboard the MV *SA Agulhas II* conduct marine research on transit to the research stations and in pre-determined areas in the vicinity of the respective islands.

In addition to these annual relief voyages during the past financial year (FY 2017/18), the MV *SA Agulhas II* conducted: (i) the first Africa-led regional scientific research cruise of the Second International Indian Ocean Expedition (IIOE-2) along the south and east coasts of Africa between Cape Town, South Africa and Dar es Salaam, Tanzania, and (ii) a local 'SEAmester' II cruise in the Southern Ocean, South Africa's Class Afloat initiative introducing marine science as an applied and cross-disciplinary field to students across South Africa, funded by the Department of Science and Technology. These cruises were specialized training cruises accounting for almost 40 days at sea. These cruises contributed towards the discrepancy between the vessel's planned (160) and actual (187) days at sea. In summary, the MV *SA Agulhas II* spent 51% of the year (187 days) at sea (Table 1), which is adequate for a ship of its caliber and purpose.

On the other hand, the RV *Algoa* (Fig. 2) is a 'workhorse' that undertakes multi-disciplinary research cruises along the South African coast, managed under the CD: Oceans and Coastal Research. Although it is not common for a 45-year old research vessel to do such an extensive amount of work, the RV *Algoa* has successfully completed all scheduled work. Due to her age, the RV *Algoa* needs to be serviced frequently and maintained at high costs to comply with international maritime laws, such that ca 23% of the allocated ship management costs was spent in dry-dock. A breakdown of the management and operational costs of both vessels for FY 2017/18 are presented in Table 1.

Table 1: Summary estimated operational and management costs (in ZAR) for the RV *Algoa* and MV *SA Agulhas II* during FY 2017/2018

	RV *Algoa*	MV *SA Agulhas II*
Year commissioned in RSA	1993	2012
Length (m) x breadth (m)	52.55 x 10.8	134.2 x 22
Gross tonnage (tons)	759	12 897
Crew and management costs	23 401 920	42 451 320
Technical costs (machinery, equipment, etc.)	13 785 989	19 665 535
Vessel operating costs (fuel, oil, lubricants)	29 498 080	87 619 054
Dry-docking	15 712 091	-
Daily rates (Average)	160 000	360 000
Total ship management costs	52 900 000	130 070 374
Days at sea	147	187
Days in port	218	178

In total, 11 cruises (including scientific equipment and ship gear trial cruises) were undertaken onboard the RV *Algoa* during the period April 2017-March 2018. Disciplines covered included Physical, Chemical and Biological Oceanography, Benthic Biodiversity and Marine Top Predators (whales, seabirds). The RV *Algoa*'s schedule for FY 2017/18 is presented in Figure 1.

The ever-increasing demand for ship's time, and the management and operational costs associated with the aged RV *Algoa* are not sustainable. Since the major portion of costs is used for maintenance rather than operational at-sea costs, DEA is currently exploring vessel replacement options.

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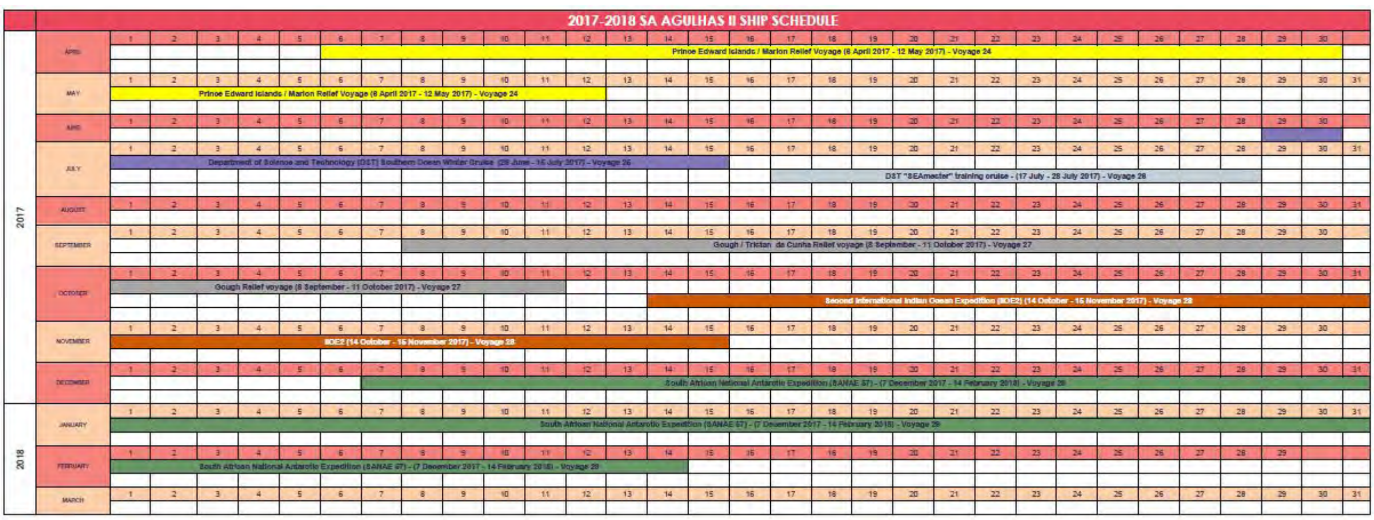

