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OCEANS AND COASTS

ANNUAL SCIENCE REPORT, **2019**

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Environment, Forestry and Fisheries
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TOOLS AND TECHNOLOGIES

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LIST OF ACRONYMS AND ABBREVIATIONS

Branch O&C	Branch: Oceans and Coasts, Department of Environment, Forestry and Fisheries
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
CPUT	Cape Peninsula University of Technology
CSIR	Council for Scientific and Industrial Research
CTD	Conductivity-temperature-depth instrument
DSI	Department of Science and Innovation
Ezemvelo	Ezemvelo KZN Wildlife
Fisheries Research	Fisheries Research, Department of Environment, Forestry and Fisheries
IUCN	International Union for the Conservation of Nature
KZN	KwaZulu-Natal
MPA	Marine protected area
MIMS	Marine Information Management System
MODIS	Moderate Resolution Imaging Spectroradiometer
NMU	Nelson Mandela University
O&C Research	Chief Directorate: Oceans and Coastal Research
OCIMS	Oceans and Coastal Information Management System
SAEON	South African Environmental Observation Network
SANBI	South African National Biodiversity Institute
SANParks	South African National Parks
SAWS	South African Weather Service
SB: IEP	Southern Benguela: Integrated Ecosystem Programme
SST	Sea surface temperature
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
The Department	Department of Environment, Forestry and Fisheries
UCLA	University of California, Los Angeles
UCT	University of Cape Town
UKZN	University of KwaZulu-Natal
UNISA	University of South Africa

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COVER IMAGE

The Prince Edward Islands, comprising Marion Island (bottom left) and Prince Edward Island (top right). Natural colour image courtesy of NASA Earth Observatory, captured by the Advanced Land Imager (ALI) on board NASA's Earth Observing-1 (EO-1) satellite, on 5 May 2009.

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SUMMARY FOR DECISION AND POLICY MAKERS

O&C Research and Monitoring

South Africa's Oceans and Coasts Annual Science Report, 2019, presents results of research and monitoring conducted by the Department's Chief Directorate: Oceans and Coastal Research (O&C Research) on a number of physical, biological and chemical aspects of oceans and coasts (including estuaries) around South Africa, in the Southern Ocean, or other parts of the African ocean regions. The science activities of the Chief Directorate support the purpose of the Branch Oceans and Coasts in the "promotion, management and strategic leadership of oceans and coastal conservation in South Africa". The various science programmes are guided by a medium- to long-term ecological research and monitoring plan that was developed for the period 2016–2030.

The plan is centred on describing and documenting marine and coastal biodiversity and complex ecosystem functioning and processes. Changes in the types and distribution of marine biodiversity, and in the physical and chemical variables that influence biota, can be identified and tracked over time. Where changes are observed, further investigations into potential drivers and stressors can be undertaken. These may include global trends associated with climate change such as increasing ocean temperature and acidification, changes in ocean currents, or local drivers such as waste water pollution or development encroaching on coastal breeding habitat of wildlife. Interrogating these observations and building scientists' and policy makers' understanding of marine ecosystems is essential for developing appropriate advice and recommendations for the use of marine resources, and for conservation and management measures.

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. These projects allow for deeper understanding of specific areas or ecosystem processes. Thus, as in the Annual Science Report for 2018, this report has a section dedicated to Monitoring Programmes with summary updates for the last calendar year, and a section for Research Highlights, presenting summaries of research that has been published or presented at symposia during 2019.

The Department undertakes science activities with internal staff and also seeks to partner and support the various national marine research nodes in other departments and universities. Integral to the plan is development of human capacity and technological innovation in the marine sciences. Wherever applicable, capacity development of staff, interns, students and outside researchers is emphasised in the contributions to this report. In addition, a new section on Tools and Technologies has been incorporated to showcase technological developments in support of O&C Research's various programmes.

