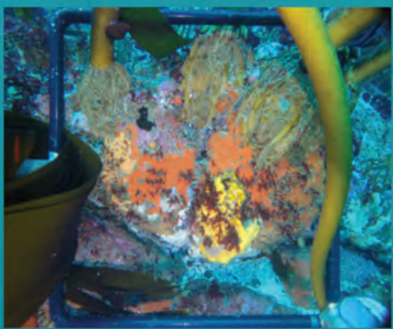
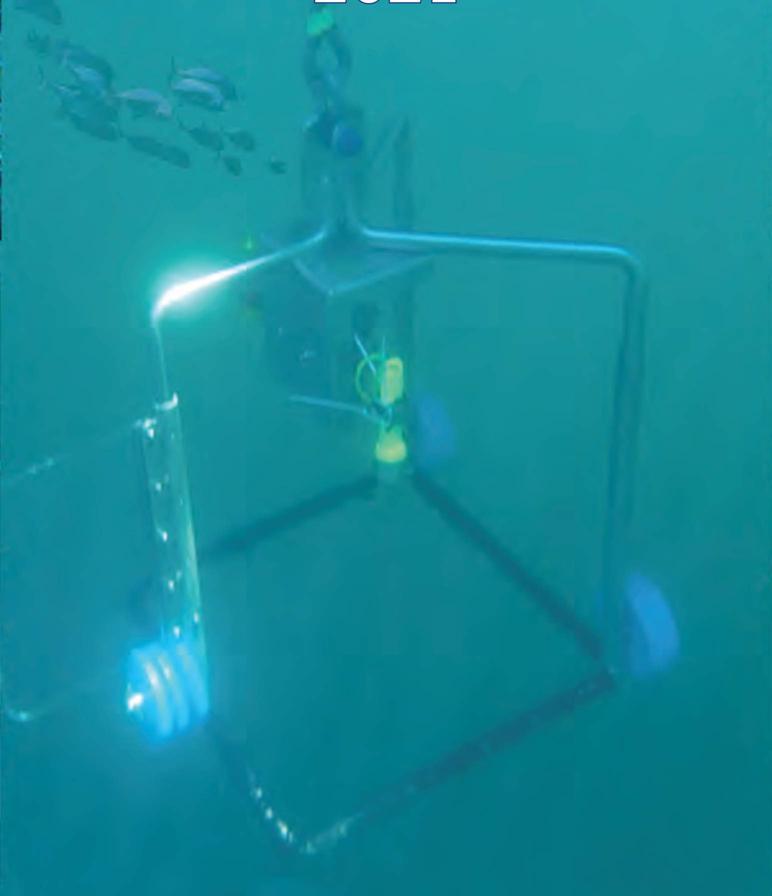
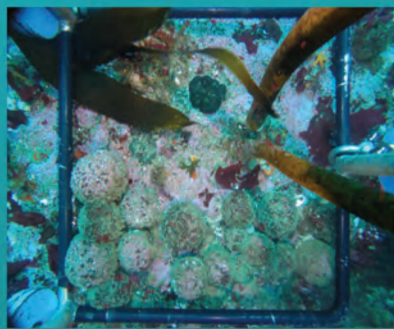
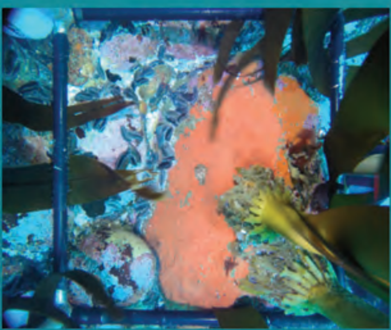
Oceans and Coasts

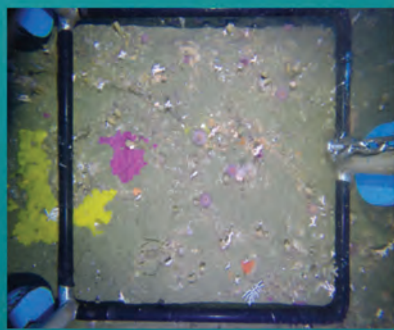
Annual Science Report 2021

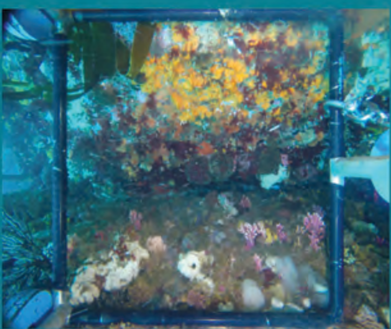












Report No. 21

forestry, fisheries & the environment
Department:
Forestry, Fisheries and the Environment
REPUBLIC OF SOUTH AFRICA

Oceans and Coasts

Annual Science Report

2021

Department of Forestry, Fisheries and the Environment

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ACKNOWLEDGEMENTS

Most staff members of the Chief Directorate: Oceans & Coastal Research contributed in one way or another to the contents and production of the Oceans and Coasts Annual Science Report, 2021. The Department wishes to express its appreciation to the many other agencies that have contributed to the work presented in this report. The at-sea, ship-based work and many coastal field trips for data collection and community engagements undertaken by the Branch: Oceans and Coasts are facilitated by the Chief Directorate's science managers and made possible by the various units within the Branch's Corporate Management Services and Financial Management Services.

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COVER IMAGE: Compilation created by Gavin Tutt, with original photographs provided by Darrell Anders and Tanya Haupt

RP13/2022
ISBN: 978-0-621-49993-3

SUMMARY AND PERSPECTIVES FOR DECISION AND POLICY MAKERS

Introduction

The oceans constitute the largest component of the Earth's system and play a crucial role in stabilising climate and supporting life on earth and human well-being. However, as indicated by the United Nations' First World Ocean Assessment (released in 2016), much of the world's ocean is already severely degraded, with changes and losses in the structure, function and benefits from marine systems. Furthermore, with projected climate changes and human population growth, stressors on the ocean will intensify, not only in localised coastal regions with high human population densities, but also at a global scale. Thus, the Decade of Ocean Sciences for Sustainable Development (2021–2030) was proclaimed by the United Nations to support efforts to reverse the cycle of decline in ocean health and create improved conditions for sustainable development of ocean economies while conserving the ecosystem. In this decade, all countries are therefore urged to maintain and increase science investments in describing and understanding the ocean and the role it plays in the planet system.

The Oceans and Coasts Annual Science Report (ASR), 2021, presents evidence of South Africa's ongoing investment in this regard. The 33 contributions (termed report cards) herein, report on research, monitoring and related activities of the Department's Chief Directorate: Oceans and Coastal Research (OC Research), in support of the Departmental mandate of conserving and managing South Africa's coastal and marine environment. The various science programmes of OC Research focus on a number of fundamental physical, chemical and biological aspects of oceans and coasts (including estuaries), and are guided by a medium- to long-term ecological research and monitoring plan that was developed for the period 2016–2030. This plan is focused mainly on describing and documenting marine and coastal biodiversity and complex ecosystem functioning and processes, to support the Department's ocean mandate.

Thus, the data and information products generated from the research and monitoring activities must ultimately be useful for informing managers and policy makers. Underlying the plan is the understanding that the most valuable scientific data collections or observations are those taken within a long-term context. However, within a framework of long-term programmatic work aimed at providing continuous or sustained observations (monitoring) and descriptions of key aspects of the marine environment, some shorter-term research elements are conducted as projects. Such projects allow for deeper understanding of marine ecosystems and processes. It is against this backdrop of continuous applied shallow and deep ocean science that staff are able to provide immediate and relevant management advice and recommendations. Such management advice is required on a range of historical issues such as fishing or shipping and new and emerging issues such as seismic surveys or where to place the increasing number of undersea internet cables.

As in the previous issue (2020), the contributions to this report are presented under three main sections. These are: Monitoring Programmes (9 report cards); Research Highlights (16 report cards), showcasing research achievements for 2021; and Technological Innovation and Training (8 report cards), which was previously called Tools and Technologies. In addition to showcasing technological developments in support of OC Research's various programmes, the latter section now incorporates evidence of training and capacity building, another key element of the research and monitoring plan. At the end of the report is the list of scientific outputs for 2021, including peer-reviewed publications and other products that reflect both the volume and quality of work accomplished by OC Research in 2021.

Overview of the 2021 Annual Science Report

From the perspective of OC Research, there are a few issues that stand out in 2021. One of these is the alarming continuance of the decline in African penguin numbers, as debate on a management intervention aimed at securing sufficient foraging fish availability in range of important breeding colonies has been drawn out. Report cards in this issue demonstrate the continuing penguin decline and the link with forage fish availability. Just as important as securing urgent management interventions, arguably, is understanding why there does not seem to be enough prey to sustain the population. In our coastal waters, it has proven difficult to disentangle effects of fishing from environmental changes on the prey resources of penguins and other top predator species. For macaroni and eastern rockhopper penguins at the Prince Edward Islands (also reported on), this is less problematic because fishing activity can be ruled out as the cause of short- to long-term variability in their foraging and demographic parameters. However, to properly understand the causes of declines in Threatened seabird populations in South Africa, we will need to advance our understanding of the oceanographic and atmospheric variations. Such understanding of the physical environment allows for insights into factors that drive (or are symptomatic of) spatial and temporal changes in the productivity of marine ecosystems, and their implications for higher trophic levels. In this issue, updates are provided for monitoring programmes on several Essential Ocean Variables (EOVs) including currents and bottom temperature (both on the Prince Edward Islands shelf), upwelling-favourable winds, ocean acidity, chlorophyll *a* concentration and microplankton community structure and diversity (all off the west coast of South Africa).

Another standout issue in 2021 was the occurrence of extreme events, in the form of large-scale mortality events affecting seals and seabirds, both referred to in report cards in this issue. Several hundred dead or dying seals were recorded on the west coast between September and December. Inspection of the environmental variables at the time revealed no obvious trigger for the seal mortality. Pathological and toxicological testing of tissue samples also yielded no clear results, but given the malnourished condition of most affected seals, reduced availability of prey is considered likely to be the primary cause of the die-off. Seal mortality events of the scale observed in 2021 are unprecedented in South Africa in recent decades, but are not that uncommon in the Northern Benguela (Namibia), where the ecosystem is in a depressed state having undergone trophic changes that are thought to be irreversible. The event may therefore provide a warning sign of an ecosystem shift associated with lower trophic level changes, underlining the importance of continuing and enhancing the monitoring of oceanographic and biological EOVs in the region. It also underlines the utility of top predators such as seals as bio-indicators of ecosystem variability and change.

Unrelated to the seal mortality, nearly 20,000 birds, most of them Endangered Cape cormorants, were recorded to have died from avian influenza in the Western Cape. The scale of these two mortality events has highlighted the need for preparedness, to be able to detect mortality events at an early stage, diagnose them, prevent spread in the case of epidemics, and to collect sufficient, adequate scientific data. In both cases, the mortality events provided learning experiences that will lead to improved responses to further events. In the case of seals, a monitoring protocol is now under development. For the seabirds, the development of an app allowing for coherent data reporting and capture to the Department's Oceans and Coastal Management Information System (OCIMS) is described in this report. The app enabled effective tracking of the spread of the epidemic and assisted the coordination of responses, highlighting the benefits of utilizing innovative technology to facilitate the capture and flow of information in such events.

A range of research highlights are presented in the report. These include findings of studies on oceanographic processes in the Southern Ocean, the southern Benguela and the east coast of South Africa. One of these report cards describes the oceanographic triggers for South Africa's "sardine run" on the east coast, an event that is considered to be one of Earth's most spectacular marine migrations, and that has considerable ecological and economic significance. Further research highlights report on studies as diverse as zooplankton barcoding, estuarine communities, coastal pollution, marine ecotourism, marine protected area effectiveness, ocean governance, wildlife interactions and tracking of animal movements at sea. An experimental study shows how reducing pH of seawater compromises the immune system of Cape urchins, drawing attention to the types of challenges that this creature can be expected to face under the two-fold increase in acidity of surface ocean waters that is anticipated by the end of this century. A decline in the biomass of this species is likely to have knock-on ecosystem effects for other species that are dependent on it such as rock lobsters (as prey) and juvenile abalone (for refuge), while kelp bed ecosystems are also likely to be altered if these important grazers are reduced. These types of studies are essential for forecasting the effects of predicted oceanic or atmospheric changes on the structure and functioning of our marine ecosystems, and their potential social and economic implications.

A range of innovative tools or technologies that have been developed in support of research, monitoring, data capture or dissemination are reported on. In addition to the OCIMS app that was developed for responding to the avian influenza epidemic, the development of a new web portal has improved capacity for data information and discovery in the Department's Marine Information Management System. Technology for underway sampling and measurement of EOVs including temperature and plankton are described, as well as testing of a sophisticated ocean model, in terms of its efficacy in simulating the variability and distribution of certain oceanographic processes in our waters. There is a widespread lack of adequate long-term *in situ* observations at appropriate spatial scales to identify and monitor oceanographic processes and features and their impacts through the water column. Towards countering the lack of observations to some degree, the global community has, in recent decades, become reliant on ocean models to elucidate such changes and variations. The southeast coast of South Africa is one example of a region where limited *in situ* observations have severely constrained our understanding of ecosystem variability and change, necessitating the use of ocean models to generate improved knowledge. However, as described in the report card, it is very important to recognise that the accuracy of all ocean models is highly dependent on the amount and quality of *in situ* and satellite observations used to parameterise them. This further highlights the critical need for continued and improved *in situ* observations and investments in ship and satellite technologies for coastal countries like South Africa that are bordered by large ocean spaces.

The report concludes with report cards on two training workshops spearheaded by OC Research for the Indian Ocean region. Ironically, the need to conduct these workshops through a virtual platform, due to physical restrictions for the ongoing global Covid-19 pandemic, increased the participation and impact of these workshops. In addition to training and capacity building, these workshops brought about enhanced regional networking, collaboration and mentorship opportunities, and moved the region closer to adoption of standardised methodology and data collection protocols that will enable region-wide comparisons and integrated data analyses. Imagery from one of these training initiatives inspired the cover image of this report.

Concluding remarks

The range of report cards to the Annual Science Report, 2021, attests to OC Research's dedication to development of staff capacity, with contributions accepted from students, interns, scientists, technical staff and senior managers. Also evident is the Chief Directorate's openness to collaborating with other organisations, including partnering with the various national marine research nodes in other departments and universities, and with regional and international institutions. No less than 17 external organisations are represented in the list of contributors to this report. As an index of research productivity, the number of peer-reviewed publications achieved in 2021 showed a pleasing increase relative to previous years. Also gratifying is that three-quarters of these outputs were accepted by international publications, attesting not only to the volume of work, but also the significant contribution of South African scientists to global knowledge.

At the time of writing this, Parties to the Convention on Biological Diversity (CBD) are in the process of developing the Post-2020 Global Biodiversity Framework (GBF), which will set out an ambitious plan to implement broad-based action to bring about a transformation in society's relationship with biodiversity. The overarching aim of this plan is to ensure that by 2050 the CBD's vision of "living in harmony with nature" is achieved. Several Parties (including South Africa) and organisations have been lobbying for better inclusion of marine and coastal biodiversity considerations in the GBF, compared to the CBD's Strategic Action Plan, 2011–2020, which the GBF will replace. Greater representation of the oceans and coasts in the goals, targets and monitoring framework of the GBF will increase the investment in marine and coastal monitoring and research that is required of Parties, including for tracking the success of the framework's implementation. The monitoring programmes, research output and technological innovations that are described in this report demonstrate that South Africa, with OC Research at the forefront, is well placed to address this challenge.

1 . CONTINUING DECLINE OF THE AFRICAN PENGUIN POPULATION IN SOUTH AFRICA

The African penguin *Spheniscus demersus* (Fig.1) was once South Africa's most abundant seabird. It is Africa's only penguin species and is endemic to the Benguela upwelling region, as this species breeds only in Namibia and South Africa. In a 2019 assessment, it was estimated that the overall population had declined by 68% between 1991 (when there were ca. 42,500 breeding pairs) and 2019. Based on that assessment, the Endangered status of the population, first conferred in 2010, was upheld. However, with inclusion of more recent counts up to 2021 (ca. 10,500 breeding pairs), the overall decline since 1991 has increased to 73%. Should this decline persist, the African penguin population may reach a critical point of no return.

In two of the three geographical regions in which they occur in South Africa, i.e. the west coast (Western Cape colonies to the north of Cape Town) and southwest coast (Western Cape colonies south and east of Cape Town), the ongoing decline in numbers has stabilised during this assessment, slowing from ca. 9%, to ca. 3% per year in the past decade (Figs. 2A and B). However, the ca. 3,300 breeding pairs lost in these regions between 2019 and 2021, represents almost 25% of the remaining South African population. In Algoa Bay in the Eastern Cape, colonies have been in decline for the past 30 years (Fig. 2C). Recently (2019), the long-term decline in this region was measured at 66%, but in just over two years, the decline since 2001 has increased to 82%. The magnitude of this decline would be sufficient to qualify the species to be up-listed to Critically Endangered (CR) if the IUCN Red List criterion A2 were applied at a regional level. The decline was exacerbated by the loss of more than 50% of the breeding pairs from the St Croix Island colony. This has been directly linked to food scarcity, with numerous chicks observed to be malnourished, and high chick mortality.

Increased ship traffic, seismic surveys and oil leaks or spills associated with ship-to-ship bunkering are other threats to African penguins in this region, but prey shortages are considered to be the main cause of the decline. Two of the main prey species of the African penguin, sardine and anchovy (forage fish) have rarely been detected in recent diet samples collected at the colony. Local and regional availability or abundances of forage fish have been linked to breeding pair numbers of penguins, the ratio of adult to immature penguins, and foraging performance. Urgent management recommendations that may benefit the African penguin population include improving food availability, for example by preventing or reducing fishing effort in key foraging areas, and mitigating the impacts of oil spills.

Authors: Makhado AB, Dyer BM, Masotla MJ, Upfold L (OC Research)

Figure 1. African penguins, photo from the DFFE photo library.

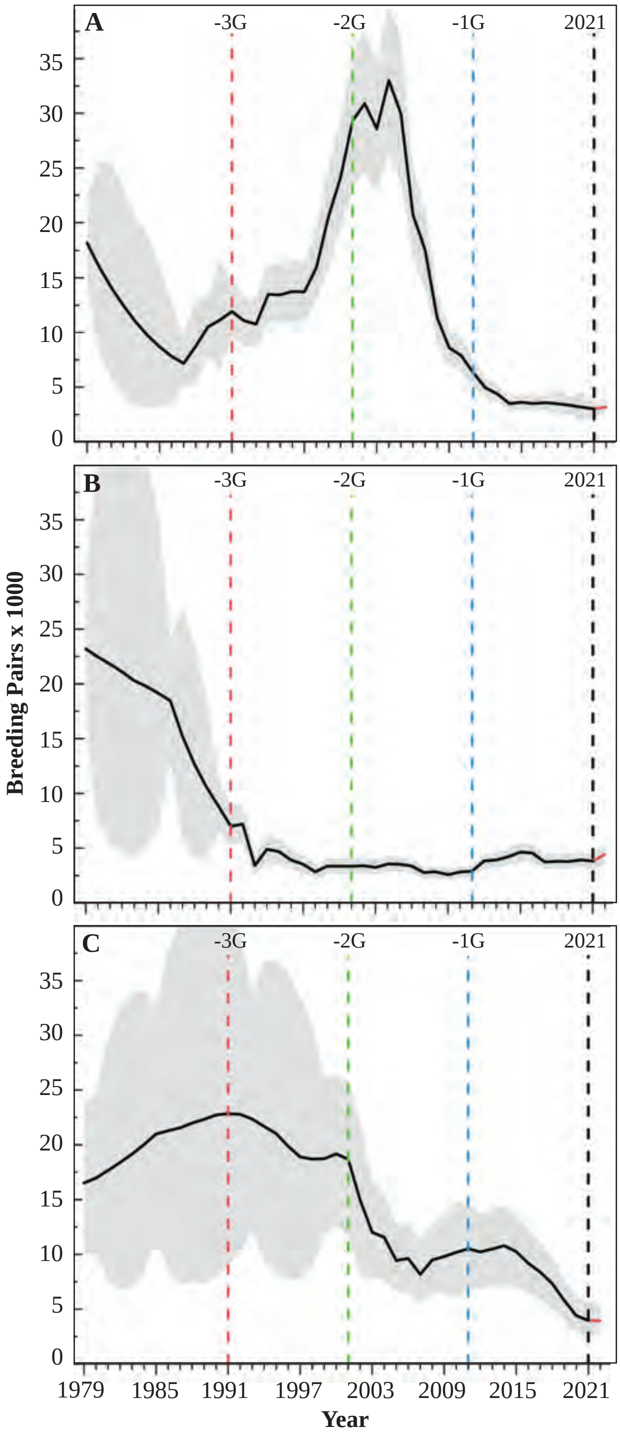

Figure 2. Changes in the African penguin breeding population since 1979 within three regions of South Africa: (A) the west coast, (B) the southwest coast, (C) the Eastern Cape. The solid line is the number of breeding pairs based on nest counts, the grey polygon represents variability in the probability of the estimate, and dashed lines are the 10-year generation lengths up to 2021.

2. LONG-TERM VARIATION IN THE POPULATION AND REPRODUCTIVE PERFORMANCE OF MACARONI AND EASTERN ROCKHOPPER PENGUINS AT MARION ISLAND (1994–2019)

Penguins have a conservative life history, characterised by long generation times and high adult survival rates. Research on their population dynamics can provide insights into variability and change in ocean systems. The Prince Edward Islands (PEIs; consisting of Prince Edward and Marion Islands) in the Southern Ocean supports ca. 300,000 and 80,000 breeding pairs of macaroni *Eudyptes chrysolophus* and eastern rockhopper *E. filholi* penguins, respectively. Long-term monitoring by DFFE shows that macaroni penguin numbers at Marion Island declined by 45% from 1994–2019, at a rate of 1.9% per year. Eastern rockhopper penguins declined even more over the same period, by 66% at a rate of 13% per year. However, their numbers then stabilised, fluctuating between 55,000 and 85,000 pairs (Fig. 1).

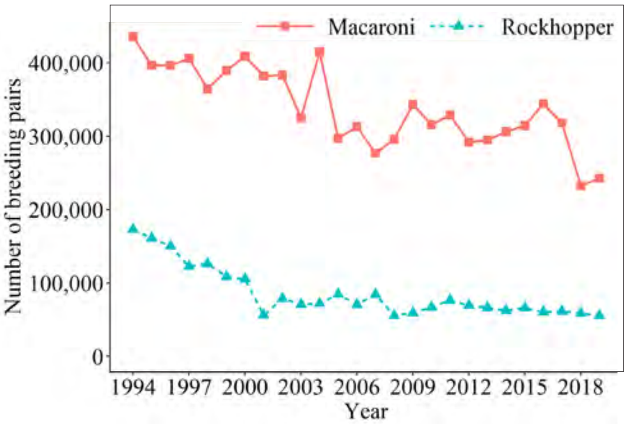

Figure 1. Time series of the number of breeding pairs of macaroni and eastern rockhopper penguins at Marion Island, 1994–2019.

The mass of breeding adults upon arrival at the islands was sampled each year. No consistent long-term trend was found for macaroni penguins (Fig. 2A), but there was a decreasing trend in the average mass of both male and female eastern rockhopper penguins from 1994 to the mid-2000s (Fig. 2B). This may explain the declining population trend of eastern rockhopper penguins until 2001. Their decline stabilised in the mid-2000s before increasing to the end of the time series. Average mass on arrival of breeding pairs was positively correlated with breeding success for both species ($r \geq 0.34$, $p < 0.1$). The two species, males in particular, undergo long fasting periods during breeding, with these results underscoring the importance of pre-breeding condition for breeding success, and hence the importance of winter foraging conditions.

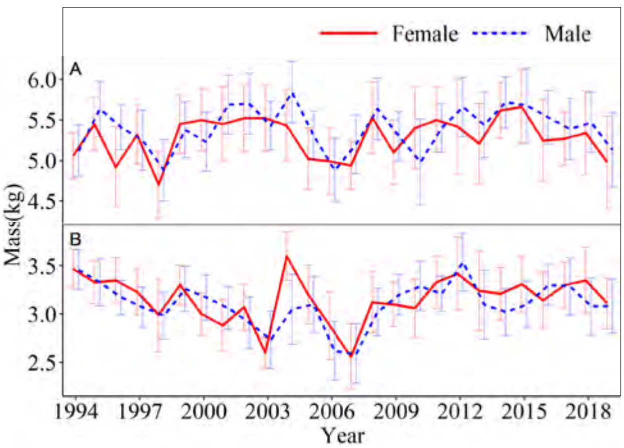

Figure 2. Time series of the average mass on arrival of (A) macaroni and (B) eastern rockhopper penguins at Marion Island, 1994–2019.

There was no obvious long-term trend in breeding success of macaroni penguins (measured by successful rearing of chicks to fledgings) but breeding success of eastern rockhopper penguins increased over the latter part of the time series (Fig. 3), corresponding with stabilisation of population numbers. For macaroni penguins, there was a positive correlation between average annual fledgling mass and breeding success ($r = 0.40$, $p = 0.04$), while for eastern rockhopper penguins this relationship was weak ($r = 0.12$, $p = 0.57$). This underscores the importance of efficient foraging during the chick rearing period, to produce larger, fatter fledglings with good chances of survival and recruitment back into the breeding population.