Figure 1: The MV SA Agulhas II *(top) and her schedule of cruises during FY 2017/18 (bottom)*

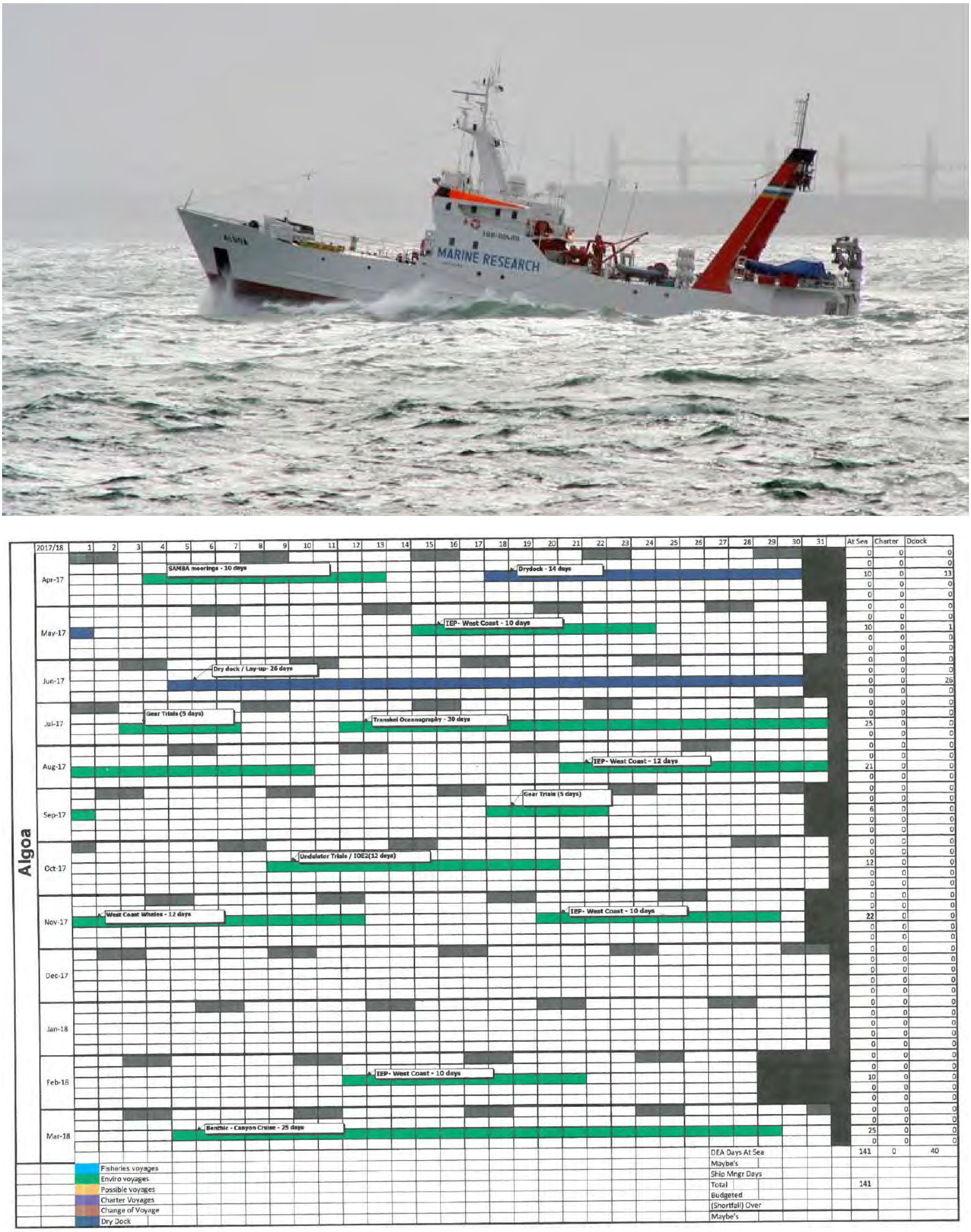

Figure 2: The RV Algoa *(top) and her schedule of cruises, indicating the disciplines undertaken onboard during FY 2017/18 (bottom)*

PUBLICATIONS 2016-2017

DEA staff contributed to 22 peer-reviewed papers in 2016 and to 32 in 2017. The number of contributions by DEA staff to conferences, symposia and workshops amounted to 159. Just over half of this total was dominated by posters and oral papers presented a four major regional or international symposia as follows: 28 such contributions were presented at the *Benguela Symposium: Opportunity, Challenge and Change* held in Cape Town during November 2016; 36 at the *16th Southern African Marine Science Symposium* (SAMSS) in Port Elizabeth during July 2017; 6 at the 10th *Western Indian Ocean Marine Science Association (WIOMSA) Scientific Symposium* in Dar es Salaam, Tanzania during October-November 2017; and 10 at the *2017 Joint International Association for the Physical Sciences of the Oceans (IAPSO) – International Association of Meteorology and Atmospheric Sciences (IAMAS) – International Association of Geomagnetism and Aeronomy (IAGA) Assembly* held in Cape Town during August-September 2017.

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