Data and information products generated from the research and monitoring activities must be useful for informing managers and policy makers, as well as the broader scientific community and the public. In addition to the national needs and priorities, the plan takes into account the strategic goals, requirements or guidance of international and regional organisations and agreements. These include United Nations Sustainable Development Goals (SDGs), Aichi targets of the Convention on Biological Diversity (CBD), the Strategic Action Programme of the Benguela Current Convention (BCC), the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), the Intergovernmental Panel on Climate Change (IPCC) and numerous others. Globally these organisations play important roles in that they provide platforms for discussions on policy direction regarding the use and status of natural resources, across terrestrial, freshwater, atmospheric and marine ecosystems.

Increasingly these organisations require basic information on natural systems so that management directions can be guided, but also to measure successes and failings of already implemented interventions. Notable science interventions on the oceans include the 2019 IPCC Special Report on the Oceans and Cryosphere in a Changing Climate, and the declaration of the United Nations Decade for Ocean Sciences (2021–2030). All countries are urged to maintain and increase science investments in describing and understanding the ocean and the role it plays in the planet system. The contributions in the report provide evidence of South Africa's ongoing investment in this regard.

The body of this report is made up of 36 contributions, termed report cards. Sixteen of the report cards are listed under the heading "Monitoring Programmes", a further thirteen of them summarise "Research Highlights", and seven showcase "Tools and Technologies". At the end of the report is the list of scientific outputs for 2019 including peer-reviewed publications and other products that speak to both the volume and quality of work accomplished by O&C Research. Producing high quality products, publishing findings in peer-reviewed literature and aiming for open dissemination of the data and data products that are generated, are considered to be key for ensuring that the research and monitoring remains relevant, applied and appreciated.

Report summary

In 2020, it is well recognised that climate change and our increasing use of the ocean are affecting important marine ecosystems and biodiversity, including marine resources, from local to global scales. To be able to balance use of ocean resources with the capacity of ocean ecosystems and biodiversity to sustain such utilisation, requires effective governance and management. This in turn needs to be supported by up-to-date ocean data and knowledge of biodiversity status and trends, in order to be able to improve forecasting abilities, respond with adaptive management or mitigation measures, and sustain the ocean economy.

To meet the needs for ocean data, Essential Ocean Variables (EOVs) have been identified as summary set of observations that balance information or knowledge requirements and cost-effectiveness for ocean science in a global context. EOVs include physical, biogeochemical, biological, as well as ecosystem variables. One of the main functions of O&C Research is to maintain long-term measurements of EOVs across South Africa's immediate ocean space as well as in the deeper ocean surrounding it. The EOVs are supported by a number of other related measurements to better understand the changes and variations observed. Collectively, these variables should provide an indication of how healthy and productive the oceans around South Africa are, and how they are changing in the short-, medium- and longer-term, thus contributing to the knowledge base on which to build policy and management actions. The Chief Directorate works, in partnership with other government science agencies, to increase observations of EOVs in the coastal and offshore areas adjacent to South Africa.

Time series of EOVs and related variables for South African waters and the Southern Ocean that have been updated or initiated in 2019 and are summarised in this report, include: coastal upwelling, hydrographical conditions of the ocean's surface, chemical and physical properties of the ocean bottom including dissolved oxygen levels and sea temperature, seawater pH and carbonate chemistry, currents, chlorophyll concentrations, zooplankton diversity and biomass, seabird and marine mammal abundance and diet, and pollution. These are discussed here, along with key research findings, in the context of global patterns and projections of changes in marine systems.

Updated upwelling indices for the past few years for West Coast upwelling cells support that there has been a long-term increase in the intensity of upwelling in the southern Benguela, as predicted under climate change. Increased upwelling is usually associated with more productive ecosystems, largely because the higher availability of nutrients in the upper layers during upwelling-favourable periods leads to greater biomass of phytoplankton, the basis of marine food webs. Therefore it is perhaps surprising that chlorophyll *a* concentrations, which provide an indication of phytoplankton biomass, have shown a slight downward trend in the long-term on the West Coast, and also the South Coast (after correcting for differences in satellite sensors). Typically of marine ecosystems associated with upwelling, strong interannual and seasonal variability in the data make it difficult to distinguish longer-term patterns, motivating for substantially more years of data to properly recognise long-term trends in spite of short-term variability.