The high interannual variability in breeding success is therefore likely affected by the environmental conditions that affect prey availability and thus feeding efficiency, both before and during the breeding period. Long-term changes in environmental conditions that may have affected feeding conditions for the *Eudyptes* spp. at the PEIs include a southward shift in the sub-Antarctic front and an increase in sea surface temperatures recorded around Marion Island since the mid-20th century.

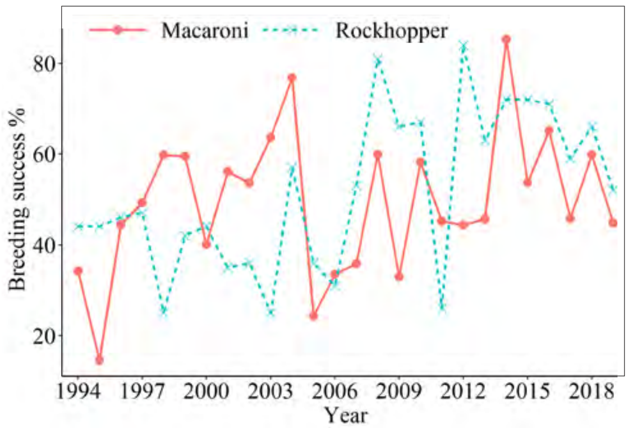

Figure 3. Time series of the breeding success (chicks fledged per breeding pair) of macaroni and eastern rockhopper penguins at Marion Island, 1994–2019.

Authors: Dakwa FE (UCT, OC Research), Ryan P (UCT), Crawford RJM, Dyer BM, Masotla MM (OC Research), Makhado AB (OCResearch, UCT)

3. LONG-TERM OBSERVATIONS OF CURRENTS ON THE PRINCE EDWARD ISLANDS SHELF

The Prince Edward Islands (PEIs) are a remote island archipelago in the sub-Antarctic zone of the Southern Ocean. The islands provide crucial breeding habitat for vast populations of seabirds and marine mammals. It is well-known that there are strong links between the oceanography and biological communities, but observations have been largely limited to periods coinciding with annual relief voyages to re-supply the research base. Since April 2014, two moorings on the inter-island shelf (Fig. 1) have been providing continuous measurements of water column current speed and direction in the region.

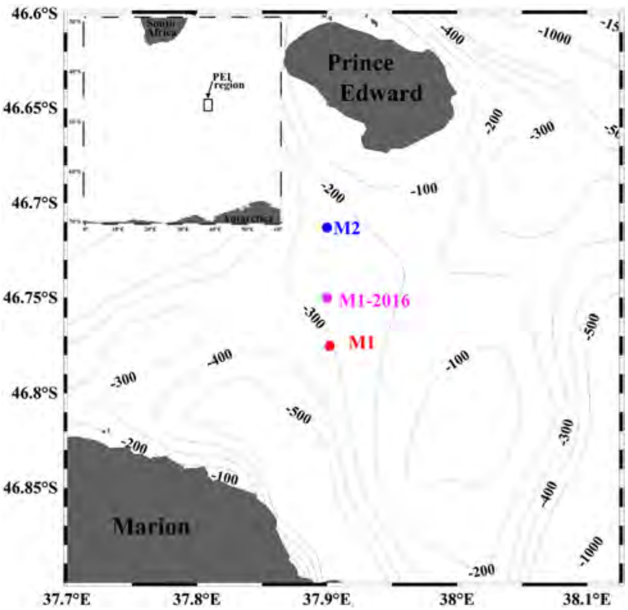

Figure 1. Bathymetry on the PEI shelf. Mooring positions M1 and M2 are shown in red and blue, respectively. The pink dot shows the location of M1 between April 2016 and April 2017.

During 2014–2021, daily mean current speeds at mooring M1 ranged between 0.01 and 50.90 cm s^{-1}, while those at M2 varied from 0.03 to 67.32 cm s^{-1} (Fig. 2). The eastward-flowing Antarctic Circumpolar Current results in much stronger zonal (east/west) than meridional (north/south) flow at the PEIs. A Taylor column (stationary anticyclonic circulation over the shelf) is indicated by westerly flow in the bottom waters at M2 (Fig. 2). This westerly flow is persistent throughout the time series, but can be enhanced or interrupted for short periods when fronts or mesoscale eddies interact with the island shelf. Retention of nutrients and biota by the Taylor column maintains enhanced productivity on the shelf, accounting for the high concentrations of marine biota at the PEIs.

Between May and July 2019, the close proximity of the southern branch of the sub-Antarctic Front (S-SAF) to the islands resulted in the strongest flow to date (>50 cm s^{-1}) at M2. A similar situation occurred between August and November 2020, when the S-SAF resulted in surface current speeds at M2 exceeding 40 cm s^{-1} (Fig. 2). During this period, currents in the upper 100 m were directed strongly southeastwards. This contrasts with the situation in winter 2019, when advection of shelf waters was strongly north- and northeastwards.

During the winter months between 2014 and 2019, data loss (vertical extensions of white shading interrupting the time series) was common in the upper 60 m at M2 (Fig. 2). This reflects the turbulent surface conditions driven by strong wind mixing associated with winter storms. Interestingly, during winter 2020, such data loss was not as evident, possibly suggesting less intense storm events than during previous years. This seems to be supported by the generally warmer bottom shelf waters in the inter-island region at this time (see Report 4).

Changes in the direction of current flow can be expected to influence the distribution of preferred prey, and hence the feeding patterns of seabirds and marine mammals breeding at the PEIs. Further detailed comparisons between currents and feeding behaviour, diet, and reproductive performance of selected predators are required to evaluate the impact of these changing flow dynamics on top predators.

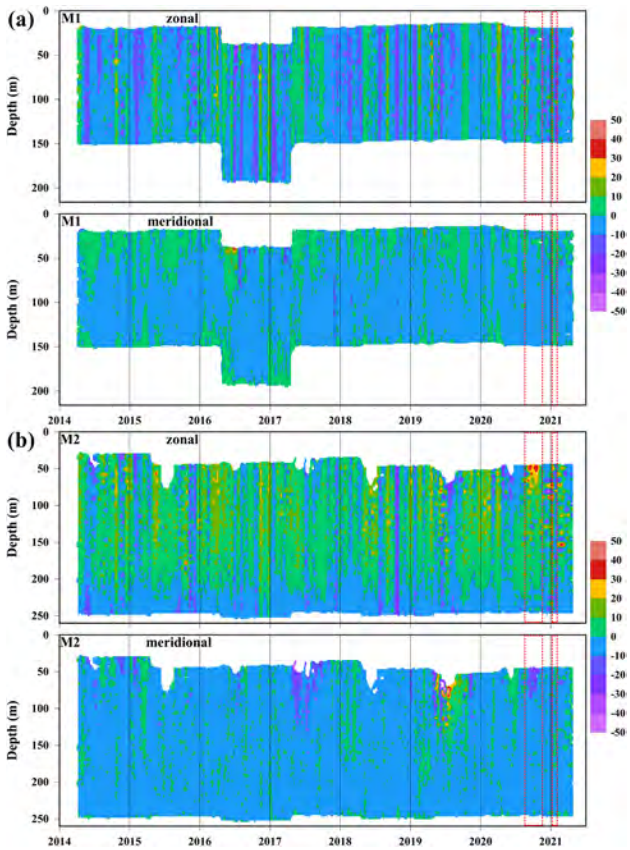

Figure 2. Daily mean zonal and meridional current components (cm s^{-1}) at (a) M1, and (b) M2. Positive values denote eastward (zonal) and northward (meridional) flow; negative values denote westward (zonal) and southward (meridional) flow. Dashed red lines show the period of strong eastward flow at M2 between August and November 2020. The period between January and February 2021 has also been marked with dashed red lines (see Report 4 for details on this event).

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4. LONG-TERM VARIABILITY IN BOTTOM TEMPERATURE ON THE PRINCE EDWARD ISLANDS SHELF

Despite their small size, the Prince Edward Islands (PEIs) provide crucial breeding habitat for vast populations of marine mammals and birds. Many of these animals depend strongly on the ambient oceanographic conditions at and around the islands. While annual relief voyages to re-supply the research base only allow hydrographic data collection during April/May each year, two moorings on the inter-island shelf (Fig. 1) have been providing continuous measurements of bottom temperature since 2014.

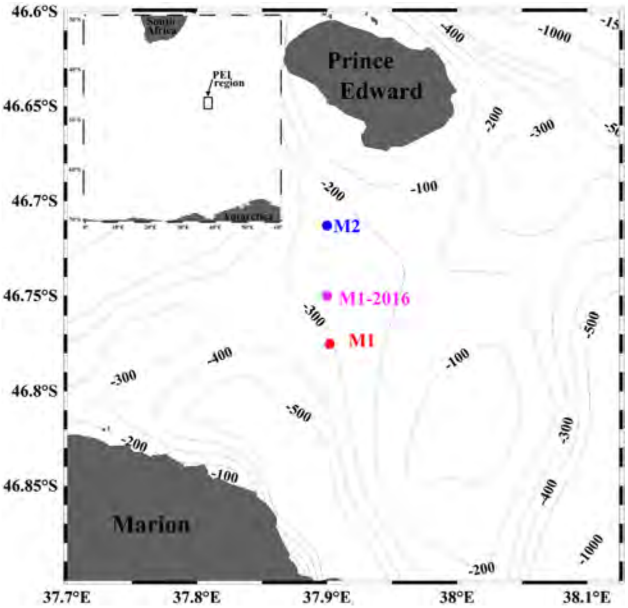

Figure 1. Bathymetry on the PEI shelf. Mooring positions M1 and M2 are shown in red and blue, respectively. The pink dot shows the location of M1 between April 2016 and April 2017.

Substantial daily, intra-, interseasonal and interannual variability was observed at both moorings, but bottom temperatures at the deeper mooring M2 (260 m depth) were consistently lower than those at M1 (174 m depth). On a seasonal scale, highest temperatures typically occur in autumn (March–May) and the lowest in spring (September–November). Meridional (north/south) meanders of the southern branch of the sub-Antarctic Front (S-SAF) resulted in lower temperatures when the S-SAF was north of the PEIs, and higher temperatures when the S-SAF was to the south.

Since January 2019, bottom temperatures have been mainly higher than the 7-year mean (Fig. 2). These elevated temperatures reflect a more southerly location of the S-SAF relative to the islands. Persistent strong northward flow at M2 (see Report 3) between May and October 2019 was associated with bottom temperatures that were 0.5–1.5°C above average (Fig. 2). In contrast, elevated current speeds observed at M2 (see Report 3) between August and November 2020 were associated with waters that were on average 0.5–1.0°C cooler than the 7-year mean (Fig. 2). A similar temperature decrease occurred during January and February 2021. Interestingly, there was no clear change in current speed during this cooling event (see Report 3).

Notably, bottom temperatures during late autumn and winter months (May–July) in 2020 were on average 0.5–1.0°C warmer than previous years (Fig. 3). Although generally warmer waters were expected due to the more southerly position of the S-SAF, such warming was not evident in 2019 (Fig. 2), when the S-SAF was also mainly south of the PEIs. This suggests less intense wind mixing and cooling during May–July 2020.

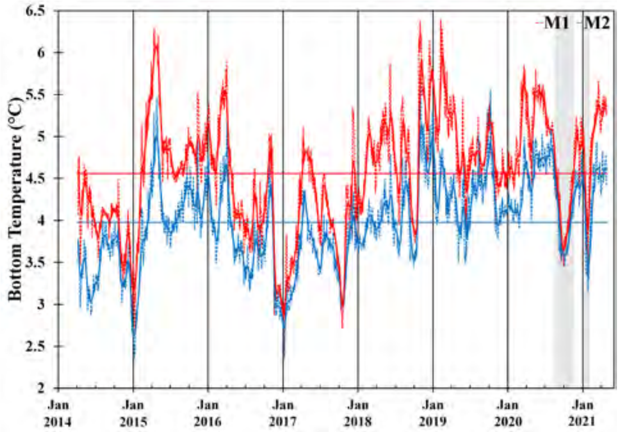

Figure 2. Daily mean bottom temperature (°C) at moorings M1 (red) and M2 (blue). Dashed lines indicate measurements while solid lines show low-pass filtered values. Horizontal lines show mean temperatures for each time series. Grey shading highlights cooling events between August and November 2020 and during January–February 2021.

Water temperatures influence geographical distributions of prey species on which the vast numbers of seabirds and marine mammals breeding at the PEIs depend. Temperature variations are thus likely to affect the distances that these animals have to travel from the islands to find food. This has consequences for time and energy spent foraging, for survival of young that are dependent on foraging adults, and ultimately for the reproductive success and abundance trends of these populations. The cooling events during late 2020 and early 2021 likely resulted in elevated productivity on the PEI shelf.

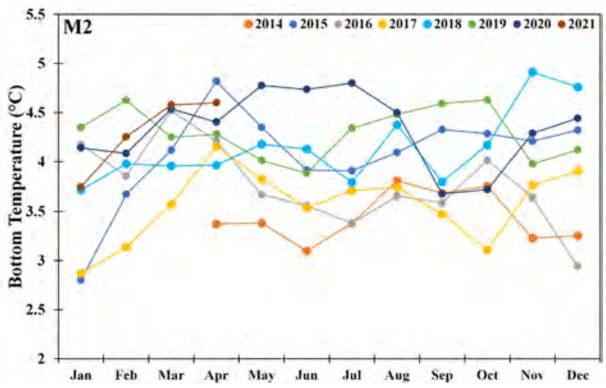

Figure 3. Monthly mean bottom temperature (°C) at mooring M2.

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5. VARIABILITY OF WIND SPEED AND DIRECTION ON THE WEST COAST OF SOUTH AFRICA

In upwelling systems, ocean productivity along the coast is largely influenced by wind-controlled processes. Coastal upwelling is generally defined by cold and nutrient-rich sea surface water that occurs in summer. In the Southern Benguela Upwelling System (SBUS) on the west coast of South Africa, these cold waters are associated with the occurrence of strong southeasterly wind forcing, which is controlled by the seasonally varying latitudinal (north-south) migrations of the South Atlantic Atmospheric High Pressure System. Therefore, wind speed and direction are important variables for describing upwelling-related coastal features and monitoring long-term changes in coastal upwelling. In this report, daily *in situ* data obtained from Automatic Weather Stations (AWS) at Elands Bay and Cape Columbine over the period 2015–2022 (Fig. 1) are used to describe the variability of wind speed and direction at these locations.

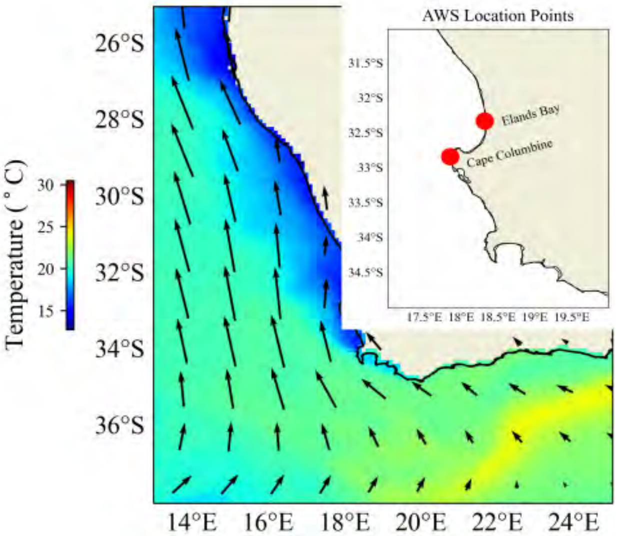

Figure 1. Map of satellite-derived sea surface temperature with wind vectors (10 m above sea level), averaged over the 2018–2021 period, depicting the average upwelling conditions during summer (December to February). The size of the wind vectors shows wind speed (longer/shorter vectors indicate stronger/weaker winds) and the wind direction is indicated by the direction of the vector. The map inset shows the locations of AWS stations at Elands Bay and Cape Columbine.

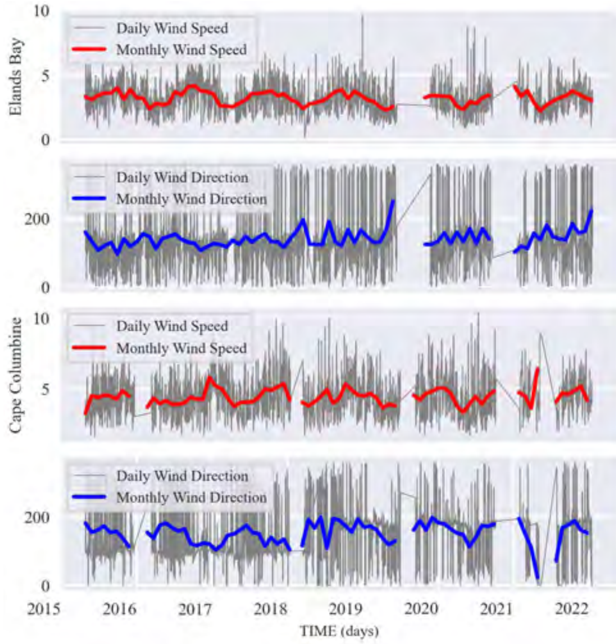

Figure 2. Time series (2015–2022) of daily (grey lines) and monthly (bold lines) averages of wind speed (red) and wind direction (blue) at Elands Bay (top) and Cape Columbine (bottom). Northerly, easterly, southerly and westerly winds are represented by 0/360°, 90°, 180° and 270°. Gaps indicate periods when data was corrupted or not available.

Figure 1 shows typical upwelling conditions in the SBUS during summer, with southeasterly winds (black vectors) prevailing and sea surface temperatures as low as ca. 14°C inshore, with warmer (ca. 25°C) water further offshore. While daily averages (grey lines) of wind speed and direction from the AWS at Elands Bay and Cape Columbine show large variability, monthly averages (red and blue lines respectively) indicate strong seasonality (Fig. 2). During summer, upwelling-favourable (southeasterly) winds are strongest (>5 m s^{-1} on average), while in winter, winds are weakest and from the west (Figs. 2 and 3). In general, wind speed at Elands Bay seems to be weaker than at Cape Columbine. Thus, upwelling is generally greater at Cape Columbine.

Over the past five years, the strongest summer-autumn winds were observed in 2017, implying that upwelling was most intense during this year. At Cape Columbine, these winds were ca. 1 m s^{-1} higher than the five-year average. In Jan–Feb 2021, winds at Elands Bay were ca. 0.5 m s^{-1} higher than the five-year average (Fig. 3). These results show that AWS are providing valuable information to enhance our understanding of short-term, localised upwelling variations.

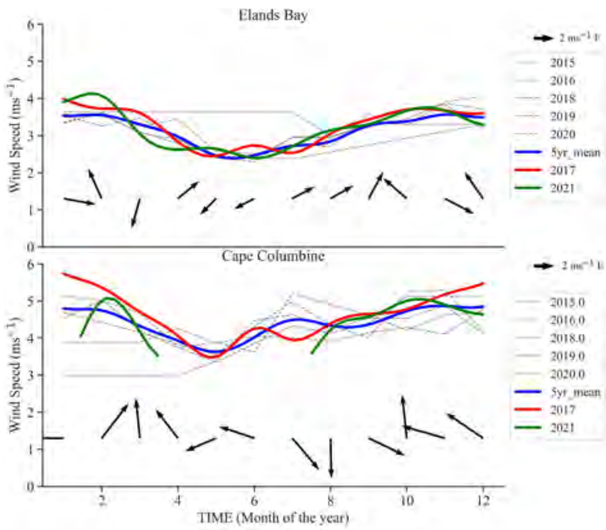

Figure 3. Annual variability of daily wind speed at Elands Bay (top) and Cape Columbine (bottom). The 2017 data are highlighted in red, the 2021 values are indicated in green, and the five-year (2016–2021) mean is shown in blue. Black vectors indicate the monthly average wind strength and direction.

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6. LONG-TERM OCEAN ACIDIFICATION TRENDS IN ST HELENA BAY

Coastal upwelling regimes inshore of Eastern Boundary Currents continue to be the most biologically productive ecosystems in the global ocean. However, changes resulting from human activities have already begun to emerge in these regions. Among these, carbon dioxide (CO_2) derived from fossil fuel combustion is lowering the pH and aragonite saturation state (Ωarag) levels in seawater. The reduction in Ωarag, a measure of the availability of calcium carbonate ($CaCO_3$), is detrimental for calcifying marine organisms such as corals, pteropods, molluscs and foraminiferans. These organisms are unable to develop their shells or skeletal structures when seawater is under-saturated with respect to $CaCO_3$ (Ωarag <1). St Helena Bay is the most productive region of the southern Benguela and is an important nursery area for pelagic fish. It is also an area that is subject to hypoxia and anoxia, which has occasionally severely impacted marine resources.

Dissolved inorganic carbon and total alkalinity observations, collected quarterly from 2013 to 2019, were used as a baseline to reconstruct a 20-year record (2000–2019) of surface pH and Ωarag. Extended Multiple Linear Regression (eMLR) was applied to monthly averages of reanalysis surface temperature and salinity (0.25° spatial resolution), chlorophyll *a* (4 km spatial resolution), and atmospheric CO_2. Here we present time series of eMLR reconstructed surface pH and Ωarag at Stations 3, 7, and 12 of the SHBML (Fig.1).

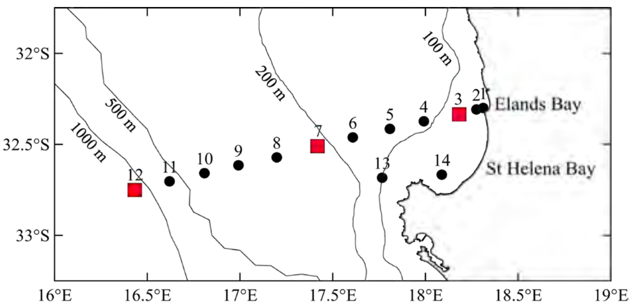

Figure 1. Map showing Stations 3, 7, and 12 (red squares) of the St Helena Bay Monitoring Line (SHBML).

Figure 2 shows that over the 2000–2019 period, surface pH and Ωarag in the inner shelf region (Station 3) declined from 7.91 to 7.81 and 1.89 to 1.52, respectively. Surface pH and Ωarag at Station 7 (Fig. 3) declined from 8.07 to 7.96 and 2.69 to 2.19, respectively. In the outer shelf region (Station 12), surface pH and Ωarag declined from 8.17 to 8.06 and 3.47 to 2.80, respectively (Fig. 4). These decreasing trends were all statistically significant.

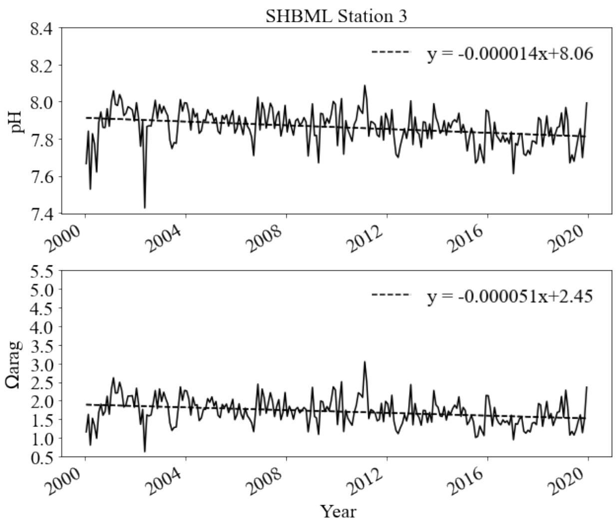

Figure 2. Time series (solid lines) and linear trends (dashed lines) of surface pH and aragonite saturation state (Ωarag) from 2000 to 2019 at Station 3 of the SHBML.

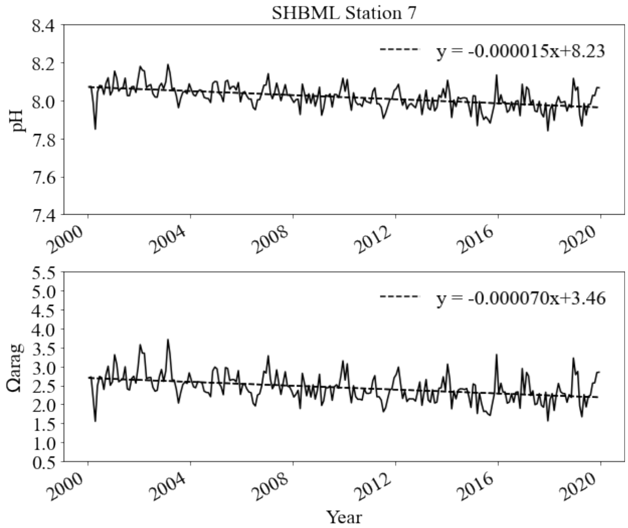

Figure 3. Time series (solid lines) and linear trends (dashed lines) of surface pH and aragonite saturation state (Ωarag) from 2000 to 2019 at Station 7 of the SHBML.

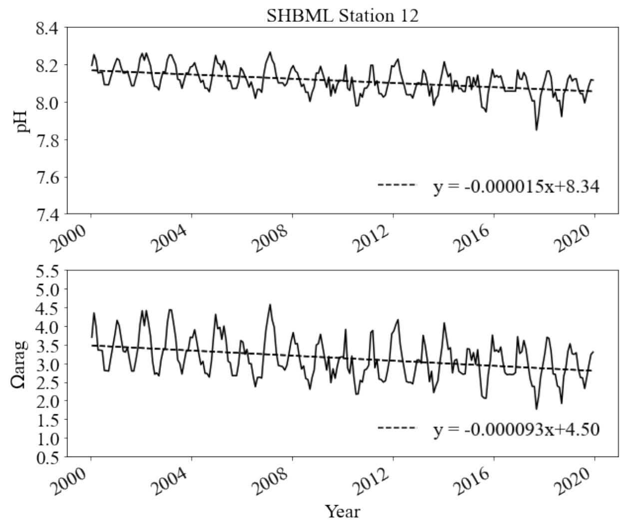

Figure 4. Time series (solid lines) and linear trends (dashed lines) of surface pH and aragonite saturation state (Ωarag) from 2000 to 2019 at Station 12 of the SHBML.

These results indicate that due to the uptake of anthropogenic CO_2 emissions by the oceans, surface waters on the west coast of South Africa are becoming more acidic (decreased pH) and more corrosive (decreased Ωarag). These changes need to be monitored due to their detrimental effects on calcifying marine organisms.

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7. CHLOROPHYLL VARIABILITY ON THE WEST AND SOUTH COASTS

Phytoplankton are crucial for a number of key marine processes, such as food web modulation, CO_2 exchanges, and the cycling of carbon and other nutrients. On the west and south coasts of southern Africa, the Benguela upwelling system and the Agulhas Bank are economically and ecologically significant as they host productive ecosystems with complex trophic structures that support numerous commercially harvested resources. To monitor environmental conditions, an index of chlorophyll *a* is computed by integrating satellite-derived surface values from the coast to the 1 mg m^{-3} level further offshore (Fig. 1).

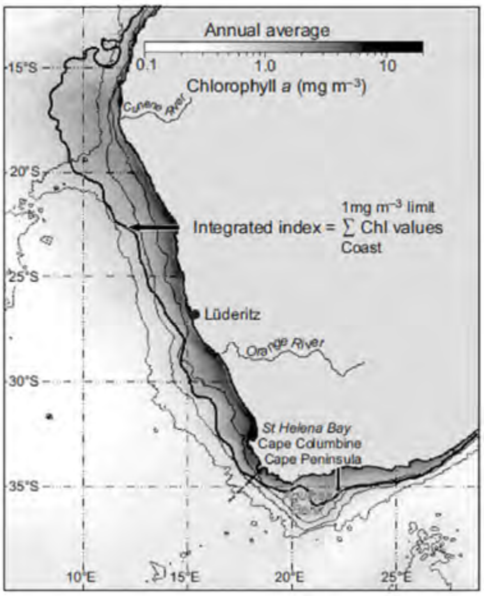

Figure 1. Annual average chlorophyll *a* concentration and location of the 1 mg m^{-3} contour (thick line).

Higher values are associated with greater phytoplankton biomass and a more productive ecosystem, while lower values indicate lower biomass and a less productive ecosystem. Highest index values are usually found off Namibia (16–26°S; Fig. 2). In 2018, biomass was the lowest since 2013. While phytoplankton biomass was elevated during 2019 and 2020, the 2021 values were once again lower. Persistent upwelling and offshore transport at Lüderitz (ca. 27°S) are typically associated with very low index values, but elevated values during summer over the past two years suggested less upwelling than usual. Along South Africa's west coast (28–34°S), index values are elevated around the Namaqualand, Cape Columbine and Cape Peninsula upwelling cells. Off Namaqualand (28.5–30°S), 2018 showed the highest values since 2013. While the 2019 and 2020 values were only slightly lower, index values during January to August 2021 were notably much lower, reflecting even less productive conditions. Along South Africa's south coast (18.5–29°E), index values are generally lower than on the west coast. During 2013-2021, the highest values occurred at 22°E in January–February 2014, with reduced peak biomass levels in subsequent years. Low values in 2016 suggested that this was the least productive year on the south coast during 2013–2021. While index values were elevated east of 22°E during 2019 and 2020, lower values overall in 2021 suggested lower productivity. The regionally-varying trends in productivity (a small but significant long-term increase in chlorophyll *a* off Namibia, and a decrease off the west coast of South Africa and on the Agulhas Bank) appear to have continued over the past year.

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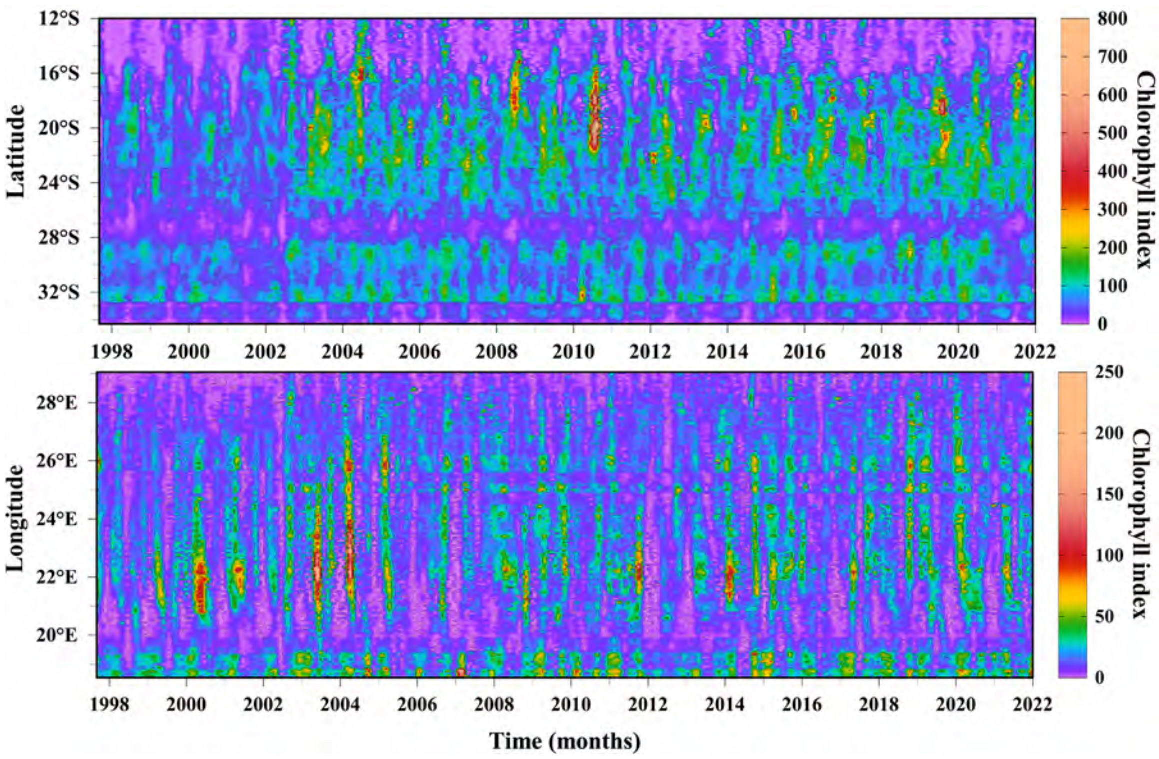

Figure 2. Monthly chlorophyll *a* indices (1997–2021) for the west coasts of Namibia and South Africa (top panel) and for South Africa's south coast (bottom panel).

8. SURFACE CHLOROPHYLL *A* CONCENTRATIONS ALONG THE ST HELENA BAY MONITORING LINE

St Helena Bay on the west coast of South Africa is one of the most productive areas of the Benguela ecosystem and has been the focus of environmental research and monitoring for several decades (Fig. 1). It is a well-known retention area, with significantly elevated plankton biomass compared to other areas off South Africa, and is an important region for many species such as small pelagic fish, hake, whales, and rock lobster.

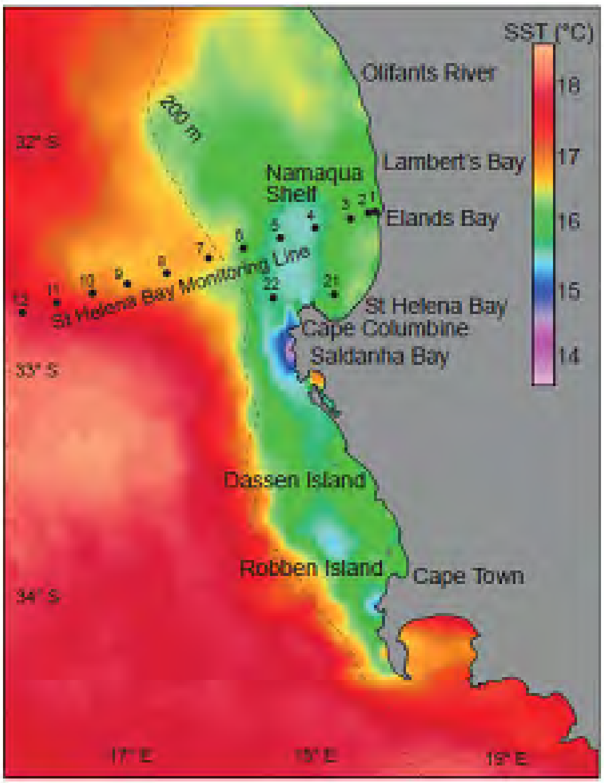

Figure 1. Map of sea surface temperature, illustrating cooler waters typically found inshore and warmer waters offshore, as well as the location of the St Helena Bay Monitoring Line.

Along the west coast, southeasterly winds drive upwelling, which transfers surface waters offshore, resulting in cool, nutrient-rich waters being uplifted to the surface from deeper depths. On a seasonal scale, higher chlorophyll *a* concentrations coincide with larger amounts of upwelling, which occur during the upwelling season (October–March) each year. Satellite-derived surface chlorophyll *a* clearly illustrate this seasonal signal, with maxima in spring/early summer and late summer/autumn (Fig. 2).

Higher chlorophyll *a* is usually associated with greater phytoplankton biomass and a more productive ecosystem, which largely results from the higher availability of nutrients in the upper layers during upwelling. In contrast, lower chlorophyll *a* indicates lower phytoplankton biomass and a less productive ecosystem, usually associated with less upwelling and nutrient availability in the surface layers during late autumn to early spring (April–September) each year. Generally, higher chlorophyll *a* occurs close to the coast and decreases with distance offshore (Fig. 2).

During 2015, high values (>20 mg m^{-3}) extended ca. 20 km offshore in autumn (March) and late spring/early summer (September to November). In contrast, values >20 mg m^{-3} were observed much closer to the coast during 2016–2019 and in 2021. During 2020, such high values extended about 10 km offshore in February-March. Elevated chlorophyll (>5 mg m^{-3}) extended approximately 110 km offshore in March 2015 – the farthest offshore extent for such elevated values since March 2010. In 2016, the farthest offshore extent (ca. 80 km) of values above 5 mg m^{-3} was observed in February and March, but in subsequent years, such values did not extend beyond 70 km offshore.

Chlorophyll *a* in 2017 was lower than in 2016 but remained elevated throughout the year. Even lower values in 2018 suggested a less productive ecosystem. Higher values for most of 2019 and 2020 suggested increased productivity. Peak values in 2019 occurred during April–August, suggesting a more productive autumn/winter than usual. In contrast, peak values in 2020 and 2021 occurred during March and October, in agreement with the usual seasonal maxima.

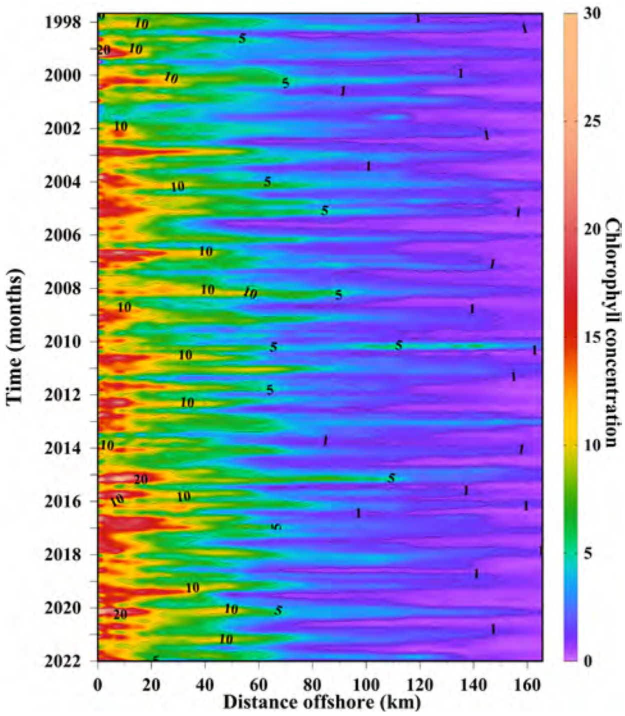

Figure 2. Time series of monthly chlorophyll *a* (mg m^{-3}) along the St Helena Bay Monitoring Line between 1997 and 2021.

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9. MICROPLANKTON COMMUNITY STRUCTURE AND DIVERSITY ALONG THE ST HELENA BAY MONITORING LINE

Microplankton are a diverse group of phyto- and zooplankton in the size range of 20–200 µm. They are important ecologically as they form the foundation of the food web, are instrumental in nutrient and carbon cycling, generate at least 50% of global oxygen, and facilitate energy flow to higher trophic levels. Due to their high sensitivity and rapid response to changes in the environment they can be used as indicators of climate change and eutrophication.

St Helena Bay is one of the most productive regions in the southern Benguela. The St Helena Bay Monitoring Line (SHBML; Fig. 1) is sampled quarterly to allow for seasonal microplankton variations to be monitored. Surface microplankton abundance and composition at each station were assessed using FlowCam imaging software. Dominant microplankton groups included diatoms, dinoflagellates, ciliates and copepod nauplii (Fig. 2). Differences in abundance were observed in August (winter) and November (spring) during 2018 and 2019 (Figs. 3 and 4).

Total microplankton abundance was high during spring 2019. Nearshore stations (up to Station 5) were generally more productive than offshore stations. Diatoms dominated the microplankton community in both winter and spring (Figs. 3 and 4). *Chaetoceros* species (spp.) were the most abundant diatoms during both years. Copepod nauplii and ciliates were more abundant at the offshore stations. Both tintinnids and dinoflagellates tended to be more prevalent during winter, especially at inshore stations. Some dinoflagellates have been shown to negatively affect invertebrate larvae, which could lead to negative impacts in the ecosystem. Further monitoring is necessary to assess long-term variability of microplankton in relation to the environment.

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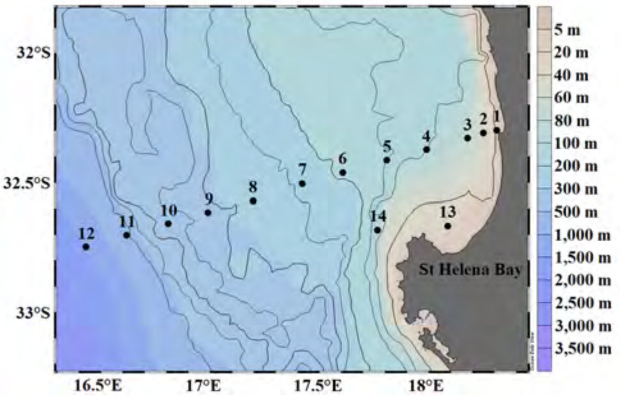

Figure 1. Map indicating sampling stations along the St Helena Bay Monitoring Line (SHBML). Black contours and shading indicate depth.

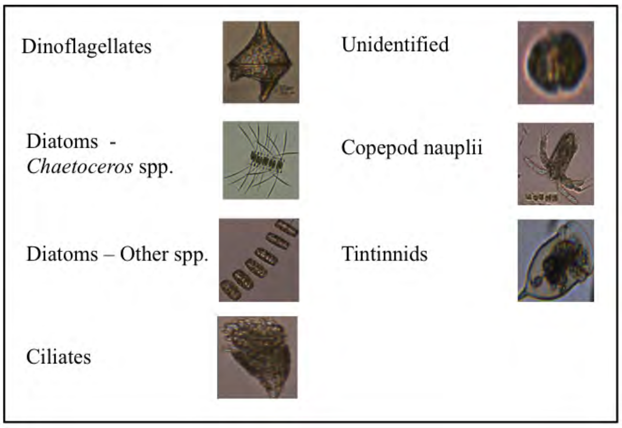

Figure 2. Microplankton groups observed during SHBML cruises.

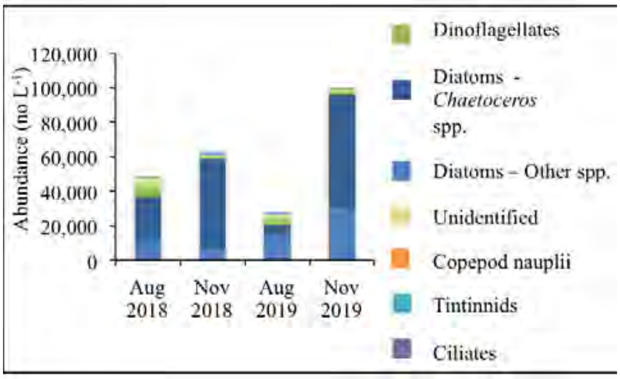

Figure 3. Total abundance of microplankton groups in August and November 2018 and 2019.

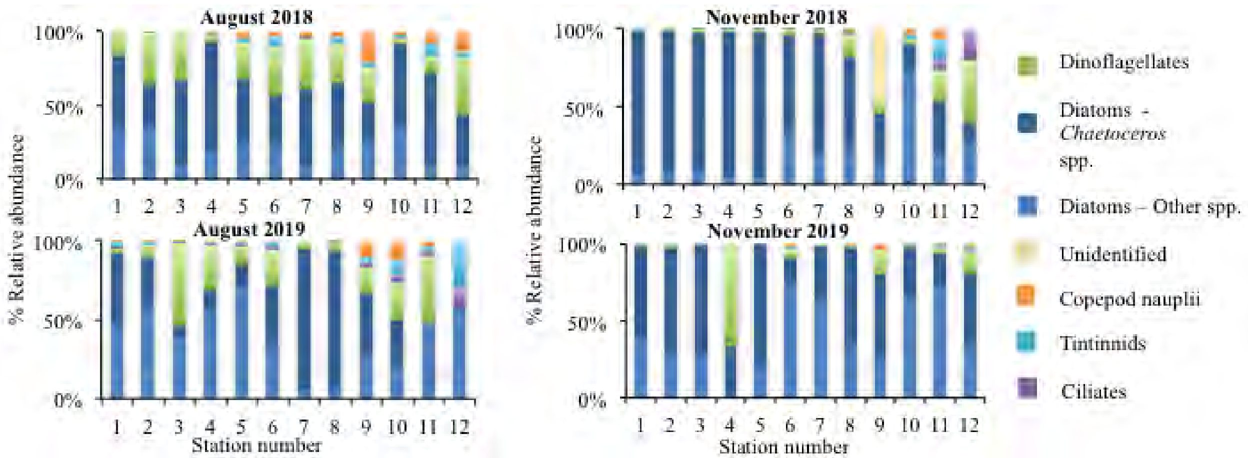

Figure 4. Relative microplankton abundance (%) along the SHBML from inshore (Station 1) to offshore (Station 12).

10. DOES LOCALISED COOLING OCCUR AT THE PRINCE EDWARD ISLANDS?

The Prince Edward Islands (PEIs) are situated in the direct route of the strong eastward flowing Antarctic Circumpolar Current. Considering the persistence of physical mechanisms that drive upwelling, we expected to observe clear localised cooling at the PEIs. Previous studies using widely spaced *in situ* Conductivity-Temperature-Depth (CTD) measurements and coarse spatial (0.25°) resolution Sea Surface Temperature (SST) showed no evidence of such cooling. In order to determine if such cooling was evident in higher spatial resolution datasets, we examined underway *in situ* observations (Fig. 1), collected during annual re-supply voyages each April from 2015 to 2019, and compared these to higher spatial resolution (0.05°) daily reanalysis SST (Fig. 2). For the sake of brevity, we only show the 2015 data.

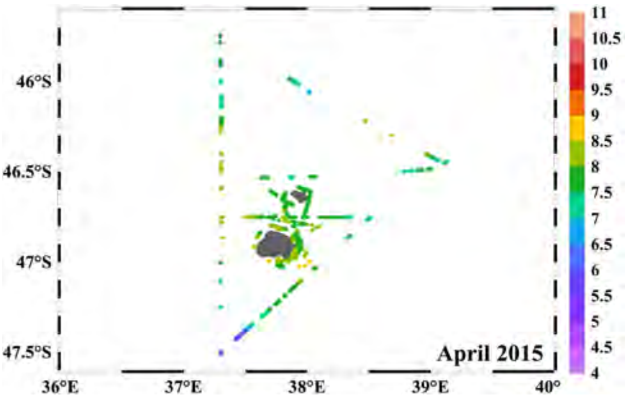

Figure 1. Surface temperature (°C) from underway TSG measurements around the PEIs during April 2015.

The oceanic environment of the PEIs is highly dynamic due to frequent meandering of the southern branch of the sub-Antarctic Front (S-SAF). When the S-SAF is positioned north of the PEIs, cooler Antarctic surface waters are observed at the islands. In contrast, when the S-SAF occurs south of the islands, slightly warmer sub-Antarctic surface waters are present at the PEIs. During April 2015, these slightly warmer (>6.5°C) sub-Antarctic surface waters were clearly observed in underway *in situ* surface temperatures (Fig. 1) obtained from a Thermosalinograph (TSG), as well as Sea Surface Temperature (SST) maps (Fig. 2).

Overall, there was good agreement between patterns observed from *in situ* and reanalysis surface temperature. However, underway measurements during April 2015, and other cruises, did not reveal any clear signals of localised cooling (Fig. 1). This is because the underway observations are usually collected over periods of several weeks. As such, they are unable to provide a detailed synoptic view of surface temperature variations at and around the PEIs.

As illustrated in Fig. 2, such a synoptic view is necessary to identify the localised cooling. Daily SST maps revealed a clear circular region of cooling (<6°C) over the PEI shelf for a period of 7 days between 17 and 23 April 2015. These cooler waters were distinct from the cooler waters south of the S-SAF (Fig. 2), and likely resulted from the combined effects of several mechanisms that drive upwelling at the islands. These mechanisms include a Taylor Column (see Report 3), persistent negative wind stress curl (i.e. clockwise rotation of the overlying air column which drives uplift of deeper, nutrient-richer water to the surface), and the interaction of fronts and mesoscale eddies with the island shelf.

Although localised cooling is expected to occur continuously at the PEIs, daily reanalysis SSTs (Fig. 2) suggest that it is infrequent. For the five cruise periods investigated, the only other observation of clear localised cooling from daily SST was from 12 to 15 April 2018 (not shown). Surface expression of this cooling may depend on the position of the S-SAF. During April 2015, surface cooling was likely more obvious in comparison to the generally warmer surrounding surface waters because the S-SAF was located south of the islands (Fig. 2). The S-SAF was also south of the islands during the 2018 cruise. When the S-SAF is located north of the PEIs, such surface temperature differences are expected to be less obvious, and not easily detectable from surface observations.

It is necessary to monitor the persistence and intensity of such cooling at the PEIs, since it likely plays a crucial role in sustaining enhanced productivity and ecosystem functioning. The limited ability of contemporary *in situ* and reanalysis datasets to detect the localised cooling can only be overcome by collecting continuous *in situ* observations throughout the water column across the entire PEI shelf.

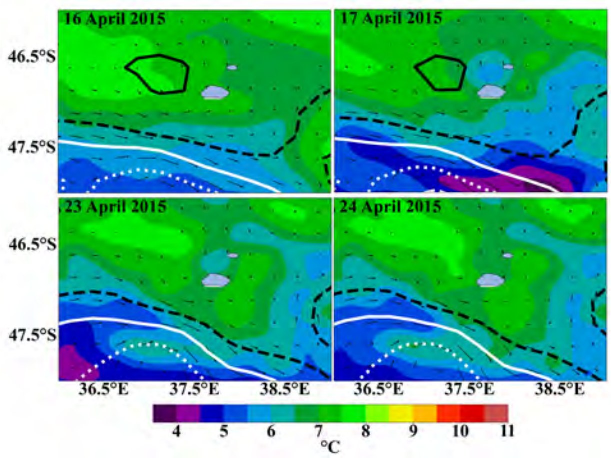

Figure 2. Selected daily reanalysis SST (°C) maps showing localised cooling at the PEIs between 17 and 23 April 2015. The solid black contour indicates a mesoscale eddy located west of the PEIs on 16 and 17 April. The dashed black contour indicates the S-SAF. The solid white contour shows the northern branch of the Antarctic Polar Front (APF), while the dotted white contour shows the middle branch of the APF. Geostrophic vectors indicate the strength (length of arrow) and direction of current flow.

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11. DOES LARGE-SCALE CLIMATE VARIABILITY INFLUENCE OCEANOGRAPHY AROUND THE PRINCE EDWARD ISLANDS?