Such variability in upwelling and productivity influence trophic transfer from the "bottom-up" in the marine food chain, affecting zooplankton, foraging fish, and higher predators such as seabirds. On the South Coast, a significant decline in the biomass of copepods (zooplankton), which feed largely on phytoplankton, was evident between 1998 and 2011, after which there was a five year hiatus in sampling. While bottom-up variability affects zooplankton, this decline has cautiously been attributed to "top-down" control by small pelagic fish such as anchovy *Engraulis encrasicolus* and sardine *Sardinops sagax* that prey on copepods. The period of reduced copepod biomass coincides with the eastward shift in small pelagic fish on the South Coast, with a greater proportion of adult anchovy and sardine located east (compared to west) of Cape Agulhas since the late 1990s. An increase in copepod biomass evident since the resumption of sampling (2016) is thought likely to be due to a decrease in small pelagic fish biomass in recent years, especially for sardine in the last decade.

Food availability, in particular the availability of small pelagic fish, is considered to be the main driver of continuing declines and distributional shifts (from west to east) of iconic seabird species such as the African penguin *Spheniscus demersus* and Cape gannet *Morus capensis* in South Africa. The prediction of the IPCC that marine species face increased extinction risk due to climate change, during and beyond the 21st century, seems especially close to home for the African penguin, as reflected within the relevant report card's title: "…trending down towards extinction". Breeding African penguins have a limited foraging range around their nesting sites, therefore ensuring that pelagic fish within this vicinity are prioritised for the provisioning of this Endangered species, seems imperative as a management intervention. However, it is also critical to minimise other sources of penguin mortality such as oil spills and predation by the Cape fur seal *Arctocephalus pusillus pusillus*. A report card on the diet of the Cape fur seal also shows linkages to small pelagic fish species, but responses of this top predator to observed changes in prey availability are generally less well understood than for seabirds. Potential behavioural responses (longer, deeper foraging dives) of the Cape fur seal to reduced pelagic prey on the West Coast, and associated physiological costs, are presented in another report card. In a similar vein, responses of the bank cormorant *Phalacrocorax neglectus* to a shift in availability of their favoured prey - West Coast rock lobster *Jasus lalandii* - are also described.

Dissolved oxygen in seawater is essential for respiration of most marine organisms, but its concentrations are inversely related to sea temperature and also affected by other processes. Globally, there has been a decreasing trend in the concentrations of dissolved oxygen over the last few decades, and with ocean warming and other changes, it is predicted by the IPCC that marine organisms will face progressively lower dissolved oxygen levels. Monitoring of dissolved oxygen levels on the West Coast showed protracted periods of hypoxic (low oxygen) conditions for bottom waters of some nearshore areas. Such periods frequently coincided with low pH and associated calcium carbonate ($CaCO_3$) under-saturation of bottom water in these areas. Calcium carbonate minerals such as aragonite are the "building blocks" for shells or exoskeletons of calcifying marine organisms including corals, pteropods and molluscs. When seawater becomes acidic (low pH) and under-saturated with respect to $CaCO_3$, it is more difficult for these organisms to maintain their shells or exoskeletons, or to develop new ones. Ocean acidification, caused by uptake of anthropogenic CO_2 emissions by seawater, is a concern for upwelling systems such as the Benguela. Global biogeochemical climate models and data analysis predict that this region will experience corrosive and irreversible consequences of ocean acidification within the 21st century.