The Prince Edward Islands (PEIs) are situated in a region of the Southern Ocean that is frequently affected by the meandering of fronts and passing mesoscale eddies. This creates a dynamic oceanic environment that strongly contributes to the provision of critical feeding grounds for large populations of top predators that breed on the islands. Large-scale modes of climate variability, such as the Southern Annular Mode (SAM), the Semi-Annual Oscillation (SAO) and the El-Niño Southern Oscillation (ENSO) and their teleconnections, are known to influence much of the Southern Ocean, causing long-term, decadal and interannual changes in the oceanic environment. A good understanding of the interannual and longer-term changes in oceanic properties, and the potential impact of climate modes around the PEIs, is essential to better understand and predict any potential future ecosystem changes.

First, temporal variability of selected oceanographic parameters at the PEIs was analysed, namely sea surface temperature (SST), wind speed, wind stress curl (WSC; rotations of vertical air columns that influence upwelling), and surface geostrophic (circulation-driven) and Ekman (wind-driven) currents. For each parameter, monthly data at a spatial resolution of 0.25° were extracted and averaged within a 2° x 2° region around the PEIs (Fig. 1). Wavelet analysis (a statistical technique commonly used to identify temporal signals in a dataset) was used to analyse the interannual and decadal-scale variations in each parameter. Subsequently, the relationship between each parameter and the climate modes (SAM, SAO and ENSO) was assessed through lag correlations.

The results suggested possible influence of large-scale climate modes on SST, geostrophic current speed and WSC around the PEIs. SST showed significant interannual (at periods of 0.8 and 2.8 years) and decadal-scale (at a period of 7.5 years) variations (Fig. 2a). WSC showed significant interannual variation at 3–4 years and 7–8 years (Fig. 2b). Geostrophic current speed showed significant interannual variability at periods of 1.3 and 4 years (Fig. 2c). In contrast, wind speed and Ekman current speed showed the strongest variability at periods between 1 and 3 months, with no significant interannual or decadal-scale variations (Figs. 2d, e).

Contrary to expectation, correlations between ENSO and SST were weak ($r < 0.3$), at lags of 1–2 and 4 years. Correlations between ENSO and geostrophic current speeds at lags of 1, 2.5–3 and 4 years, and between ENSO and WSC at a lag of 12 years, were also weak ($r < 0.2$). Correlations between the three local oceanographic parameters and both the SAM and SAO were also negligible.

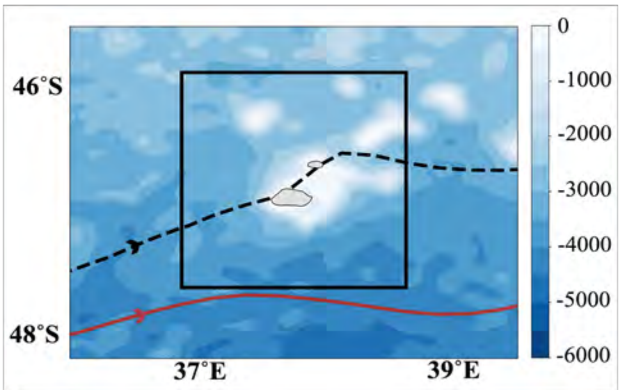

Figure 1. Bathymetry (m) around the Prince Edward Islands archipelago in the Southern Ocean. Long-term mean positions of the southern branch of the sub-Antarctic Front (S-SAF; dashed black line) and the northern branch of the Antarctic Polar Front (N-APF; solid red line) are shown. The black box indicates the 2° x 2° study area within which data were averaged, and arrows indicate the average flow direction.

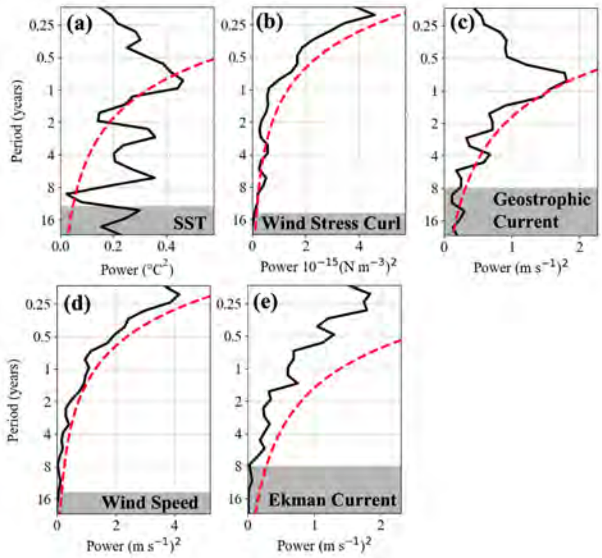

Figure 2. Wavelet analysis results for (a) SST (1982–2020), (b) WSC (1979–2020), (c) Geostrophic current speed (1993–2020), (d) Wind speed (1979–2020), and (e) Ekman current speed (1993–2020) around the PEIs, with the 95% confidence level indicated (dashed red lines). Interannual and decadal signals are significant when the power exceeds that at the 95% confidence level. The grey shaded areas indicate where signals are insignificant due to the limitations of the lengths of the respective time series.

A possible reason for the lack of clear correlations is that different climate modes interact with each other and essentially moderate each other's effects on the local oceanographic parameters. For example, ENSO may be operating to increase SST, while SAM or SAO is acting to decrease SST at the same time. Other climate modes that are unaccounted for here, such as the Indian Ocean Dipole or the Antarctic Circumpolar Wave, could also be influencing oceanographic variability at the islands. Moreover, substantial shorter-term variability may in some cases mask the longer-term climate-driven signals, which are typically weaker (Fig. 2). Longer time series may thus be necessary to identify significant climate-driven signals, highlighting the need for continued observations.

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12. NEW MOORED OBSERVATIONS REVEAL CONTRASTING OXYGEN SEASONALITIES ALONG THE SOUTHERN BENGUELA COAST

On the west coast of South Africa, the southern Benguela Upwelling System (sBUS) experiences seasonal wind-driven upwelling that introduces nutrients to the surface layers, promoting enhanced phytoplankton production and sustaining a diverse ecosystem (Fig. 1). One of the consequences of such enhanced productivity is the development of an oxygen minimum zone (OMZ), where dissolved oxygen (DO) is consumed as organic matter decays. In the sBUS, the OMZ is most pronounced in the bottom waters of St Helena Bay, but also develops elsewhere in nearshore regions along the coast towards the end of the upwelling season.

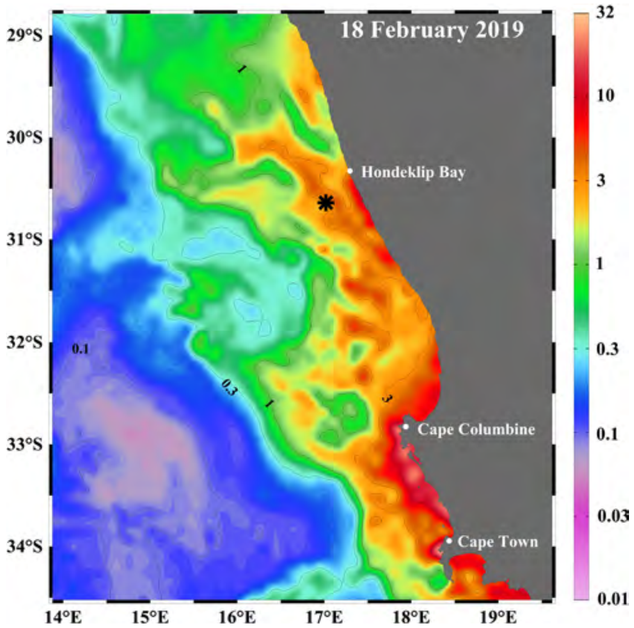

Figure 1. Satellite chlorophyll *a* (mg m^{-3}) for 18 February 2019, illustrating the mooring site (black star).

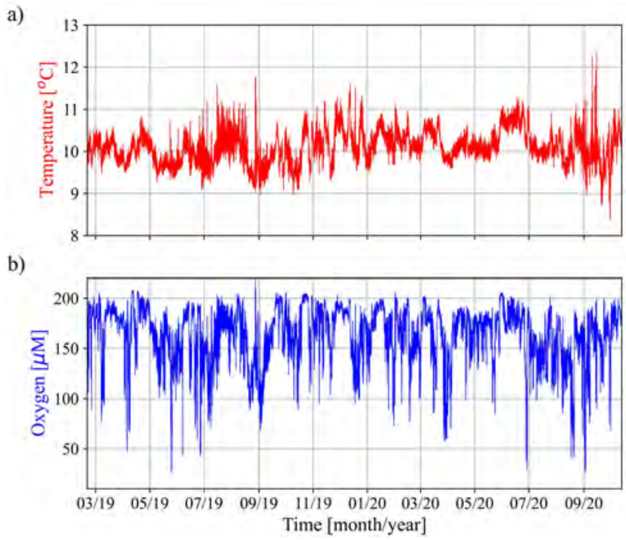

Figure 2. Time series of (a) temperature, and (b) oxygen at the mooring near Hondeklip Bay.

As part of a German/South African collaborative research project to investigate trophic transfer efficiency in the sBUS, a research cruise was conducted on the German research vessel RV *Meteor* during February 2019. A mooring equipped with a miniDOT sensor (MDO) was deployed at the position 30.64°S and 17.02°E, southwest of Hondeklip Bay (Fig. 1). The MDO measured temperature and DO at a depth of 96 m (ca. 74 m above the sea floor) at 10-minute intervals, for a 20-month period from February 2019 to October 2020 (Fig. 2), when it was recovered during a research cruise on the South African research vessel RS *Algoa*.

Diurnal variability was evident, with DO reaching maxima around 9 am, while minima occurred during the late afternoon. This implies enhanced downward mixing of warm, well-ventilated surface waters, favoured by cooling and reduced stratification in the surface layers during the late afternoon and at night (Fig. 3). DO also showed rapid and dramatic short-term decreases of ca. 100 µM over a few days at a time (Fig. 2), due to offshore transport of oxygen-depleted waters from the shallower nearshore area along the coast.

Surprisingly, the seasonal cycle of DO near Hondeklip Bay was marked by minima during winter and maxima in summer (Fig. 3). This seasonality is in contrast to DO seasonality further south in St Helena Bay, where DO minima are usually observed at the end of the upwelling season, with maxima occurring in winter. The opposing seasonal DO cycle, that was observed southwest of Hondeklip Bay (Fig. 3), was likely caused by the more frequent periods of enhanced horizontal mixing that transported oxygen-depleted water from the nearshore region to the mooring location, and by the breakdown of the upwelling front, during winter.

It is important to note that the mooring was deployed for a relatively short period, and thus we are unable to make inferences on the reproducibility of this DO seasonal cycle from one year to the next. This stresses the crucial need for continuous, long-term, high temporal resolution observations throughout the sBUS, to adequately capture the variability of environmental conditions that impact the surrounding ecosystem.

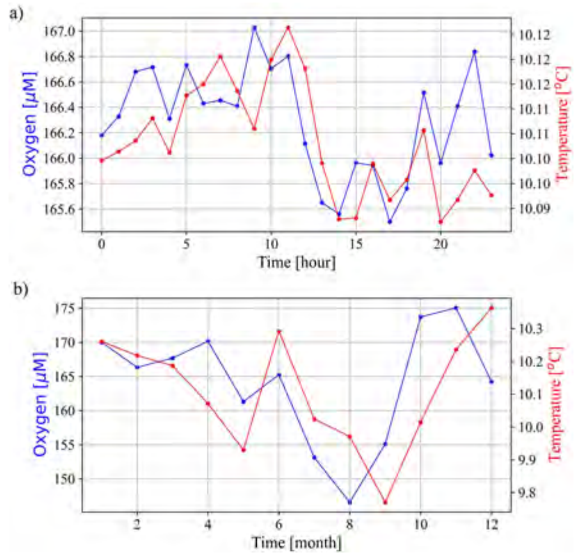

Figure 3. (a) Diurnal, and (b) seasonal variation of oxygen and temperature at the mooring near Hondeklip Bay.

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13. CURRENT REVERSALS OFF PORT EDWARD ON THE EAST COAST OF SOUTH AFRICA

Along the east coast of South Africa, environmental conditions on the narrow continental shelf are strongly influenced by the dynamics and variability of the fast, southwestward-flowing Agulhas Current (AC). Large solitary AC meanders consist of cyclonic eddies travelling southwards along the inshore edge of the AC, and are commonly referred to as Natal Pulses and Durban Eddies. These eddies are typically associated with inshore current reversals (i.e. northeastward flows are observed, in contrast to the more regular southwestward flow of the AC), as well as upwelling of nutrient-rich water which has been shown to stimulate increases in phyto- and zooplankton biomass. Most previous environmental studies in this region have been based on data that reflect conditions averaged temporally (over several days) and spatially (over larger geographic areas), as observed during research cruises. In this study, we examined historical, high temporal resolution moored observations to provide a baseline description of currents and bottom temperature variations across the shelf.

In September 2005, bottom mounted Acoustic Doppler Current Profilers (ADCPs) were deployed at three locations across the shelf, just south of Port Edward (Fig. 1). The mooring at P1 was located 3.2 km offshore at 36 m depth, P2 was 6.3 km offshore at 64 m depth, and P3 was 10.2 km offshore at a depth of 162 m. Southwestward flow dominated at P1 (89% of the time) with current speeds between 0.33 and 163.38 cm s^{-1}. Similarly, southwestward flow was observed at P2 (88% of the time) with speeds varying from 0.32 to 188.99 cm s^{-1} (Fig. 2). Despite the shorter measurement period at P3, there was good agreement with the current variability observed further inshore at P1 and P2.

Previous studies demonstrated that the AC was located around 10 km from the coast, but here we observed that the AC extended as far inshore as 3.2 km from the coast. Current speeds in the upper ocean layers at P2 and P3 exceeded 100 cm s^{-1} most of the time, indicating the presence of the AC. At P1, such strong southwesterly flow was only observed between December 2005 and May 2006, suggesting possible seasonal variation in the intensity and/or shoreward extent of the AC. However, substantially more years of observations are required to confirm this.

A total of 11 northeasterly flow events, ranging from 1–15 days in length, were observed during the measurement period. Due to the shorter record at P3, only 4 of the 11 events were captured at the offshore location. During September and November 2005, as well as January–February and April 2006, northeasterly flow through the full water column resulted from cyclonic eddies travelling southwards along the inshore edge of the AC. The remaining northeasterly flow events were associated with smaller scale shoreward and offshore movements of the AC, which resulted in much shorter periods of current reversals. Each of these current reversals was associated with substantial short-term variations in bottom temperature, with daily fluctuations of up to 4°C. Contrary to expectation, correlations between bottom temperature and current reversals were poor and not statistically significant, since both warming and cooling were observed during the more regular southwesterly flow, and during the northeasterly current reversals. This reflects the complex temperature response to current variability in the region, and highlights the need to extend high temporal resolution sampling to better capture and understand this variability.

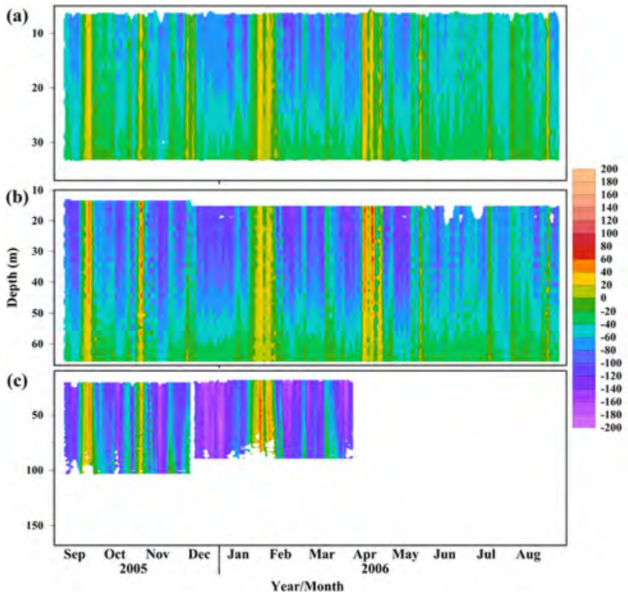

Figure 2. Meridional current speed (cm s^{-1}) at mooring positions (a) P1, (b) P2, and (c) P3, showing northward (positive) and southward (negative) flows off Port Edward.

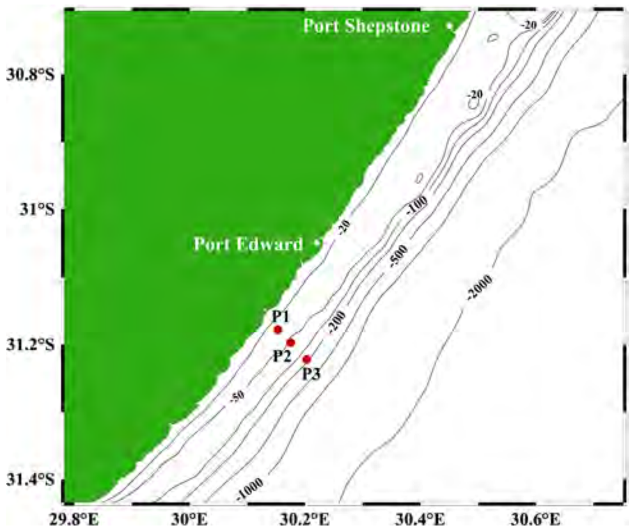

Figure 1. Bathymetry off Port Edward on the east coast of South Africa. Red dots show mooring positions (P1, P2 and P3).

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14. OCEANOGRAPHIC TRIGGERING OF SOUTH AFRICA'S SARDINE RUN

The KwaZulu-Natal sardine run is a mass migration of South Africa's commercially most important small pelagic fish, the sardine *Sardinops sagax*, from warm-temperate waters on the south coast to subtropical waters on the east coast (Fig. 1). It is one of Earth's most spectacular marine migrations and is both ecologically and economically important. The tens to hundreds of millions of sardines that participate in the run are accompanied by numerous other small pelagic fish, and together, these swarms attract large numbers of marine predators. The spectacle further supports a temporary artisanal fishery and provides an important source of tourism revenue during the not so busy winter months.

First reported in the mid-1800s, numerous explanations have been proposed for the sardine run, including equatorward movement of juvenile fish, feeding migrations facilitated by habitat expansion, herding of sardines by predators, and relic spawning behaviour towards an area that may have been an important nursery during the last ice age. Given that marine species around South Africa tend to be subdivided into regional populations associated with distinct biogeographic provinces, it was previously thought that east coast sardines represent a separate stock component that mixes with sardines resident on the south coast during summer, but then separates from them during winter to travel toward their east coast spawning grounds. Although the east coast sardines can be distinguished from those elsewhere in southern Africa using phenotypic (physical) characteristics, this may be due to the stress involved in the migration, and traditional genetic analyses have not supported the existence of separate populations.

Using genomic data of hundreds of South African sardines, we found that east coast sardines were not unique, but clustered with west coast sardines, and were distinct from those on the south coast. This new finding suggests that sardines participating in the run must be migrants that originate from the cool-temperate Atlantic, and are not actually well adapted to the warmer, subtropical conditions on the east coast. Recently, we have identified a completely novel explanation for the sardine run.

Mesoscale cyclonic eddies along the inshore edge of the Agulhas Current drive upwelling, which transports cold, nutrient-rich water from depth onto the shallower shelf (Fig. 1). When these eddies occur along the southeast coast during autumn and winter, shelf waters can become temporarily cooler than those further west along the south coast. This cooling creates conditions that favour west coast sardines, triggering an aggregation of these migrants at the northeastern limit of the south coast. Intermittent upwelling, driven by the interaction of the Agulhas Current with the continental slope, likely facilitates further northward movement of the sardines in cooler water at 100–200 m below the surface. Eventually, the sardines find themselves in "hot water" - subtropical water that exceeds their preferred thermal range, suggesting that the sardine run does not benefit South Africa's sardine population.

Authors: Teske PR (University of Johannesburg), Lamont T (OC Research), van der Lingen CD (Fisheries Management, Fisheries Research and Development)

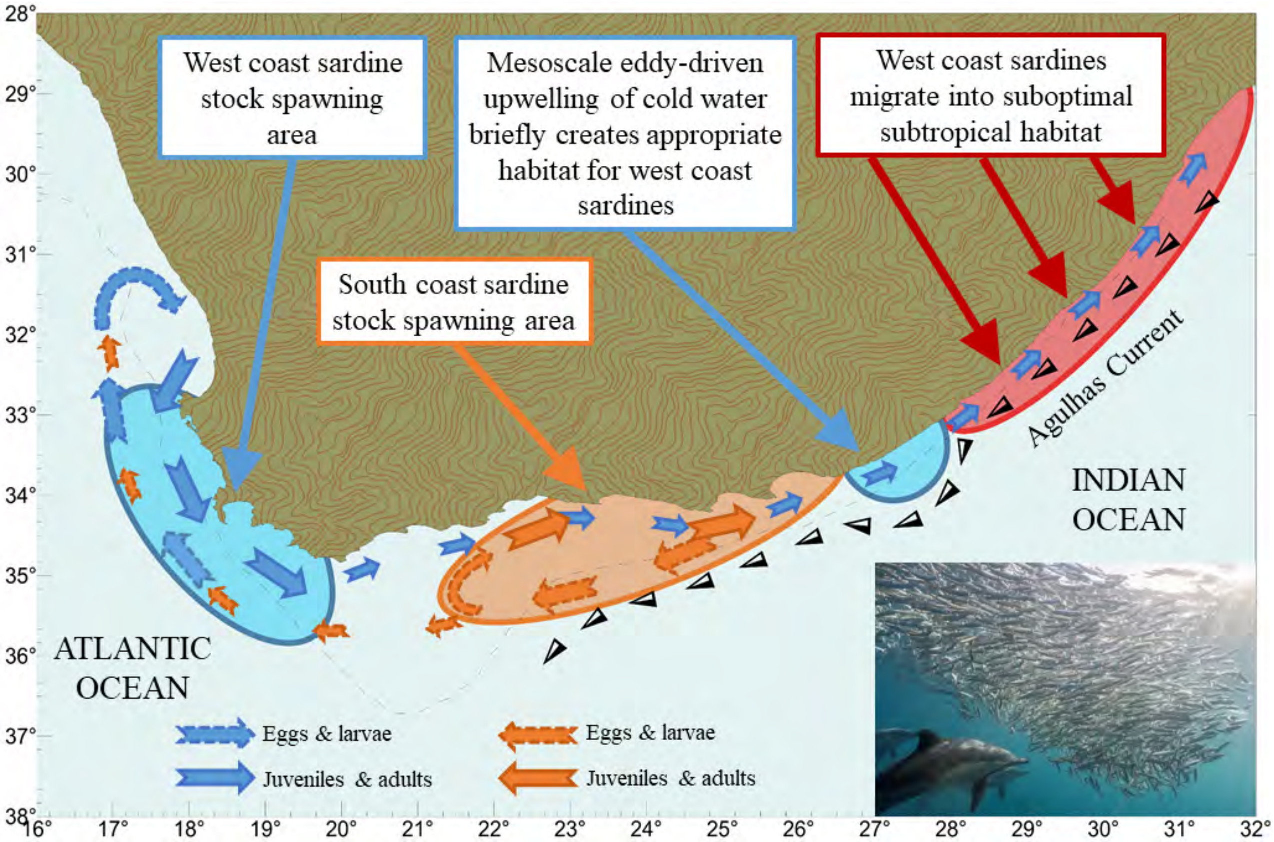

Figure 1. Schematic illustration of sardine migrations culminating in the sardine run. Photo inset: common dolphins, *Delphinus capensis*, feeding on sardines during the run (credit: Steve Benjamin; www.animalocean.co.za).

15. STORMWATER CONTRIBUTION TO MICROPLASTICS IN COASTAL ZONES AROUND CAPE TOWN

Due to inadequate waste management and poorly designed drainage systems, urban runoff and associated pollutants including plastics are commonly discharged into shallow coastal waters via stormwater outlets. In South Africa, between 0.09 and 0.25 million tons of marine plastic pollution originates from land-based sources, with Cape Town responsible for a significant quantity of this pollution. A pollutant of emerging concern is microplastics (MPs), with rivers and stormwater outlets shown to be key transporters of these tiny (<5 mm) plastic particles into the coastal environment. This study investigated the distribution of MPs in the coastal environment, within sediments, seawater and marine organisms, near Cape Town. Seasonal differences were also assessed, in particular whether MPs are more abundant during the winter rainfall season when stormwater outlets discharge more water, compared to the dry summer season.

Three study areas were selected along the Cape Peninsula, at Camps Bay, Mouille Point and Three Anchor Bay. Each area comprised an "impacted" site near a stormwater outlet and "control" site ± 200 m away from the outlet. Sampling took place during two seasons, in summer 2020 and winter 2021. Fauna that were sampled comprised three different feeding groups: filter feeders (mussels), grazers (sea urchins) and carnivores (whelks). Seawater and sediment samples were also taken at each site.

A total of 1,362 samples were analysed, with 4,814 MP particles recorded during the two sampling periods. Samples from impacted stormwater sites had consistently more MPs in samples than control sites (Fig. 1). Against our expectation, we recorded significantly less MPs in winter than in summer, indicating that the abundance and build-up of MPs and other waste products may increase during the summer period. This may be either because more MPs are entering the coastal waters during summer, or because they tend to be flushed out during winter, e.g. during stormy weather.

Interestingly, the mean concentration of MPs found in biotic samples from the intertidal zone was significantly higher than in the shallow subtidal zone (Fig. 2). This may be because stormwater outlets discharge runoff directly into the intertidal zone, or because most plastics are buoyant and get washed up on the shore. Mussels contained more MPs in their soft tissue than sea urchins and whelks, during both seasons. This was not surprising because mussels are non-selective feeders that digest any particles depending on their size. Whelks are directly impacted by the abundance of MPs since they are a key predator of mussels on rocky shores.

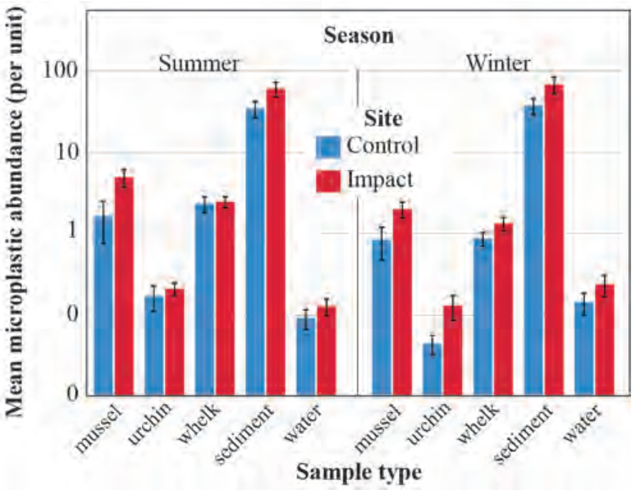

Figure 1. Mean seasonal abundance of MPs per unit in biotic (soft tissue weight- in grams) and abiotic samples (water per 100 L; sediment per 0.2 kg) across impact and control sites. Error bars represent the 95% confidence interval.

This study showed that stormwater outlets introduce significant quantities of MPs into the coastal region, which are then ingested by coastal organisms. Further research is needed on MP impacts on the coastal environment, and the City of Cape Town discharge systems should be improved to reduce MP pollution.

Authors: Ariefdien R (OC Research), Sparks C (CPUT), Pfaff M (UCT)

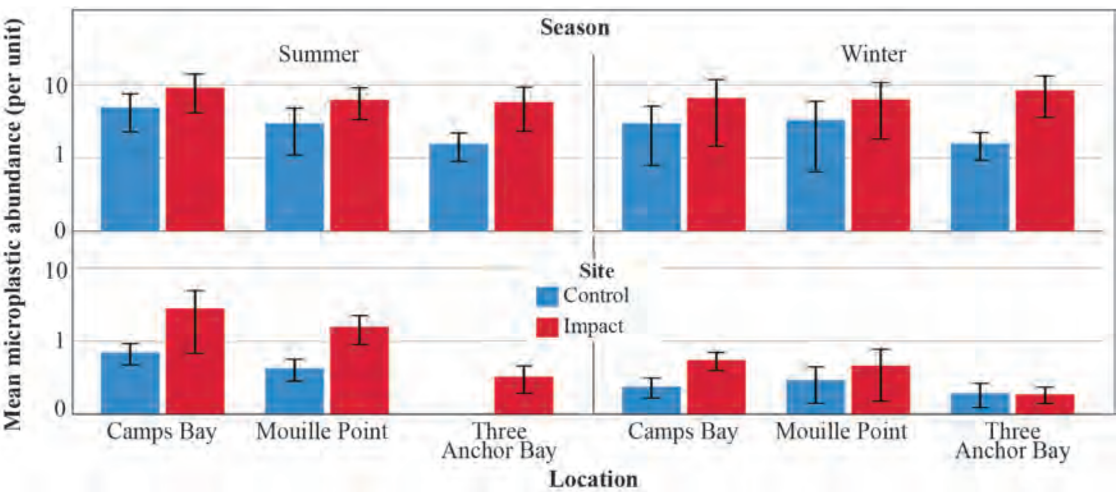

Figure 2. Mean seasonal abundance of MPs per unit biotic (soft tissue weight- in grams) and abiotic samples (water per 100 L; sediment per 0.2 kg) found at Camps Bay, Mouille Point and Three Anchor Bay across impact and control sites in the subtidal and intertidal zones. Error bars represent the 95% confidence interval.

16. DNA METABARCODING OF MARINE ZOOPLANKTON IN SOUTH AFRICA – HOW GOOD IS THE REFERENCE DATABASE?

Zooplankton play an essential role in marine pelagic food webs, through biogeochemical cycling and energy transfer to higher trophic levels. Zooplankton include "full-time" plankton (holoplankton) that spend their whole lives as part of the plankton, and "part-time" plankton (meroplankton) consisting of the early life stages of crustacean, fish and mollusc species. The rapid response of zooplankton to environmental changes makes them ideal indicators of ecosystem health and biodiversity.

Using traditional microscope analysis to identify zooplankton specimens is labour-intensive and time-consuming because of their small size, large numbers, high diversity and community complexity. Over the past two decades, DNA barcoding and online reference databases such as the Barcode of Life Data Systems (BOLD) and GenBank have revolutionised species identification and discovery. These DNA barcodes allow for distinction between visually similar species and identification of species irrespective of life stage, and reduce researcher bias through the use of standard online reference databases.

Metabarcoding is the application of DNA barcoding to taxonomically complex samples that contain more than one organism or species. It uses the same reference databases as DNA barcoding but allows for the simultaneous identification of multiple taxa by using high-throughput sequencing methods. We investigated the availability of DNA reference barcodes for marine zooplankton expected to occur in the coastal waters of South Africa (SA) as an initial step toward developing a regional metabarcoding protocol.

Exploration of zooplankton DNA records on BOLD revealed proportionally fewer representative barcode records per taxon from SA compared to those available globally (Fig. 1). Ray-finned fish (Actinopterygii) were the most comprehensively sampled aquatic group globally (64% of species barcoded) and in SA (48%), with an 89% success rate in assigning immature specimens (including eggs and larvae) to species level. For crustaceans, barcode records were available for only 18% of known species globally and 6% in SA. This study has highlighted two clear trends in SA. Firstly, for nearly all groups, there were proportionally fewer records of known species compared to global datasets. Secondly, barcode records were dominated by meroplanktonic taxa with large benthic or pelagic adult stages that are of value to commercial or recreational fisheries. Despite comprising the bulk of zooplankton diversity, including most potential indicator species, holoplanktonic taxa were underrepresented.

There is thus an urgent need to expand and validate barcode reference databases of all key zooplankton classes to improve the resolution and representivity of metabarcoding outputs. Metabarcoding of marine zooplankton has now been successfully applied in SA as a pilot project, and the methodology is poised to shift research emphasis from individual species to assemblages, to facilitate high-resolution monitoring of zooplankton biodiversity in pelagic ecosystems, and to accelerate discovery of new species.

Authors: Singh S, Groeneveld JC (ORI), Huggett J (OC Research), Naidoo D (ORI), Cedras R (UWC), Willows-Munro S (UKZN)

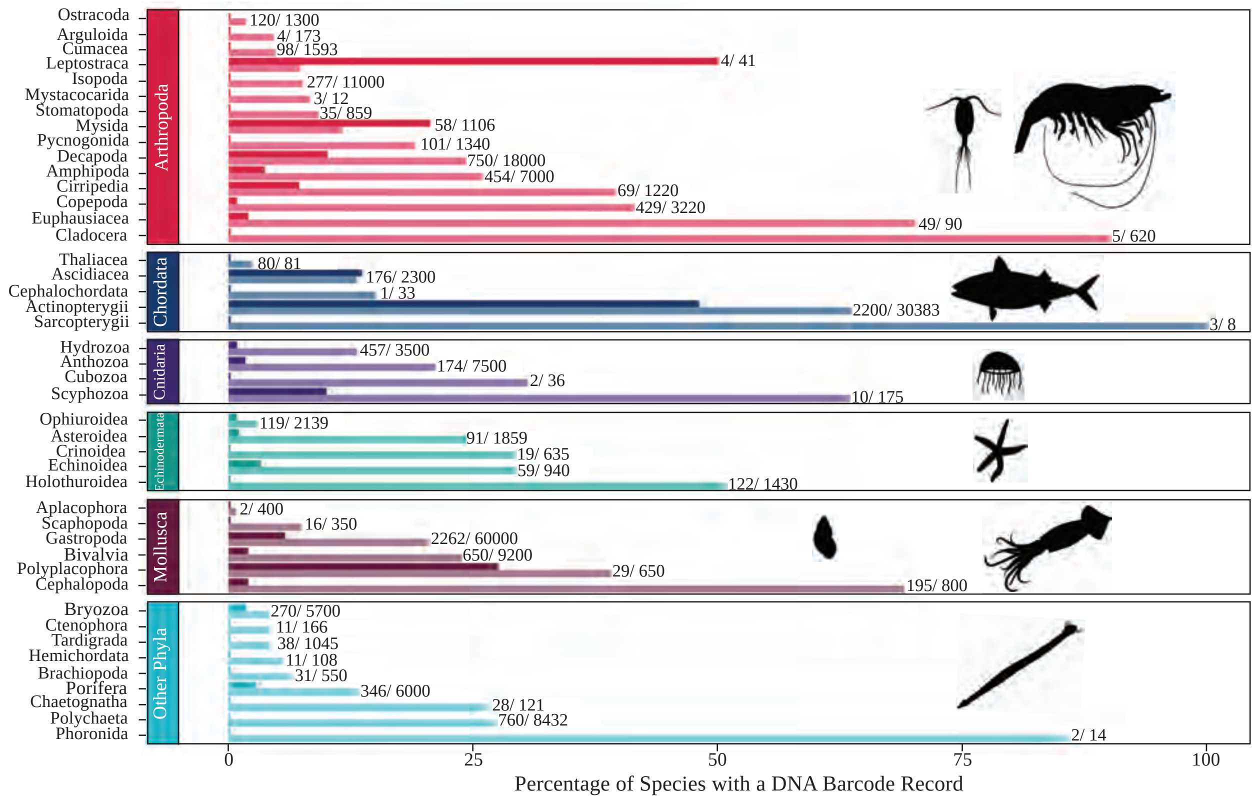

Figure 1. The relative percentages of DNA barcode records available for selected marine zooplankton taxa, globally (pale bars) and for South Africa (dark bars). The numbers of species known locally/globally are indicated next to the bars. Adapted from Singh et al. 2021. *African Journal of Marine Science* 43: 147–159.

17. MACROFAUNAL COMMUNITY OF A LARGE TEMPORARILY CLOSED ESTUARY DURING PROLONGED MOUTH CLOSURE

South Africa is a water scarce country with an increasing population and a growing demand for freshwater resources. This high demand for water negatively impacts ecosystems such as estuaries, where a reduction in flow may result in more frequent and prolonged closure of the estuary mouth. Prolonged closure may alter water chemistry and inhibit recruitment and migration of fish and invertebrates between the estuary and the sea.

The concentration of salts, referred to as salinity and typically measured in parts per thousand (ppt) of salts in water, is an important physico-chemical variable responsible for structuring spatial patterns of physical/biogeochemical properties and biota. Strong horizontal salinity gradients may be present in the estuary when the mouth is open, but mesohaline (salinity = 5.0–17.9 ppt) or oligohaline (0.5–4.9 ppt) conditions often replace these gradients during prolonged mouth closure. Temporarily closed systems are usually dominated by both marine and estuarine biota, whereas during oligohaline conditions, freshwater and estuarine biota dominate. Previous studies in temporarily closed estuaries (e.g. uMdloti in KwaZulu-Natal) have shown that polychaetes tend to dominate when the system is closed, while oligochaetes dominate after prolonged closure and diluted salinity.

The Groot Brak estuary in the Western Cape is a large temporarily closed estuary that has undergone substantial modifications due to human impacts and remains closed for 80% of the time. Under natural conditions, the estuary mouth would alternate between being open or closed throughout the year, and would undergo various physico-chemical states with corresponding shifts in estuarine conditions and biota. The likelihood of mouth closure under natural conditions would peak in January–February and June. However, under present-day conditions, the mouth of the estuary shifts between a primarily marine dominated state (typically October–March), and a closed mouth state (typically April–September). To determine the response of benthic macrofauna to the present-day estuarine regime, 11 locations were sampled in May 2019 (autumn) and January 2020 (summer) (Fig. 1).

The mouth of the estuary was closed during both sampling periods. Polyhaline conditions (18–29 ppt) prevailed throughout the estuary during autumn (mean salinity = 22.60 ± 1.86 ppt), with mesohaline conditions in summer (15.90 ± 3.31 ppt). There was no salinity gradient observed

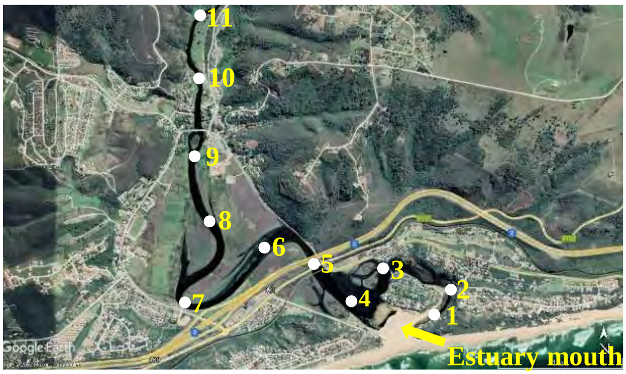

Figure 1. Map showing the locations of the 11 sampling sites.

in the estuary, which is typical under prolonged mouth closure conditions.

A total of 24 taxa were recorded during the study period, with the polychaetes *Capitella capitata*, *Aquilaspio sexoculata*, *Ceratonereis erythraeensis*, and the amphipod *Grandidierella lutosa* dominating. Previous studies found that the macrofaunal community was dominated by the mudprawn *Upogebia africana*, the sandprawn, *Kraussillichirus kraussi* and the bivalve, *Loripes clausus*. *U. africana* and *K. kraussi* were not recorded in the present study, while *L. clausus* was present in low numbers. Lower numbers of *U. africana* may be due to prolonged mouth closure since their recruitment is dependent on a marine phase. Lower numbers (or observations) of *K. kraussi* can be attributed to the cessation of reproduction at salinities <16 ppt, with deeper burrowing to their preferred salinity.

The results of the study have shown the changes that have occurred in the macrofaunal benthic community due to prolonged closure of the estuary mouth. Additional sampling during an open phase will determine if community structure and composition returns to the state it was in prior to the prolonged mouth closure, with mud- and sandprawns dominating.

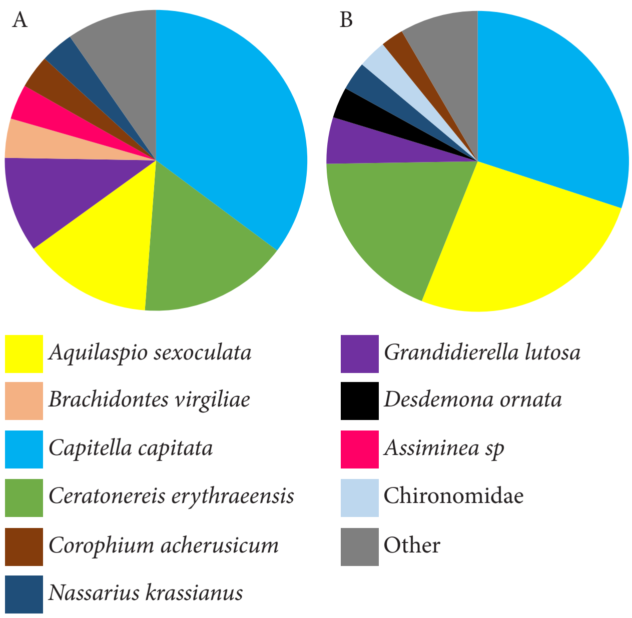

Figure 2. Dominant benthic macrofauna of the Groot Brak estuary during autumn (A) and summer (B).

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18. A COMPROMISED IMMUNE SYSTEM: THE CAPE URCHIN IN A RAPIDLY ACIDIFYING WORLD

High CO_2 emissions continue to lower the pH of the world's oceans. The result is Ocean Acidification (OA), a phenomenon which negatively impacts marine life and associated ecosystems. An example of marine organisms that are potentially negatively impacted by OA are echinoderms, such as sea urchins, sea stars and sea cucumbers. These benthic organisms are calcifiers that rely on calcium carbonate ($CaCO_3$) to construct their shells and skeletons. Because OA is causing many parts of the ocean to become under-saturated in $CaCO_3$, these organisms are particularly relevant to studying the physiological impacts of OA.

The traditional approach to this is short-term exposure experiments. These generally reveal that echinoderms, particularly the adult life stages, are relatively robust to OA. However, longer term, or chronic exposure to low pH conditions (i.e. hypercapnia) is required to reveal the true eco-physiological impacts.

The Cape urchin, *Parechinus angulosus*, is a widely distributed, keystone species in South Africa. In sea urchins, cellular immune defences are shared amongst the coelomocytes, a population of cells occurring in the coelomic fluid (blood equivalent). Amongst these are red spherule cells which have antiseptic properties used to fight off harmful bacteria. To examine if chronic exposure to hypercapnia affects the immune response of *P. angulosus*, we exposed adult urchins to hypercapnic (pH = 7.4) and normocapnic (pH = 8) conditions for ca. six months (Fig. 1). Thereafter, counts of the total coelomocytes, and in particular, red spherule cells, were significantly lower per ml of coleomic fluid in hypercapnic versus normocapnic urchins (Fig. 2). These results indicate that, in increasingly acidifying waters, the immune system of the Cape urchin may be compromised.

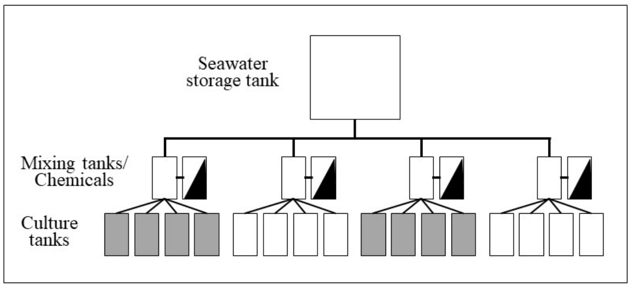

Figure 1. An illustration of the long-term experimental set-up. Seawater flowed from storage tanks into mixing tanks where pH was manipulated, before flowing into culture tanks housing urchins in hypercapnic (grey) and normocapnic (white) conditions.

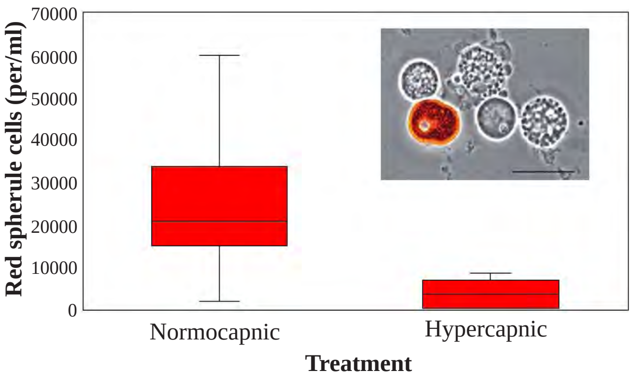

Figure 2. Total red spherule cell counts (per/ml of coelomic fluid) after exposure to normocapnic and hypercapnic conditions (inserted image adapted from Coates et al. 2018. *Journal of Innate Immunity* 10: 119–130).

The significant decline in red spherule cell numbers for hypercapnic urchins further indicates that these organisms may not easily recover from bacterial infections, or injuries including spine loss (Fig. 3). Thus our study provides evidence that adult life stages of echinoderms are not exempt from stressors, and chronic exposure is crucial in revealing the real, long-term, eco-physiological effects of OA.

At the end of this century, a two-fold increase in acidity is expected in surface ocean waters. With such unprecedented rates of change, coupled with the cumulative impacts of other anthropogenic stressors, marine taxa such as echinoderms will likely face considerable challenges. A significant decline in *P. angulosus* populations will most likely have a knock-on effect on benthic communities, including for species that are dependent on urchins such as rock lobsters (as prey) and juvenile abalone (for refuge). Kelp bed ecosystems are also likely to be altered if these important grazers are reduced. Experimental studies such as this one that enhance our understanding of how organisms respond to environmental change can inform adaptive management and conservation efforts.

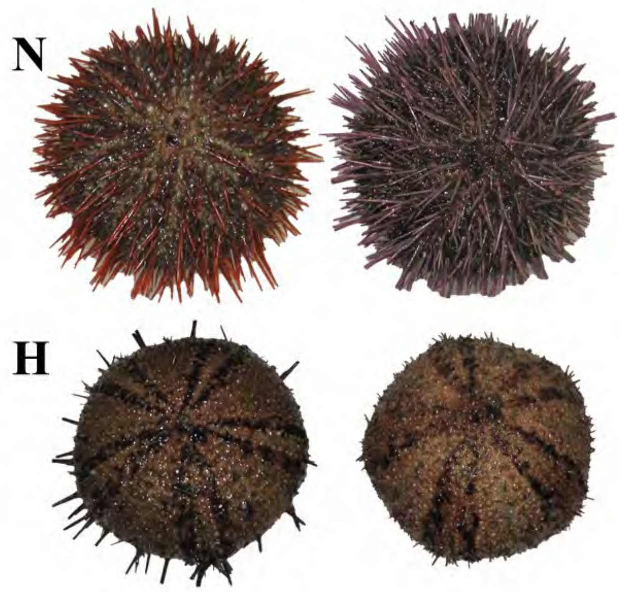

Figure 3. Hardy normocapnic (N) urchins (top), versus spine loss and bacterial infections in hypercapnic (H) urchins (bottom).

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19. BEHAVIOURAL RESPONSE OF CAPE FUR SEALS TO SWIM-WITH-SEAL TOURISM ACTIVITIES IN THE ROBBERG MPA

Swim-with-seal (SWS) ventures have become a popular tourist activity in the Western Cape. The activity commenced in 2009 at the seal breeding colony in the Robberg Marine Protected Area (MPA) in Plettenberg Bay (Fig. 1). Currently, little is known about the potential impacts of SWS, especially the associated disturbance on the well-being of the seal colony. This is cause for concern given the growth in popularity of the activity and increasing numbers of operators, including those in the Cape Town area. We therefore initiated a behavioural study at the Robberg MPA to assess impacts of SWS tourism on the seal colony, with a goal of providing advice for the management of this activity.

Figure 1. Swim-with-seal activities as viewed from the observation point above the Robberg seal colony.

Behavioural observations were conducted from the cliff tops above the seal colony. A vantage point was chosen that allowed for observations of both an impact site (a part of the colony adjacent to SWS activity) and a control site (separate from SWS activities). In terms of study design, sequences of photographs of the seal colony were taken before the arrival of the tourist boat, during the period of SWS activity, and after the departure of the boat. This was done for both the impact and control sites. The images, which provided a digital record of seal activity in the colony, were augmented by video recordings and visual observations using binoculars. Data were also collected on the numbers of swimmers in the water, their behaviour, and the environmental conditions (air and seawater temperatures, wind speed/ direction and visibility). Data collection was hampered by Covid-19 restrictions, but it was possible to collect data for 55 tourist visits during 39 days from November 2020 to October 2021.

Seals in the images were counted and classified according to four behavioural activities (lying down, sitting, moving and grooming). No change was apparent in the proportions of animals for each of these behavioural categories in the impact area relative to the control area (Fig. 2A). Similarly, no difference was apparent between the impact and control sites with respect to the relative numbers of animals entering versus exiting (hauling out of) the water (Fig. 2B). The only apparent difference between the impact and control sites was in the relative numbers of animals showing varying levels of alertness (Fig. 2C). The results therefore indicate that while there is awareness by seals in the colony of the SWS activities occurring nearby, overall behaviour patterns do not seem to be impacted. These results are preliminary and a more detailed analysis shall be conducted, taking into account the environmental data collected during sessions. Repeated-measures analyses will be performed to ensure an adequate comparison of impact and control sites within each observation session.

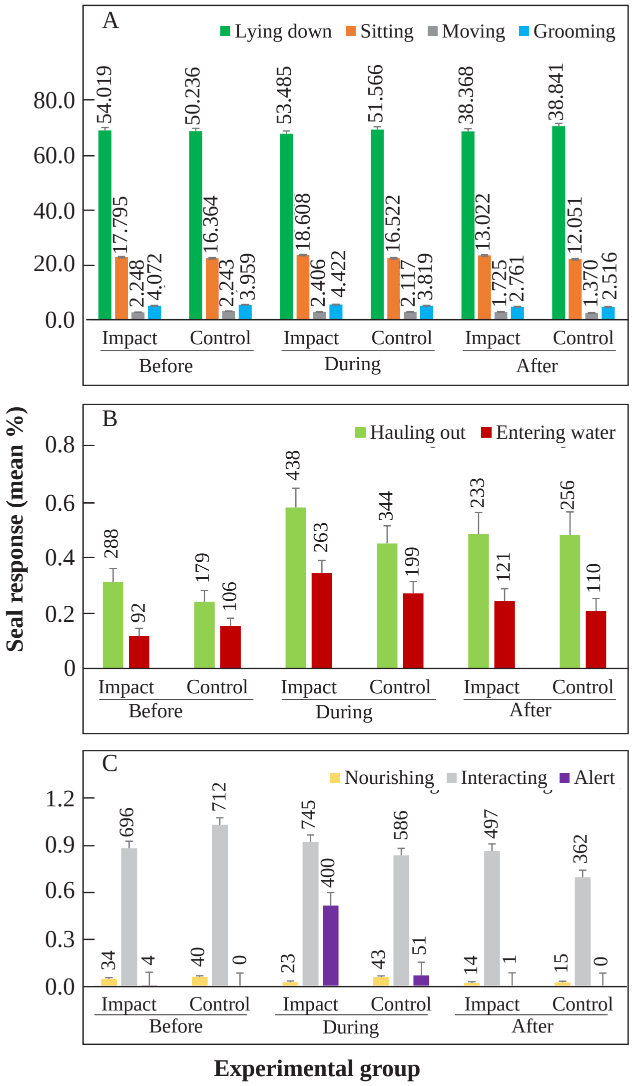

Figure 2. Comparison of seal responses for different behavioural categories between impact and control areas, before, during and after SWS activities. Data labels show the total number of counted seals represented by each data point with standard error bars.