Simultaneous impacts of acidification, hypoxic conditions and other drivers such as warming, can lead to interactive, complex, and amplified impacts for marine species and ecosystems. Continued monitoring of these EOVs is essential to determine long-term trends on a local scale, but these indicators should also be extended to other geographic areas, besides the West Coast. Monitoring should be accompanied by assessment of vulnerable marine organisms to determine their performance under varying conditions. Experimental research being conducted by O&C Research with other partners, reported here, investigates responses of selected marine taxa, including the commercially important abalone *Haliotis midae*, to changes in pH and temperature.

Understanding carbon uptake by the ocean is critical for understanding how the carbon cycle and climate are evolving under the impact of anthropogenic activities, and to be able to predict future states of the climate system. In this regard, carbonate chemistry measurements conducted in the Southern Ocean, under the Department's partnership with Department of Science and Innovation to undertake summer and winter science voyages to the Antarctic using the *SA Agulhas II*, will contribute to further understanding of ocean chemistry patterns and processes in the Southern Ocean, one of this planet's most important CO_2 sinks. In this report, emphasis is given to this and several other Southern Ocean studies, especially at or around South Africa's Prince Edward Islands (PEIs), by dedicating a subsection to these report cards, and through the choice of cover image. This reflects O&C Research's growing research interest in the Southern Ocean, which is related to the its fundamental role in influencing our regional and global climate, and the fact that sub-Antarctic islands such as the PEIs form ideal sentinels of climate change, partly due to the low anthropogenic influence there.

An investment by the Department in deploying and maintaining two oceanographic observation moorings at the PEIs since 2014 is now showing a return through detailed observations of currents and temperature at the islands. Bottom temperature shifts as recorded by the moorings reflect latitudinal shifts in the position of the sub-Antarctic Front in relation to the islands. Water temperatures influence the characteristics of biological communities in the water column, including the prey species on which the vast numbers of seabirds and marine mammals breeding at the PEIs are dependent. By influencing the geographical distributions of preferred prey species, temperature variations are likely to affect the distances that these animals have to travel to find food. This has consequences for time and energy spent foraging, the survival of young that are dependent on foraging adults, and ultimately for the reproductive success and healthy population numbers. Such higher resolution studies that provide insights into how these islands support their biodiversity, complement other O&C Research investigations of the islands and surrounds using satellite remote sensing, ship-based surveys or land-based research on seabirds such as the macaroni and rockhopper penguins, *Eudyptes chrysolophus* and *Eudyptes chrysocome*.

Apart from South Africa and the Southern Ocean, O&C Research has also been active in research and monitoring in other ocean regions. Reported here are descriptions of important oceanographic features and processes in the south-east Atlantic Ocean and the south-west Indian Ocean. The former uses *in situ* data retrieved from Argo floats to describe mixed layer depth, which is critical to many physical, chemical and biological processes in the ocean. The latter describes how plankton is entrained in meso-scale eddies on the southern Madagascar Shelf and transported to the open ocean. Further work is required to determine whether this transport can extend all the way to the African continent, providing a vector for genetic material between the coasts of Madagascar and the continent, as suggested by the "suitcase hypothesis".

While climate-associated drivers such as warming, acidification and lowered oxygen threaten marine ecosystem functioning and biodiversity, the IPCC cautions that the interactions between these and simultaneous human drivers such as habitat modification, over-exploitation of stocks, pollution and invasive species will amplify the detrimental effects of climate change. Ocean and Coastal Research's interest in pollution is reflected in an investigation of nutrient levels and their effects on invertebrate communities at two southern Cape estuaries, and a pilot study of microplastic pollution at Durban harbour. The latter was conducted with external partners (CEFAS, UK) under the Department's larger pollution endeavour, the Source to Sea initiative. Both of these studies demonstrate where impactful management interventions can be made to mitigate pollution. Less feasible are management interventions to counter already established marine alien species, such as two species of alien barnacle that have become established and spread along the East Coast, as detected by the O&C Research-led National Rocky Shore Monitoring Programme. Management effort must therefore be focused on preventing or mitigating new introductions, including through monitoring and control of aliens in the ballast waters of ships, and of fouling communities on hulls of vessels.