Authors: Basson R, Kirkman SP (OC Research), Findlay KP (CPUT)
Contributors: Malwela N, Ariefdien R, Mushanganyisi K, Swart L (OC Research), Abrahams C, Vos S (CapeNature), Penry G (NVT)

20. ECOLOGICAL EFFECTIVENESS OF SOUTH AFRICA'S MARINE PROTECTED AREAS

There has been considerable work in recent years on improving the extent and representivity of marine protection in South Africa, but less focus on evaluating the effectiveness of Marine Protected Areas (MPAs). Given the growing demand for marine resources from various sectors, for which activities may be restricted or prohibited in MPAs, there is an increasing need to justify the existence of MPAs by providing evidence of their effectiveness.

A review of relevant scientific literature was conducted to assess the ecological effectiveness of South Africa's MPAs. Most studies were found to focus on the protection and recovery of fishery-targeted linefish species, or harvested intertidal resources, highlighting a shortage of studies on non-targeted species, including what are regarded as "iconic" taxa, such as turtles. Specifically, most of the studies focused on fish or shark species (46%) followed by invertebrates (26%), with the rest covering flora, iconic species, or larval phases. Also evident was that most research has been limited to a subset of the larger coastal MPAs (Fig. 1), such as Tsitsikamma (mainly linefish), Dwesa-Cwebe (mainly invertebrates), De Hoop, Goukamma and iSimangaliso (mainly fish).

Most of the studies (ca. 60%) focused on changes in population parameters in species or communities, associated with protection. Fewer studies looked at ecosystem effects, the spillover of adults or larval export from MPAs to adjacent areas, or benefits to fisheries in adjacent areas (Fig. 2).

The majority of studies focusing on population parameters of species recorded beneficial ecological effects. These were detectable as increases in parameters (abundance, biomass, size or reproductive output of species), inside versus outside of MPAs, or before and after MPA proclamation (Fig. 3). Results for comparison of community-level parameters were more ambiguous, but most studies again showed positive ecological effects (not shown here).

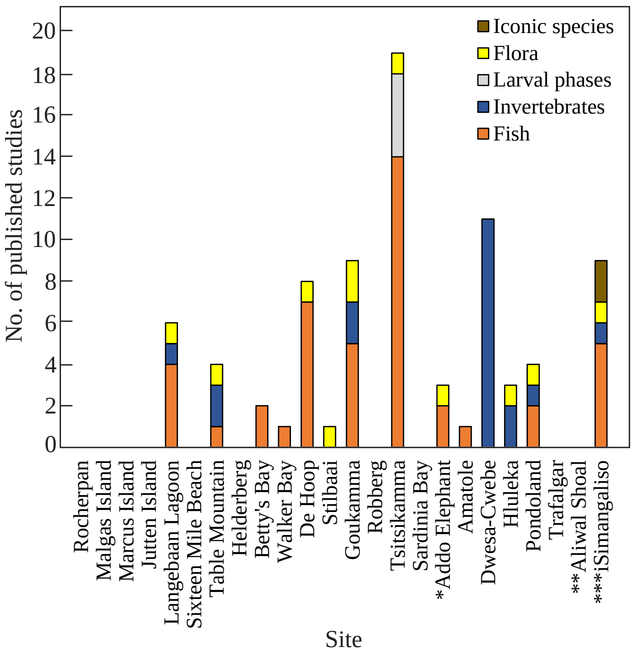

Figure 1. Numbers of published studies per MPA assessing their ecological effectiveness for five categories of taxa or life forms, namely fish, invertebrates, larval phases, flora and iconic species. The bars are indicative of the number of relevant studies per site. Only MPAs declared before 2019 are included, some of which were modified in 2019 (*expansion of former Bird Island MPA; ** expansion of previous Aliwal Shoal MPA; *** the expansion and combination of former St Lucia and Maputaland MPAs).

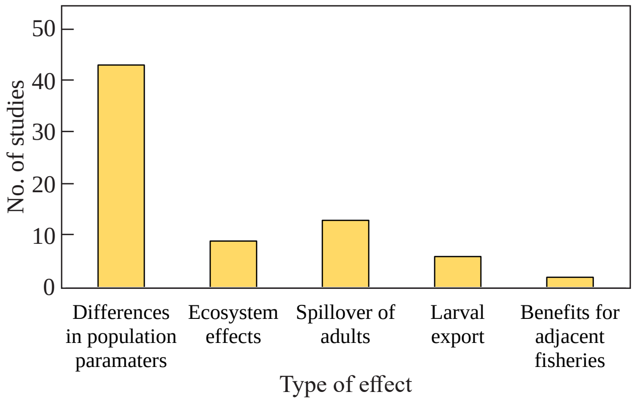

Figure 2. Different types of effects that are applicable to assessing ecological effectiveness of MPAs, and the numbers of studies in which they have been evaluated.

The results definitively addressed the main objective of this study, namely to assess whether South Africa's MPAs provide effective protection for its marine species and species assemblages. Further research and monitoring to achieve evaluations of MPA ecological effectiveness are recommended, with enhanced focus on neglected MPAs and species (Fig. 2), and on lesser studied effects (Fig. 3).

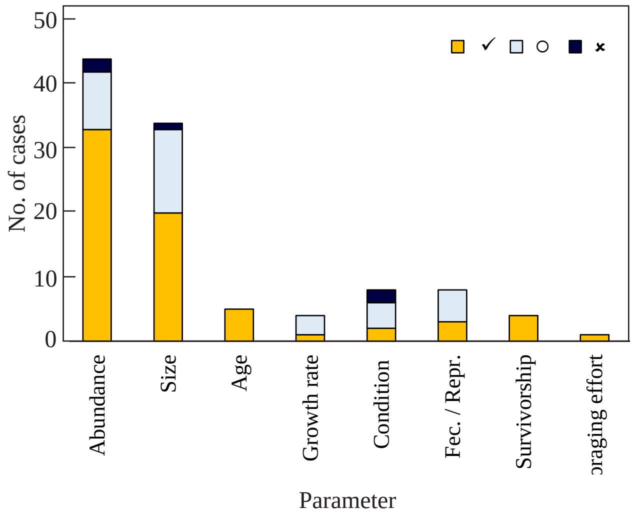

Figure 3. Literature review results showing published MPA effects at the level of individual species. Effects are categorised as positive (✓), weak, neutral, insignificant or inconclusive (O), or negative (x). The number of cases represents the sum of species per MPA for which effects were tested. Abundance is inclusive of density, catch rate, biomass and percentage cover; Size represents either length or mass; Fec. = fecundity; Repr. = reproductive output.

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21. THE POLYCENTRIC GOVERNANCE APPROACH OF THE BENGUELA CURRENT CONVENTION

The concept of Large Marine Ecosystems (LMEs) was developed to provide a uniform method to sub-divide the global ocean into functional units. The sixty-six recognised LMEs across the global ocean have been defined according to their physical and biological characteristics, and many of them span the jurisdictions of multiple countries. South Africa shares and participates in the governance of three LMEs, namely the Benguela Current LME on the west coast (BCLME), the Agulhas Current LME on the east coast, and the Antarctic LME in the Southern Ocean. To achieve effective ocean governance of these LMEs, participating governments and their various ocean sector departments are required to integrate their work, both at national and regional levels.

The governance approach of the Benguela Current Commission (BCC), an intergovernmental organisation that implements the Benguela Current Convention (member states include Angola, Namibia and South Africa), was investigated to evaluate its support to effective transboundary management. The working arrangements of the BCC are considered to be polycentric to some extent (i.e. to have multiple centres of authority, with some coordination; Fig. 1).

Higher levels of polycentric governance are favoured for regional ocean governance mechanisms because they promote multi-directional integration across authorities, towards a common goal. In the case of the BCC, this common goal is the implementation of the ecosystem-based approach to ocean governance, nationally, regionally and globally. Specialist Working Groups (WGs), where each member state is represented through national departments and agencies across ocean sectors, are key to the success of the polycentric approach. The function of WGs is to bring together experts from the member states to contribute towards regional information sharing and planning.

The BCC would be able to achieve more integrated and effective polycentric governance through defining and implementing coherent transboundary governance objectives and interventions. Actions must be cross-sectoral and co-designed across the active user sectors and member states. Water quality standards, for example, can be defined as common precautionary guidelines for active economic sectors and management authorities, in each of the member states.

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Further reading: Naidoo et al. 2021. *Frontiers in Marine Science* 8:703451

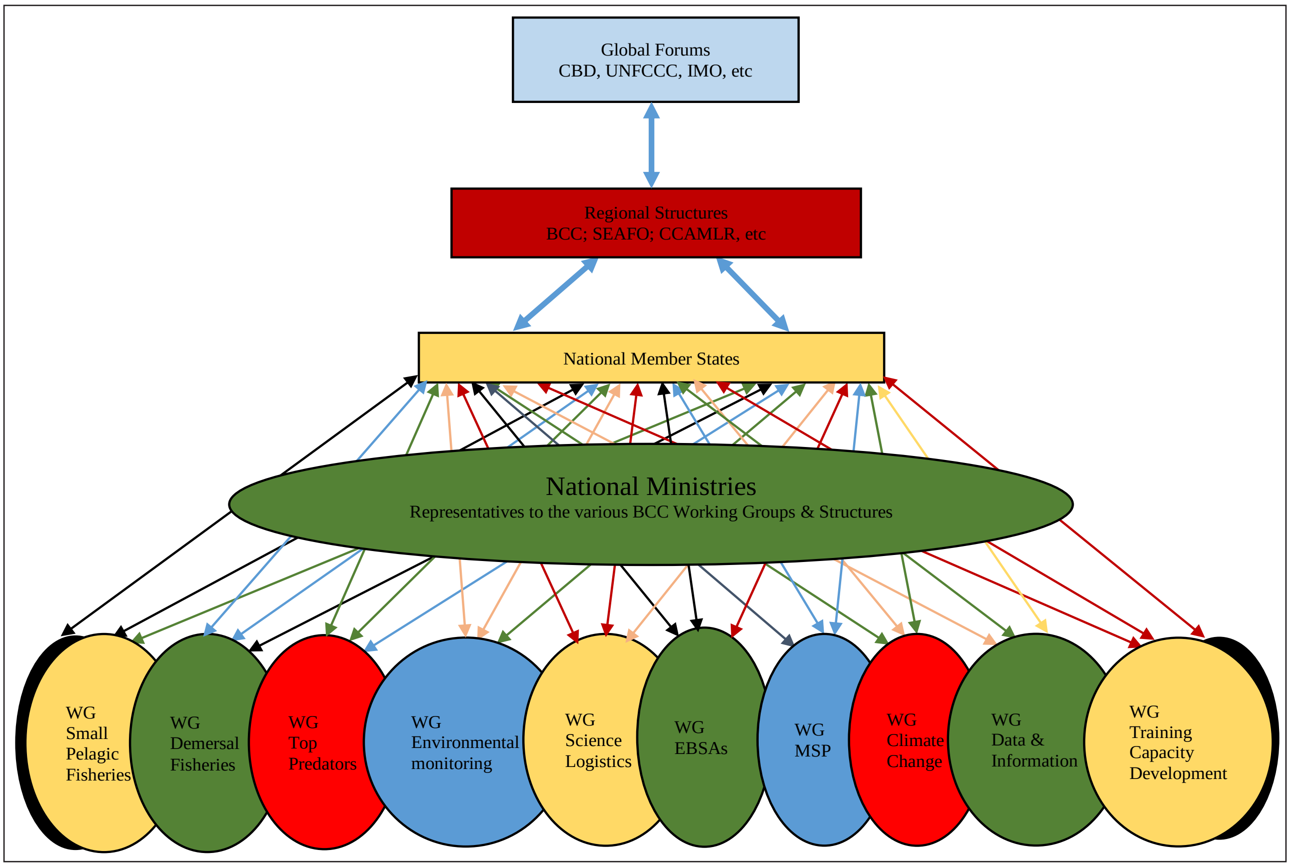

Figure 1. Simplified schematic illustration of governance architecture around the BCC (adapted from Naidoo et al. 2021). Note that not all global and regional forums and their linkages are shown. WG = working group. EBSAs = Ecologically and Biologically Significant Areas; MSP = Marine Spatial Planning; SEAFO = South East Atlantic Fisheries Organisation; CCAMLR = Convention for the Conservation of Antarctic Marine Living Resources CBD = Convention on Biological Diversity; UNFCCC = United Nations Framework Convention on Climate Change; IMO = International Maritime Organisation.

22. INTERACTIONS BETWEEN CAPE FUR SEALS AND CAPE GANNETS AT MALGAS ISLAND - A NEED FOR URGENT MANAGEMENT INTERVENTION

The Cape gannet *Morus capensis* is an iconic seabird species, endemic to southern Africa and classified as Endangered in terms of IUCN Red List criteria. All the extant breeding colonies of this species face various threats, and at Malgas Island in the Western Cape, predation by Cape fur seals is one of the major threats currently. It is likely that historically these species bred in close proximity to each other on the same coastal islands, before severe modification of the islands due to unregulated seal harvesting, and exploitation of seabird eggs and guano. Seals were prevented by humans from hauling and settling on the islands while they were being managed for exploitation of the seabird products. However, since these activities ceased in the 1980s, seals are now able to haul out at such locations without being disturbed.

In the last two decades, a shortage of forage fish off the west coast of South Africa has been evident in the annual diet samples of Cape gannets at Malgas Island. Seals, which have considerable dietary overlap with the gannets, are also likely to have been affected by the same prey shortages. An increase in predation of gannets earlier this century, particularly of fledglings in the waters around the island, was therefore considered to be a likely consequence of the reduced availability of the seals' normal prey. As a management intervention to address the predation, culling of "rogue" seals commenced, successfully reducing seal-gannet predation. Unfortunately, the effort was not sustained, and predation by Cape fur seals on Cape gannets has become a regular occurrence in the waters around the island.

More recently (since 2015), a new phenomenon has been detected on Malgas Island, whereby seals are observed predating on Cape gannets on their nests within the colony (Fig. 1). As a result, the extent of the colony has contracted considerably since 2016 (Fig 2; Table 1). Birds nesting on the periphery of the colony are more exposed to predation, thus breeding success will be higher in the interior of the colony. The change to the colony shape is therefore most likely a behavioral adaptation, with experienced birds selecting nest sites that minimise exposure to predation. Interestingly, the average distance between neighbouring nests has remained relatively constant. This is because aggressive interactions with neighbours also influences breeding success, therefore nests are spaced to minimise these interactions.

Figure 1. A collage of dead Cape gannets with various kill marks as a result of seal predation at Malgas Island, December 2021.

Table 1. Details of area reductions at the Malgas Island Cape gannet colony, 2016–2019. Note that in each year there is recruitment of breeding birds.

Year	Colony Area (ha)	Area lost to seal predation
2016	1.07	0.01
2017	0.82	0.25
2018	0.82	0.0
2019	0.7	0.012

With predation now occurring both on land and in the surrounding waters at Malgas Island, the impact of Cape fur seals on this Endangered species is greater than ever. Only three breeding colonies of gannets exist in South Africa and urgent management intervention is therefore vital.

Figure 2. A visual presentation from above of how the Cape gannet breeding colony at Malgas Island has changed in shape and extent between 2016 (left) and 2019 (right).

Recommendations

The islands should be manned, at least during the Cape gannet breeding season, if not for the whole year. Seals must be discouraged from hauling out or settling on the immediate islands, and the culling of "rogue" seals both on the island and in the surrounding waters is recommended. The use of streamers or scarecrows erected at the seal entry point to the gannet colony should be assessed as a possible mechanism to deter seals from approaching nesting birds.

Authors: Masotla MJ, Dyer BM, Visagie L, Crawford RJM, Makhado AB (OC Research)

23. THE FIRST SATELLITE TRACKING OF MOVEMENTS OF LONG-FINNED PILOT WHALES IN SOUTH AFRICA

Two species of pilot whale, the short-finned *Globicephala macrorhynchus* and long-finned pilot whale *G. melas* (Fig. 1), occur in South African waters. The former species is thought to be confined to the southwest Indian Ocean whereas *G. melas* inhabits the southeast Atlantic Ocean, where it prefers deep waters along the continental shelf, and tends to follow prey inshore. Historical data from stranded animals indicate that the diet of *G. melas* is dominated by the oceanic squid *Todarodes angolensis*. Stomach contents of recently stranded animals were almost exclusively full of yet to be identified squid beaks, which tend to be retained in the gut such that other consumed prey (e.g. fish) are underrepresented in the stomach contents of stranded animals.

Figure 1. Long-finned pilot whale with characteristic light streaks behind the eye and dorsal fin.

Until recently, information on *G. melas*' distribution was based only on stranding records. However, dedicated effort by DFFE scientists and valuable reporting by water users (e.g. divers) has generated new records of live encounters offshore of south and west South Africa. Observed group sizes ranged from 8–100 individuals (Fig. 2).

In August 2021, two adult *G. melas* individuals were tagged opportunistically with Spot 5 range tags in an Impact Minimally Percutaneous External-electronics Transmitter (LIMPET) configuration. The tags (767 and 772) were configured to transmit daily and were deployed remotely, using a crossbow, into the dorsal fin and the base of the dorsal fin. They attached to the fin by means of titanium darts with backward-facing petals. Tags 767 and 772 transmitted for 12 and 15 days respectively, resulting in a total of 62 and 74 transmitted positions (Fig. 3). During the study, 767's movements were within latitudes 33–36°S, from offshore of Cape Columbine to the Agulhas Bank. The movement patterns of 772 were within latitudes 32.8–34.8°S,

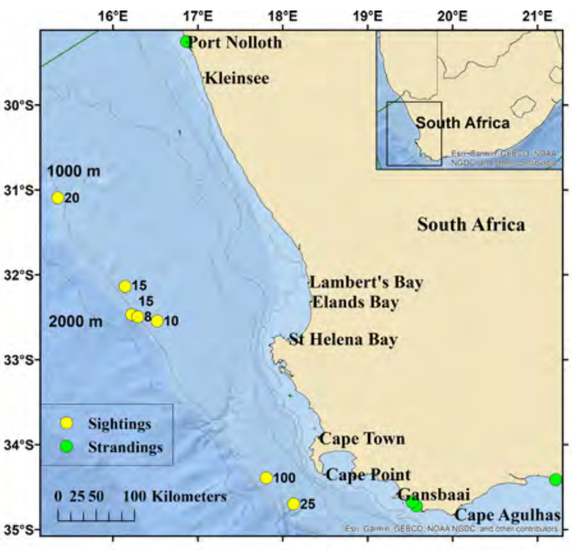

Figure 2. Distribution of long-finned pilot whales. The number of sightings is indicated at each location.

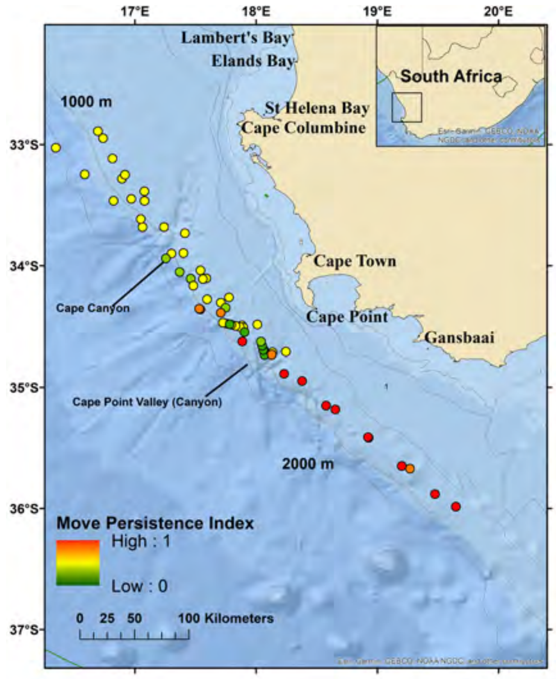

Figure 3. Estimated move persistence by both *G. melas* individuals along the satellite tracks.

corresponding with areas offshore of Cape Columbine and southwest of Cape Point. Movements were confined to the edge of the continental shelf, with 767 travelling 1,460 km in total, and 772 travelling 941 km.

A time-varying move persistence (mp) model was used to objectively identify changes in movement patterns of the two animals along a continuum (index 0–1). Higher index values infer travelling, while lower values indicate area-restricted-search behaviour, which is associated with feeding (Fig. 3). Model output indicated that *G. melas* conducted area restricted searches mostly along the continental shelf edge, with concentrations in canyon areas, especially around the Cape Point Valley, and to a lesser degree around the Cape Canyon.

The waters above underwater canyons are known to be highly productive and are targeted by commercial fisheries in South Africa. Although no squid fishery operates along this portion of the continental shelf, the association of these two *G. melas* individuals with the underwater canyons regions suggests that there could be target prey in these areas. Surveys should be undertaken in these areas to assess the abundance and distribution of squid and other potential prey species of these oceanic cetaceans.

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Acknowledgements: We thank Barry Stringer of Hout Bay Charters for providing a boat for the tagging trip. Tegan Carpenter-Kling is acknowledged for troubleshooting the model in R-Studio

24. EFFECTS OF LIMITED FORAGE FISH AVAILABILITY ON AFRICAN PENGUINS

The status of many predator populations is dependent upon availability of prey, which can influence foraging effort, body condition and various demographic parameters, including survival, breeding participation and success. Insufficient food resources may negatively affect demographic parameters, leading to population decreases. Given current and projected future change in South Africa's marine environment, there is growing concern regarding potential effects that climate-mediated shifts on the availability of prey will have on the long-term viability of marine top predator populations, including seabirds.

In the Benguela ecosystem, the African penguin *Spheniscus demersus*, is one of four endemic seabird species that is currently classified as Endangered in terms of IUCN criteria. Each of these species is known to compete with fisheries for prey, and prey depletion is recognised as a major driver of recent declines in their populations, although other threats have been noted. Seabirds are central-place feeders during breeding, meaning that they must regularly return to their breeding colony, and as such they have limited foraging ranges. The foraging range of the African penguin during breeding is especially limited because it must swim to find food, unlike volant (flying) seabirds. They are therefore particularly vulnerable to impacts of localised exploitation on prey availability around their breeding colonies.

African penguins depend mainly on energy-rich small pelagic fish, especially sardine *Sardinops sagax* and anchovy *Engraulis encrasicolus*, for food. Both abundance and quality of prey are important in influencing the penguins' population dynamics. However, small pelagic prey has undergone both distributional shifts and declines in biomass in the last two decades. The size of the African penguin breeding population appears to be highly related to the changing biomass of small pelagic prey, and has declined correspondingly (Fig. 1). As the penguin population declines, colony sizes also dwindle, rendering them susceptible to Allee effects (reduced growth rate due to overcrowding) and higher probabilities of extinction. Based on empirical evidence, for a colony to have 0% likelihood of extinction in the medium term (40 y), it requires >5,000 breeding pairs. In 2004, three colonies exceeded this size, but none do currently (Fig. 2). Most colonies are now <100 breeding pairs with a very high likelihood of extinction, while several others are extinct.

Conservation efforts should focus particularly on remaining colonies with 1,000–5,000 breeding pairs, which are estimated to have only a 33% probability of extinction over 40 y, as opposed to colonies with <250 breeding pairs and a 100% likelihood of extinction. With food shortage likely driving the decline, it is vital to ensure adequate food availability within range of breeding colonies. Interventions to achieve this may include closing important seabird foraging areas (often adjacent to key colonies) to relevant fishing, implementing ecosystem thresholds below which such fishing is restricted, or attempt to artificially establish new colonies in the vicinity of prey resources.

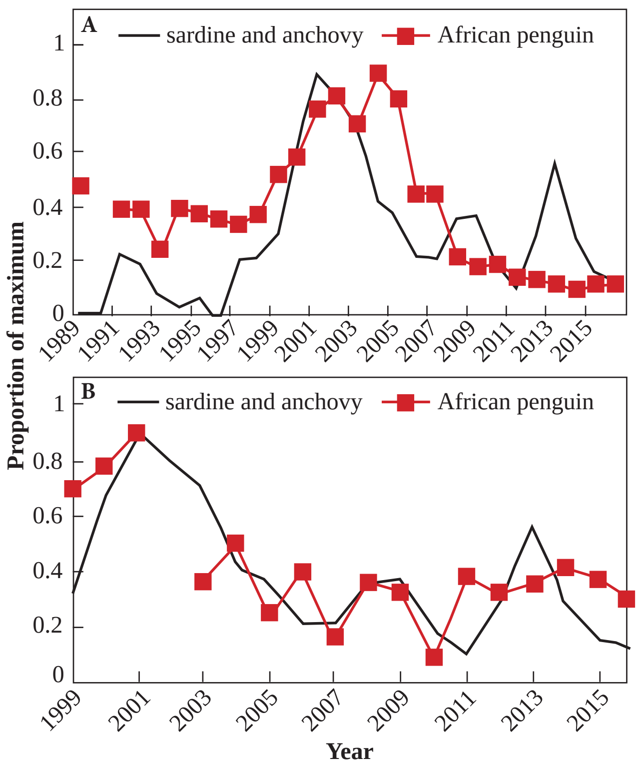

Figure 1. Comparison of time series of standardised estimates (maximum = 1) of the combined sardine and anchovy biomass versus the breeding population size of African penguins, for (A) the west and southwest coasts of South Africa (1989–2016) and (B) Algoa Bay colonies (1999–2016).

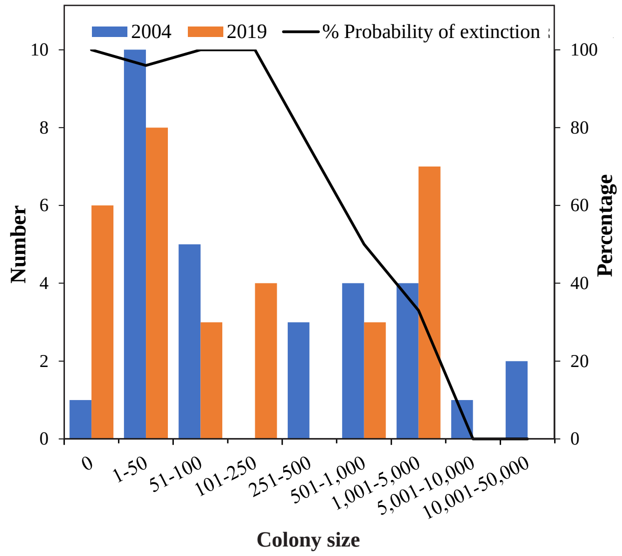

Figure 2. Numbers of African penguin colonies in different size categories in 2004 and 2019 in South Africa and Namibia (bars, left y-axis). Also shown is their probability of extinction over a 40 y period (black line, right y-axis), based on empirical information in Crawford et al. 2001 (*South African Journal of Marine Science* 23: 435–447). The 0-category for colony size includes colonies that existed in 1956, but were extinct by 2004 or 2019.

Authors: Makhado AB, Crawford RJM, Dyer BM, Visagie L, Masotla MJ (OC Research)

25. MORTALITY EVENT OF CAPE FUR SEALS IN SOUTH AFRICA DURING 2021

Cape fur seals *Arctocephalus pusillus pusillus* breed off the coasts of Angola, Namibia and South Africa. The South African population, which includes colonies at 25 localities, mostly on the west coast (Fig. 1), was estimated at ca. 725,000 individuals in 2020. This is about 40% of the total population, which has previously been estimated at up to 2 million. Known threats to the conservation of the species include entanglement in fishing gear, bycatch during trawling, overfishing and environmental perturbations affecting prey availability, increased impacts of extreme weather (storms drowning pups, heat stroke) and epidemic diseases.

Mass mortalities in Cape fur seals have previously only been reported for Namibia. The 1994/95 mass mortality event in Namibia was the largest known for any seal species. In South Africa, an unprecedented mortality event was recorded between September and December 2021. Mostly pups and juveniles were affected, at colonies around the West Coast Peninsula (Fig. 1) and to the north (i.e. Lambert's Bay and Elands Bay). Approximately 1,660 dead seals were found on the beaches, and subsequently buried. Sporadic reports of emaciated seals were also received from the south coast and as far east as Gqeberha.

Post-mortem investigations of carcasses (Fig. 2) revealed that seals died in a poor condition with reduced blubber reserves. Protein energy malnutrition was detected for aborted foetuses, for juveniles and subadults, and for one adult. A series of tests for bacteria (e.g. brucella and salmonella), viruses (e.g. distemper and avian influenza) and biotoxins (e.g. domoic acid and dinophysistoxin) were conducted to identify possible underlying factors.

All test results were negative or insignificant, although the negative results for domoic acid may have been affected by delayed testing due to limited laboratory availability and funding. Some dying seals were observed to undergo convulsions, which commonly occur due to domoic acid poisoning. However, these signs can also be attributed to hypoglycaemia (abnormally low blood sugar), which can be caused by long-term starvation.

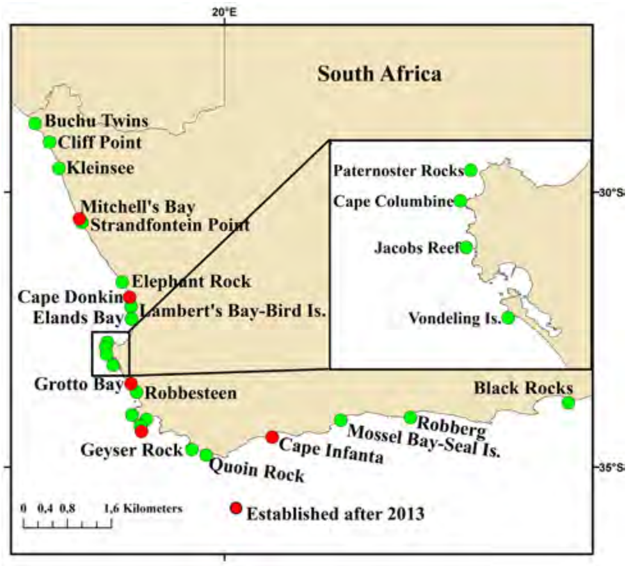

Figure 1. Distribution of Cape fur seal colonies around South Africa.

Figure 2. Dead seal pup found lying on a rock in St Helena Bay during the 2021 mortality event.

No unusual environmental conditions that may have triggered the die-off, or caused it indirectly, could be identified. For example, there were no harmful algal blooms (HABs), which typically occur at a different time of year (February-March). The 2021 wind forcing, circulation patterns, and water column structures (vertical variations in temperature and salinity) near the affected colonies showed no obvious differences compared to environmental conditions observed during 2020. Nevertheless, fisheries research surveys showed 2021 to be a year of below average recruitment of anchovy and sardine, which are favoured prey of seals. Fisheries catches were also poor, with only 44.4% of the Total Allowable Catch (TAC) being landed. These results support the low availability of at least some of the seals' prey resources.

However, the underlying causes of the 2021 mortality event remain uncertain. Various samples have been preserved for future testing using alternative methods in collaboration with the international community. On the positive side, the event provided a learning experience for veterinary pathologists and marine biologists alike. In a process led by the state veterinarian and DFFE, a monitoring protocol, including sampling and testing guidelines, will be developed prior to the next breeding season. It is envisaged that these new protocols will enable early detection of diseases and poor health in the seal populations.

Authors: Seakamela SM, Kotze PHG, McCue SA, De Goede J, Lamont T (OC Research), Pieterse J (Cape of Good Hope SPCA), Smith M (CSIR), Anthony T (Western Cape Department of Agriculture)

Acknowledgements: We thank organisations that participated in monitoring and responding to this event; including West Coast Seal Project, SeaSearch and Hout Bay Seal Rescue

26. OCIMS DATA MANAGEMENT RESPONSE EFFORTS TO THE AVIAN INFLUENZA OUTBREAK

Between October and November 2021, the Western Cape Government (WCG) veterinary services reported that approximately 18,388 birds had died as a result of an avian influenza (AI) outbreak. Of these mortalities, 17,926 were Cape cormorants *Phalacrocorax capensis*, an Endangered species that is endemic to Southern Africa. While it was not declared a disaster, the Provincial Disaster Management Centre (PDMC) was activated in September 2021 to coordinate the response, in the interest of public heath and safety.

Initial reporting mechanisms were uncoordinated, with information received in various formats such as text messages, spreadsheets, social media or telephonic reports. There was thus a need to formalise a coherent reporting structure that could incorporate locational information to monitor the spread of the outbreak. The DFFE Oceans and Coastal Management Information System (OCIMS) team proposed the use of Geo Apps for in-field data collection that can be deployed on any Windows, Android or IOS device.

Thus, with input from the WCG, a data capture form using an online platform (ESRI Survey123) was developed to provide information to better manage the current event and serve as a technology pilot for improved management of future events. The platform creates and stores data in a cloud-hosted geodatabase comprised of spatially enabled homogenous groupings of features with standardised attributes. The primary attributes include the bird species, time, date, location, condition of the affected bird(s), interventions and images where available. To facilitate the data capture process, the forms are accessible through a simple graphical user interface on the user's device (Fig. 1).

Geodatabases are spatially enabled, meaning data can be seamlessly integrated into various visualisation applications. Thus, an interactive webmap was developed and hosted in DFFE's ArcGIS Online cloud. The map updates in real time, and allows universal access to a single source of data at any given time. On conclusion of the declared incident, the data will be made available for general access via the Marine Information Management System (MIMS). Between 1 October 2021 and 31 January 2022, the app was used by delegated trained officials to report multiple affected bird species found during 297 individual coastal monitoring patrols. Data were submitted at the time of observation and were immediately available for interrogation, visualisation and/or download via the webmap. Subsequently, the time-enabled data provided an animated visual depiction of the spread of the outbreak, based on the date, time and location of observations (Fig. 2).

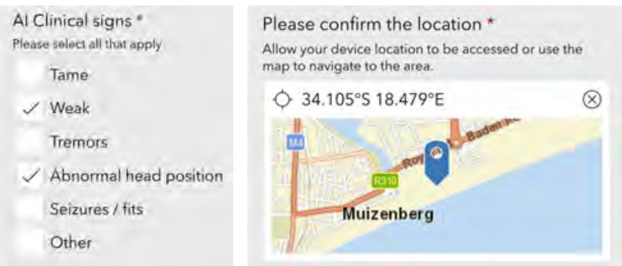

Figure 1. An example of data capture through the interface on a smartphone.

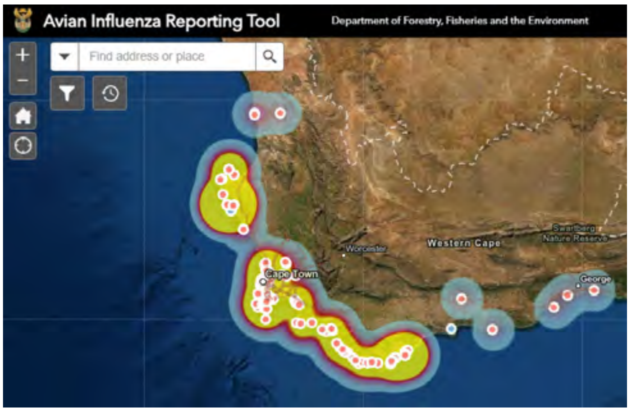

Figure 2. Online webmap interface with red dots indicating where affected birds were found, and blue dots showing where patrols occurred, but no birds were found. The hotspot intensity radius (red margins with yellow fill) depicts the total number of birds found per site, relative to other sites (a greater radius indicates a higher number of affected birds).

Through this data management approach, coordination across sectors was improved as data were received in real time and data formats were standardised and readily available for analysis and/or reporting. The time-enabled function afforded authorities the ability to visually monitor the spread of the outbreak, consider hotspots, and determine the deployment of resources. Through combined local knowledge, regular stakeholder engagements and embracing technological solutions, the overall response efforts to monitor and curb the progression of the outbreak were improved, with lessons learnt through this experience that can be applied to future extreme events.

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27. NEW MIMS WEB PORTAL IMPROVES DATA SHARING AND DISCOVERY

In 2014, OC Research, in partnership with the South African Environmental Observation Network (SAEON), embarked on a journey to preserve marine and coastal datasets collected by the South African marine science community through data hosting on the DFFE Marine Information Management System (MIMS) platform. The motivation, objectives and a brief description of the development of the MIMS were highlighted in the 2019 Annual Science Report. Here we present on recent progress, including increased functionality and user experience following the launch of the new MIMS web portal.

This portal (Fig. 1) provides access to marine observations in both (near) real-time and delayed modes, and supports a full range of processes such as data discovery, extraction, access and citation in a timely manner. Access to data is facilitated through a single-entry point. Some of the key developments that have improved data access and sharing since 2019 are the new MIMS catalogue and the new MIMS ticket system. The catalogue was developed to improve data discovery and accessibility and provide users with dynamic ways to search for datasets. The MIMS handles a large number of datasets, and the catalogue now allows keyword-driven searches to focus results, based on, for example, sensor type, project, or vessel name specifications.

The ticket system allows users to request any dataset archived on the MIMS, and also to track progress on their requests, ensuring that users receive their requested datasets in a timely manner. The ticket system also enables data providers to submit their data in a systematic way. It implements 'end to end' data management by ensuring that all requirements such as metadata records are completed prior to data submission.

The South African marine science community generates a substantial variety of data, including additional data products generated from *in situ*, satellite, and model output. The aim of the MIMS is to ingest and provide long-term archiving of all of these datasets, regardless of format. For example, the MIMS has accessioned a total of 712 recent datasets and has completed the ingestion of historical data collections from the now-defunct South African Data Centre for Oceanography (SADCO). To keep up with the growing needs of these datasets and products, newly added computing infrastructure has increased the storage and computational capability of the MIMS by 150%.

The MIMS therefore provides the gateway to South Africa's marine and coastal data collected in multiple disciplines (ocean physics, chemistry, biogeochemistry and biology), with users spending less time searching for data due to the user-friendly nature of the portal. The MIMS will also be working closely with the Benguela Current Commission (BCC) to develop a regional geoportal to expand data discovery regionally and internationally.

Authors: Rasehlomi T (OC Research), Chiloane L (SAEON), Krug M (OC Research)

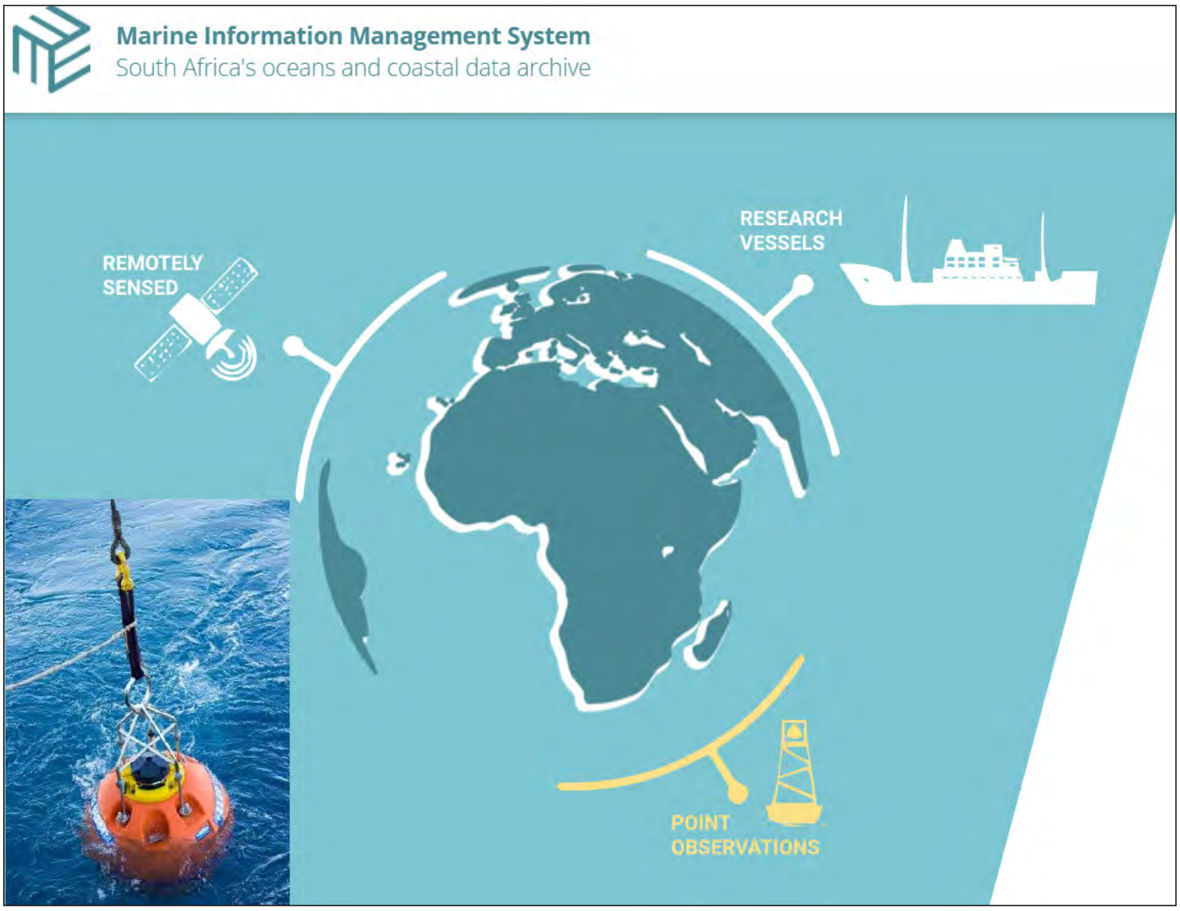

Figure 1. The MIMS web portal available via https://data.ocean.gov.za.

28. UNDERWAY TEMPERATURE MEASUREMENTS FROM THE THERMOSALINOGRAPH ON THE SA *AGULHAS* II

A Thermosalinograph (TSG) is an instrument that continuously measures *in situ* temperature and conductivity. All DFFE research vessels are equipped with a SBE38 sensor, which measures temperature at the intake on the vessel's hull, and a SBE45 TSG that measures temperature and conductivity, every 6 or 10 seconds (Fig. 1).

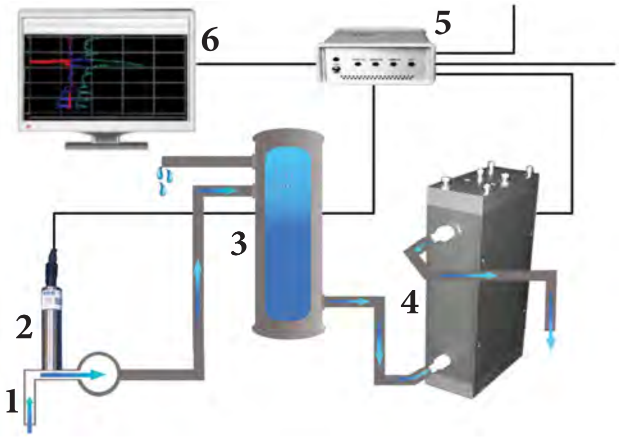

Figure 1. Simplified schematic diagram of a TSG installation: 1 = hull intake, 2 = SBE38 sensor, 3 = de-bubbler, 4 = SBE45 TSG 5 = interface box, and 6 = computer acquiring and storing TSG data.

Seawater is pumped continuously from just below the sea surface (5 to 7 m depth) through a plumbing system to the TSG (Fig. 1). Prior to the water reaching the TSG, it passes through a de-bubbler that reduces air bubbles to allow for more accurate measurements. The SBE45 measures temperature over a range of -5 to 35°C, with a resolution of 0.0001°C. The conductivity cell measures over a range of 0–70 mS cm^{-1}, with a resolution of 0.0001 mS cm^{-1}.

During the annual SA *Agulhas* II voyage in April 2020 (Fig. 2), we collected TSG data between Cape Town and the Prince Edward Islands (PEIs) and compared it to the Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA) Sea Surface Temperature (SST) data. OSTIA SST and the SBE38 temperature showed good agreement, with only minor differences, particularly at sharp gradients associated with oceanographic fronts and features. TSG data provides very high spatial resolution observations along the ship's track, while OSTIA SST has a much coarser spatial resolution. Thus, it is expected that strong gradients will be smoothed out in the lower resolution SST data.

The TSG temperature is on average 2°C warmer than the SBE38 (Fig. 2). Such consistent warming of seawater from the hull intake to the TSG is abnormal and illustrates a technical design flaw for the SA *Agulhas* II. In comparison, differences between intake and TSG temperatures on another DFFE research vessel, the RS *Algoa*, are on average well below 0.5°C. During the 2021 SA *Agulhas* II voyage to the PEIs, diagnostic tests revealed that the large temperature differences were likely due to the long plumbing lengths required to transport seawater from the hull intake to the TSG in the scientific laboratory. This plumbing is situated directly below heater-warmed decks and passes through areas of the vessel that are kept constantly warm by internal air-conditioning, further exacerbating the warming of seawater en route to the TSG.

TSG data provides high-resolution characterisations of surface temperature and salinity variations that are useful for long-term studies to identify climate-related surface oceanographic changes. This data is also required to improve knowledge on air-sea exchange, and can play an important role in validation of satellite SST, as well as other modelled datasets. Thus, continued acquisition of accurate *in situ* TSG data is crucial, and efforts to eliminate the abnormal warming of the TSG seawater supply on the SA *Agulhas* II are currently underway.

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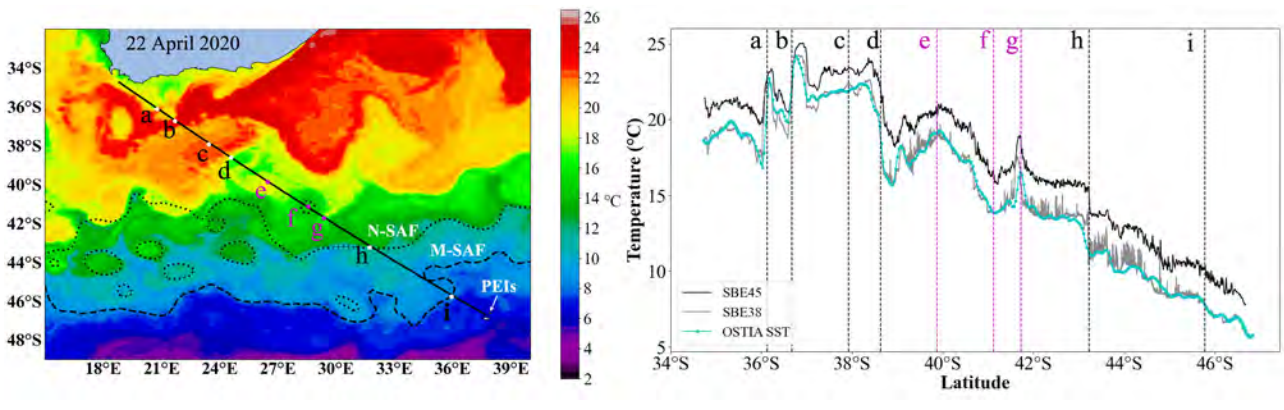

Figure 2. Left: OSTIA SST map on 22 April 2020 showing the ship's track (black line) between Cape Town and the PEIs. Right: SBE38, SBE45 and OSTIA temperature extracted along the ship's track. Labels indicate the positions of fronts (in black) and features (in purple), with a = warm water plume inshore of the Agulhas Current (AC), b = inshore edge of AC, c = northern edge of Agulhas Return Current (ARC), d = southern edge of ARC, e = anticyclonic eddy, f = cyclonic eddy, g = warm water plume advected around the cyclonic eddy, h = northern branch of the sub-Antarctic Front (N-SAF) and i = middle branch of sub-Antarctic Front (M-SAF).

29. GLORYS OCEAN MODEL CAPTURES EVENT-SCALE MESOSCALE EDDIES ON THE SOUTHEAST COAST OF SOUTH AFRICA

Due to limited societal drivers, such as large-scale fisheries and marine mining, shelf regions along the southeast coast of South Africa have remained largely under-sampled. In order to improve the understanding of hydrographic conditions and the influence of the Agulhas Current on the southeast coast shelf, DFFE, together with the African Coelacanth Ecosystem Programme (ACEP) Phakisa Ocean Cruises initiative, conducted multi-disciplinary surveys during summer and winter of 2017. These cruises provided the only high spatial resolution *in situ* hydrographic observations in this region to date. Despite providing an excellent baseline description of the shelf hydrography, they essentially remain "snapshots" of conditions during the cruise periods. Given the limited *in situ* sampling opportunities, we examined output from the GLORYS (Global Ocean Reanalysis and Simulation) model to determine whether the model can be used to investigate the influence of mesoscale eddies on shelf regions in more detail.

GLORYS assimilates satellite-derived along-track sea level anomalies, sea surface temperature (SST), as well as *in situ* temperature and salinity from profiling Argo floats. We expanded previous evaluations (see Report 27 from 2020) by demonstrating the ability of GLORYS to adequately simulate event-scale mesoscale dynamics. Although mesoscale eddies observed by altimetry (Fig. 1a, b) are all captured by GLORYS (Fig. 1c, d), there are some notable differences. On 19 January 2017, the size and shape of the cyclonic eddy (CE1) is more distinguishable in GLORYS than in the altimetry. The anticyclonic eddy (AE1) observed in the model cannot be clearly identified in the altimetry (Fig. 1a, c). Similarly, on 29 July 2017 (Fig. 1b, d), altimetry shows a single cyclonic eddy (CE2), while GLORYS shows two distinct features (CE1 and CE2), in agreement with higher spatial resolution SST data (not shown). These discrepancies are due to differences in spatial resolution between satellite altimetry (ca. 25 km) and GLORYS (ca. 8 km), which means that the model is able to resolve much smaller features than altimetry.

GLORYS simulated the water column structure over 50 different vertical levels, which allows for more detailed investigations of vertical variations. Figure 2 highlights eastward flow (in red) along the northern side of the cyclonic eddy, with westward flow (in blue) along the southern side. This image clearly demonstrates that the eddy is intensified in the upper 1000 m but extends throughout the water column. Upwelling associated with the eddy is discernible from upward-doming temperature isotherms, highlighting the movement of cold, nutrient-rich waters from deeper layers to the surface (Fig. 2). These observations illustrate that GLORYS effectively simulates mesoscale ocean variability, providing daily three-dimensional views that substantially expand our contemporary *in situ* and satellite observational capability in the region.

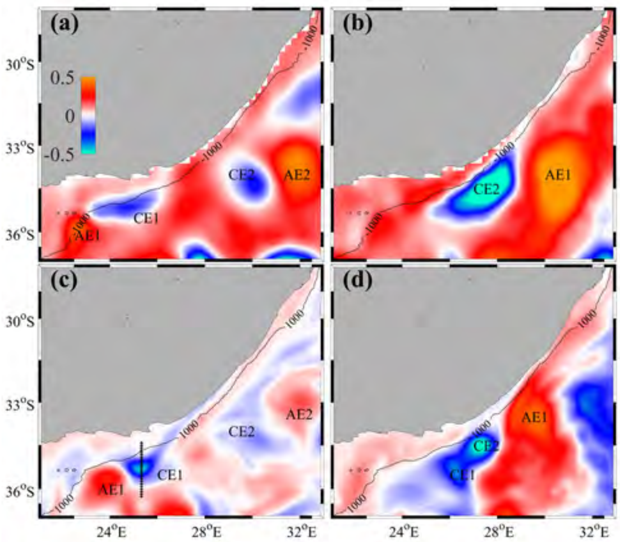

Figure 1. Sea level anomaly (SLA) maps from (a, b) satellite altimetry and (c, d) GLORYS model output, illustrating mesoscale eddies observed on 19 January and 29 July 2017. Anticyclonic eddies are labelled with AE, while CE indicates cyclonic eddies. The black line in panel (c) indicates the transect along which data for Figure 2 were extracted.

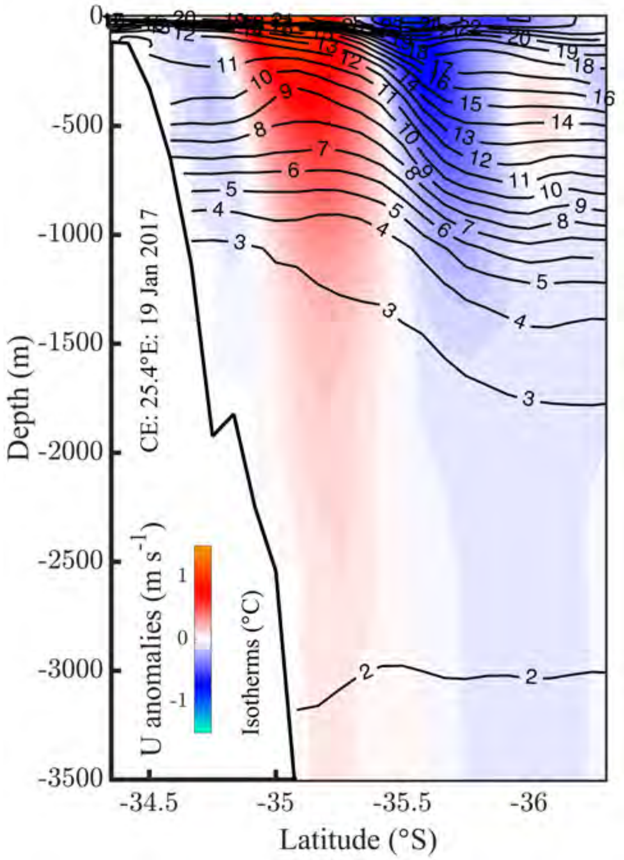

Figure 2. Vertical section of zonal (west-east) current speed (m s^{-1}) anomalies throughout the water column, along a transect (black line on Figure 1c) across the cyclonic eddy (CE). Positive values denote eastward flow, while negative values denote westward flow. Black contours indicate conservative temperature (°C).

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30. HYDROGRAPHY OF THE SOUTHEAST COAST OF SOUTH AFRICA AS DETERMINED FROM THE GLORYS OCEAN MODEL

Environmental conditions on South Africa's southeast coast are strongly influenced by the dynamics and variability of the Agulhas Current (AC), which is the strongest Western Boundary Current in the Southern Hemisphere. Previous *in situ* studies have provided clear demonstrations of upwelling that is driven by small-scale movements of the AC, as well as by mesoscale eddies along the inshore edge of the AC. This upwelling introduces nutrient-rich water from deeper depths onto the shelf, which enhances biological productivity on the shelf by stimulating increases in plankton biomass. Following on from Report 29, which demonstrated that the GLORYS (Global Ocean Reanalysis and Simulation) model captures mesoscale variability with good accuracy, we further investigated how well the model output compared with *in situ* data, collected during the summer and winter seasons of 2017. We also examined the distribution of water masses on the southeast shelf.

During January–February 2017 (summer), *in situ* bottom temperature showed cold (<10°C) water extending onto the shelf and toward the coast in the southwestern part of the region (Fig. 1a). This was a direct result of upwelling and advection associated with a cyclonic eddy along the inshore edge of the AC (see Report 29 for eddy location). In contrast, during July–August 2017 (winter), there was no eddy present along the southern part of the southeast shelf, and bottom temperatures were much warmer (>15°C), with the 10°C isotherm confined to the continental slope further offshore (Fig. 1b). Although a cyclonic eddy was observed during the July–August cruise period, this eddy was located further offshore (see Report 29 for eddy location) and had minimal influence on shelf conditions (Fig. 2b). In addition, both cruise periods showed a clear latitudinal temperature gradient, with warmer water in the north, and generally cooler water toward the south (Fig. 1).

While the *in situ* data were collected over periods of several weeks (Fig. 1), the GLORYS model simulates daily representations of oceanographic conditions throughout the region (Fig. 2). Bottom temperature maps from the GLORYS model showed excellent agreement with the *in situ* data. The latitudinal temperature gradient was also apparent in GLORYS output (Fig. 2). Similarly, shelf cooling induced by the cyclonic eddy was evident on 19 January (Fig. 2a), with relatively warmer conditions on 29 July (Fig. 2b). This provides further evidence of the ability of the GLORYS model to adequately simulate event-scale responses to mesoscale variability, suggesting that the model output provides a reasonable means of monitoring oceanographic variability in this region, in the absence of *in situ* observations. The accuracy of GLORYS is likely due to the routine assimilation of satellite data, as well as *in situ* observations from profiling Argo floats.

It is, however, important to note that model simulations are highly dependent on the choice of numerical scheme, the criteria used to parameterise it, as well as the quality and quantity of the forcing fields and assimilated observations. Analysis of water masses present on the shelf (Fig. 3) showed that GLORYS correctly captures the large-scale distribution of water masses, but fails to identify the warm, low salinity waters associated with river outflow in the surface layers during summer. This is primarily due to the absence of river discharge data in the simulation, and the lack of adequate and sufficient river discharge observations to assimilate into the model. This highlights the need to continue and expand *in situ* observations in the region.

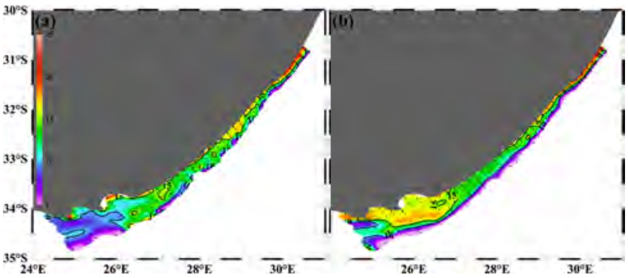

Figure 1. Maps of *in situ* bottom Conservative Temperature (°C) during (a) January–February 2017, and (b) July–August 2017. The solid black contours indicate the 15°C and 10°C isotherms. Black dots indicate sampled station positions.

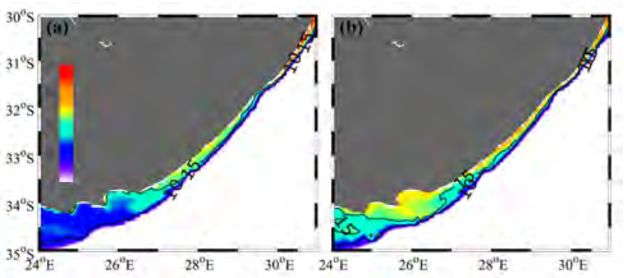

Figure 2. Maps of GLORYS bottom Conservative Temperature (°C) on (a) 19 January 2017, and (b) 29 July 2017. The solid black contours indicate the 15°C and 10°C isotherms.

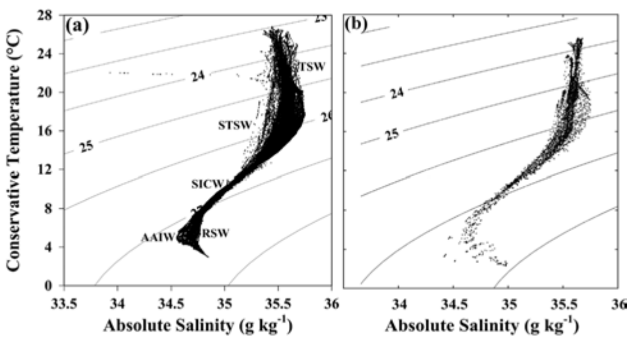

Figure 3. Conservative Temperature versus Absolute Salinity relationships for (a) *in situ* data from cruises during January–February and July–August 2017, and (b) GLORYS model output during the cruise periods. TSW - Tropical Surface Water, STSW - Subtropical Surface Water, SICW - South Indian Central Water, AAIW - Antarctic Intermediate Water, and RSW - Red Sea Water.

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31. THE SOUTH AFRICAN CONTINOUS PLANKTON RECORDER SURVEY – MAPPING PLANKTON COMMUNITIES AT THE BASIN SCALE

The Continuous Plankton Recorder (CPR; Fig. 1A) is a mechanical device designed for towing from merchant ships on their normal trading routes. It is towed behind vessels at a constant depth of ca. 10 m, allowing underway collection of both phytoplankton and zooplankton. As the CPR is towed, water enters through the front aperture, and plankton is trapped between two layers of 270-µm silk mesh. Both silks are spooled together into a formalin-preservation tank, preserving the 'plankton sandwich' until subsequent laboratory analyses.

CPRs are robust and can operate successfully at speeds of up to 25 knots and in rough seas. Although initially designed to support fisheries, CPRs have contributed to mapping seasonal, annual and long-term changes in plankton abundance and diversity since 1931 and have been towed in most of the world's oceans, including the Southern Ocean.

Plankton are sensitive to environmental change and are ideal indicators of ocean ecological health. Plankton data are therefore relevant for a range of management and conservation-related matters, including impacts of climate variability and change. Common applications include monitoring responses to ocean warming, acidification, eutrophication, pollution and fisheries, and monitoring of marine biodiversity, invasive species, harmful algal blooms, microplastics and pathogens affecting human health (e.g. cholera bacteria). Plankton data from CPRs can also contribute to biogeographic classifications, which are useful for planning of MPA networks.

A 'Proof of Concept' tow between Luanda and Port Elizabeth (Gqeberha, Fig. 1B), in the Benguela Current Large Marine Ecosystem (BCLME) was conducted successfully in Oct/Nov 2005. Selected data from this survey (Fig. 1C), includes the Phytoplankton Colour Index (PCI), which is an indicator of phytoplankton biomass, and the relative abundance of various key zooplankton taxa. Since then, 32 surveys have been conducted as part of the South African CPR survey (SA-CPR), covering over 43,000 nm (Fig. 1D). Most effort has focused on the Southern Ocean, since it is poorly sampled relative to other oceans and particularly vulnerable to climate change. In 2021, quarterly tows across the South Atlantic from Brazil to Angola were initiated as part of the AtlantECO programme.

Recent technological advances are enabling the addition of sensors to CPR bodies to measure a range of physical variables, fluorescence and even molecular information. Along with DNA extraction from historical formalin-preserved samples, these additions promise to yield valuable data on basin-scale changes in plankton biodiversity in response to climate change.

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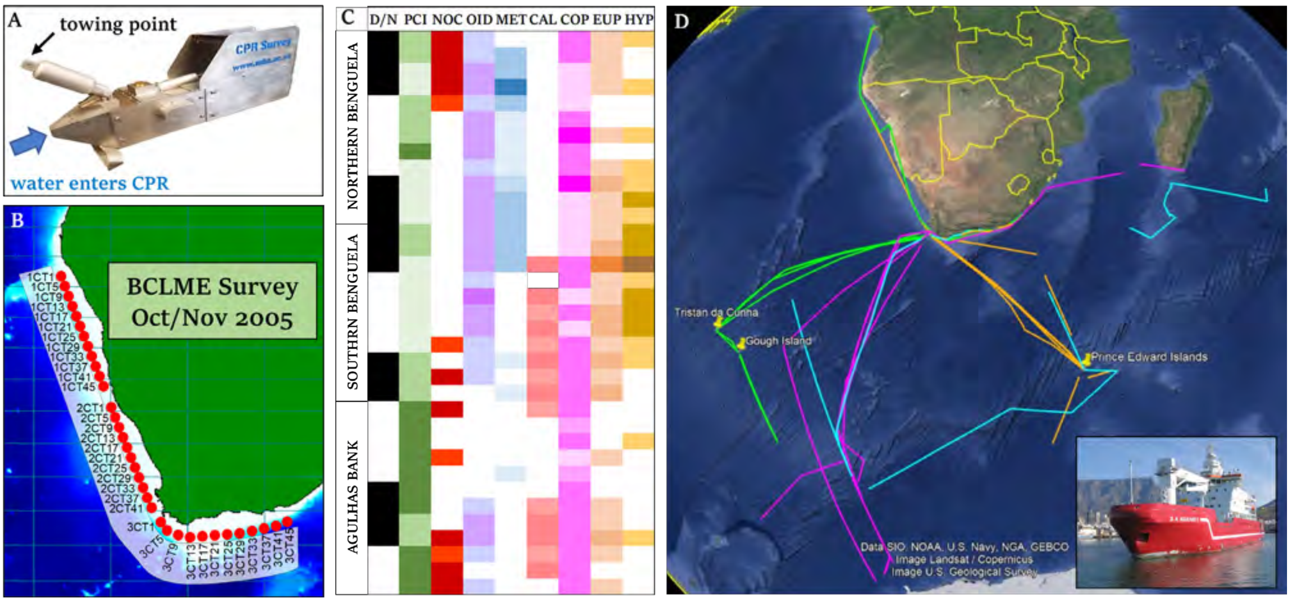

Figure 1. (A) A CPR; (B) the BCLME proof of concept tow route in 2005, with red dots indicating locations of analysed samples; (C) data from the BCLME survey in 2005, where D/N indicates day or night sampling (white or black squares respectively), PCI is the phytoplankton colour index, NOC is the red-tide species *Noctiluca scintillans*, OID and MET are upwelling-associated copepods *Calanoides natalis* and *Metridia lucens*, CAL is *Calanus agulhensis*, the dominant copepod on the Agulhas Bank, COP is total copepod abundance, EUP is late stage/adult euphausiids (krill), and HYP is hyperiid amphipods. Paler/darker shades indicate lower/higher concentrations; (D) SA-CPR tows completed to date around Southern Africa. Colour key: green = spring, magenta = summer, orange = autumn, blue = winter. Inset: the SA *Agulhas* II from which most SA-CPR tows in the Southern Ocean have been conducted.

32. THE 2022 WESTERN INDIAN OCEAN REGIONAL BENTHIC IMAGERY WORKSHOP

The Second International Indian Ocean Expedition (IIOE-2) is a globally renowned program, and one of its objectives is to enhance collaboration and capacity development within the Indian Ocean community. As part of this initiative, DFFE hosted two IIOE-2 expeditions in Mozambique, Tanzania and the Comoros during 2017 and 2018, to train individuals from the Western Indian Ocean (WIO) in a variety of marine disciplines. Participants in the benthic biodiversity team were introduced to both traditional and innovative methodologies, including underwater camera systems.

Underwater instruments such as drop or towed cameras, baited remote underwater videos (BRUVs) and remotely operated vehicles (ROVs) (Fig. 1), have increased our understanding of benthic biodiversity by enabling the collection of data from shallow and deep habitats alike. Imagery evaluations are an important research tool used by both scientists and industry, and the non-destructive nature of these techniques allows for use in protected areas.

The workshop, hosted by DFFE and sponsored by the Marine Science for Management (MASMA) programme of the WIO Marine Science Association (WIOMSA), provided training on how to use underwater imagery to better understand benthic invertebrate communities and associated fish assemblages. Initially planned as a physical workshop, it was eventually held via a Zoom webinar platform, due to the global Covid-19 pandemic. The event, which was conducted in partnership with Scifest Africa and specialists from the region and beyond, drew 266 participants (researchers, lecturers, students, technicians and interns) from within the WIO and neighbouring countries (Fig. 2).

Sessions covered: (i) An overview of benthos, showcasing findings of the IIOE-2 expeditions; (ii) Survey design using visual techniques with suitable monitoring strategies for Marine Protected Areas and the use of GIS to standardise long-term monitoring; (iii) Data collection using camera systems along with step-by-step training videos demonstrating the set-up and operation of a drop camera, towed camera and BRUVs; (iv) Annotation techniques and imagery analyses; (v) BRUV research, and (vi) Good data management practices to enhance access and utilisation of data for inputs to spatial conservation planning and management. A discussion session covered the best practices for regional-scale habitat classification, data challenges to overcoming these barriers, and developing of collaborations and infrastructure.

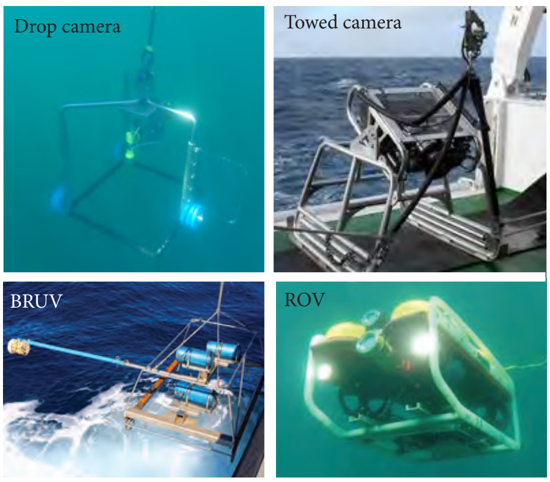

Figure 1. Examples of visual sampling equipment. Photographic credit: DFFE, SAEON, SAIAB.

Figure 2. Countries represented at the workshop. Source: L Williams (OC Research).

Workshop outcomes included: (i) International attendance with a far greater audience than anticipated prior to Covid-19 (266 vs 20!); (ii) Participants trained in the steps required to collect underwater imagery; (iii) A free online training resource (https://www.youtube.com/channel/UC3FT8SyYif6X_b1s4zchgog/videos) - a digital legacy accessible to researchers both regionally and globally; (iv) Step-by-step training videos for three different camera systems, providing both a teaching tool and a first step in standardising techniques across institutes; and (v) A well-established network for benthic-image-based research within the WIO.

There is a clear need for continued development of sampling guidelines, best practice protocols, locally relevant species identification resources and image databases in the region. Thus it is important to build on the momentum established through this workshop, while continuing to form and strengthen partnerships. In this regard, the lack of resources and infrastructure required to utilise underwater imagery may be seen as an opportunity for promoting collaboration and innovation within the region.

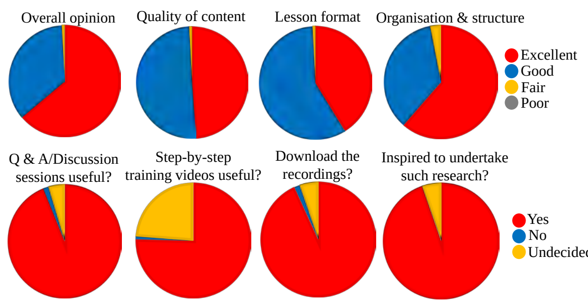

Figure 3. Workshop success, as gauged from the feedback captured in an online evaluation form.

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33. TRAINING WORKSHOP ON BIOLOGICAL OBSERVATIONS IN THE INDIAN OCEAN

Countries around the Indian Ocean rim rely on a healthy ocean to provide food security. However, climate change has resulted in numerous challenges, including ocean warming, acidification and deoxygenation, which are already having extreme impacts on ocean biology. These impacts are predicted to increase over the coming decades. Accounting for such changes in the conservation and sustainable management of the ocean requires baseline data provided by observations; however, these data are still insufficient for most of the world's oceans. Hence, one of the ten key challenges of the UN Ocean Decade is to 'Expand the global ocean observing system'.

In support of this challenge, the Indian Ocean Global Ocean Observing System (IOGOOS) partnered with the Sustained Indian Ocean Biogeochemistry and Ecosystem Research (SIBER) team, the Indian National Centre for Ocean Information Services (INCOIS), the Malaysian Centre for Marine and Coastal Studies (CEMACS), and the South African DFFE, to host a virtual training workshop on "Biological Observations in the Indian Ocean (from Microbes to Megafauna), from 8–12 November 2021. Financial and logistical support was provided by the International Training Centre for Operational Oceanography (ITCOocean) at INCOIS and the Intergovernmental Oceanographic Commission (IOC) of UNESCO.

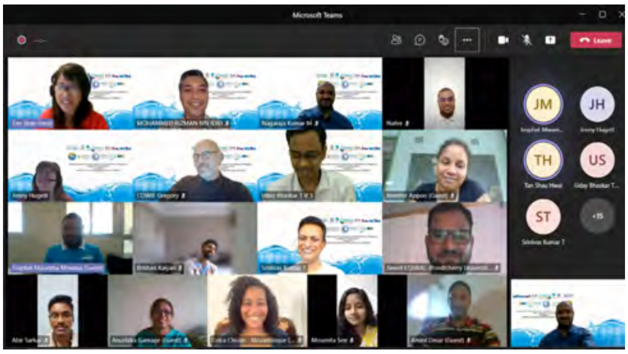

Figure 2. Screenshot from a feedback session with young Indian Ocean researchers.

The main objectives of the workshop were to (i) promote the need for sustained biological observations in the Indian Ocean, (ii) promote best practices for biological observations in the Indian Ocean, and (iii) present methods which are practical and affordable, as well as those considered as state of the art. This vision was guided by the Essential Ocean Variable (EOV) framework developed by GOOS. Biological EOVs have been defined for six Functional Groups and four Habitat States (Fig. 1).

The workshop was attended by 70 students and young researchers from 22 countries (mainly Indian Ocean Rim, Fig. 2), with training provided by experts from Australia, Kenya, Malaysia, Mozambique, Philippines, Réunion, South Africa, the United Kingdom and the USA. Techniques that were presented include microbial imaging and sequencing; applications of Bio-Argo data, remote sensing applications for harmful algal blooms, fronts and fisheries, seagrass and mangrove cover, and megafauna; zooplankton image analysis and metabarcoding; eDNA; benthic imagery (various camera and video platforms including ROVs, AUVs and BRUVs); and acoustic telemetry and satellite-tagging for fish, sharks, turtles, seabirds and mammals.

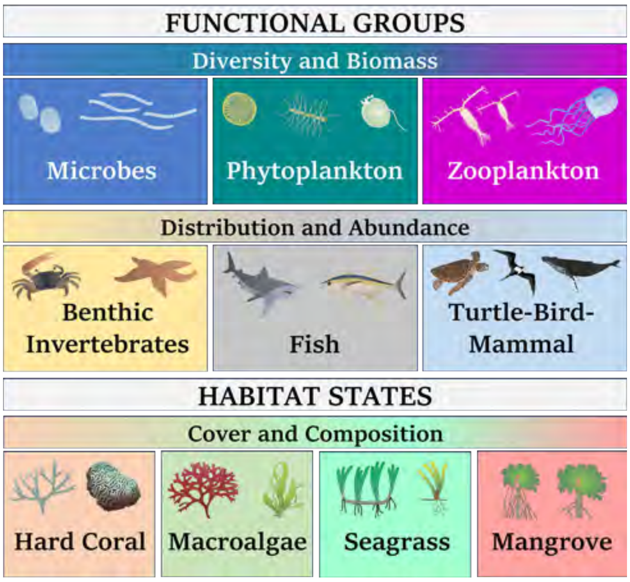

Figure 1. GOOS Biological Essential Ocean Variables (EOVs).

A keynote presentation on 'The use of biological indicators in ecosystem assessments' addressed the importance of developing ecological indicators that are fit-for-purpose and regionally meaningful. These include indicators for locally relevant organisms (e.g. *Noctiluca*), and for physical features influencing local biology (e.g. boundary currents).

A desired outcome for this workshop was enhanced regional networking, collaboration and mentorship opportunities, and to create a cohort of regional ambassadors for biological observations (Fig. 2). Adoption of standardised methodology and data collection protocols will enable comparisons and integrated data analysis across the region. This approach will be promoted in future regional workshops, including hands-on training sessions.

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