A solid knowledge foundation for various management intervention options has been made possible by an enhanced understanding of the South Africa's ocean and coastal ecosystems ensuing from research and monitoring studies. An example is the prioritisation of marine areas for protection and the debates and negotiations surrounding MPAs and their zonation. Interdepartmental discussions over the last few years realised an increase in the number of MPAs from 25 to 41 in 2019, with the percentage area of protection increasing from 0.6 to 5.4%. As shown in this report, this has considerably increased the ecological representativeness of South Africa's MPA network and contributed towards achieving global protection targets for 2020 (Aichi target 11). Besides protected area coverage, there is increasing emphasis, globally, on addressing the effectiveness of protected areas, in terms of meeting their conservation objectives. This is the theme of a study conducted at the Table Mountain National Park MPA and reported here. The study showed that no-take zones of the MPA are effective at maintaining high densities of a harvested limpet species, *Cymbula granatina*, in line with the management objectives.

Increasingly the Department's dedicated and stable research and monitoring programmes provide scope for addressing additional research questions (beyond the research and monitoring plan) with little extra effort, or opportunities for rare discoveries or observations. For example, biodiversity sampling of the seafloor off the West Coast, using the Department's RV *Algoa*, allowed exploration of the different sediment types that provide habitat for benthic fauna. Including geological aspects in O&C Research's programmes is relatively new and builds on the relationship with the Council for Geoscience. During routine monitoring on board the same vessel during a cruise of the Southern Benguela: Integrated Ecosystem Programme in 2019, a very rare sighting was made of a blue whale *Balaenoptera musculus intermedia* mother with calf. This was only the third confirmed blue whale sighting in South African waters in the post-whaling era, after whaling had reduced global population numbers from about 240 000 to only about 360, by the early 1970s. Off the South Coast, research to estimate abundance of another cetacean, the Endangered Indian Ocean humpback dolphin *Sousa plumbea*, afforded an opportunity to assess social relationships between individuals, using the same fin-identification images that were generated for investigating abundance. From the images it could be determined how often known individuals were together in groups, in order to analyse relationship strengths. Strong relationships that were shown between several individuals are considered atypical for this species and may represent a behavioural response to reduced group sizes associated with declining numbers of the population.

A study of foraging behaviour of sea turtles on the East Coast used a novel technique of analysing chemical signatures from barnacles that attach themselves to the turtles' shells. From the chemical signatures, turtle foraging areas could be broadly identified. This information is applicable to conservation planning, and the approach is relatively cost-effective. Such innovations that support the goals of the research and monitoring plan and provide useful information for management planning and decision-making, are encouraged in the Chief Directorate. Other technological developments and innovations that support the research and monitoring plan, or facilitate the storage, accessibility, dissemination or application of data generated through research and monitoring, are described in the new section on Tools and Technologies.

Included in this new section is an introduction of the Department's data and information management systems, and related data and computing knowledge products that are either already available or under development. The Chief Directorate seeks to take full advantage of the computing capabilities that are available to archive data and make them accessible and applicable, through a variety of interfaces, to a range of users. These include scientists, decision-makers and various ocean and coast users across the formal and informal sectors. Related products described in this section include data processing tools, products for real time monitoring of ocean temperature and currents, and ocean forecasting models to assist in operations and rescue at sea.

The deep ocean (> 200 m depth), which is the largest habitat on the planet by volume and area, is known to represent a vast repository of biodiversity and biological resources, and to provide critical climate regulation. However, it remains the planet's least explored, observed or understood habitat. Recent studies using climate models warn that rates of climate change in the world's ocean depths could be seven times higher than current levels by 2050, owing to different rates of global heating at different depths. As warming already absorbed at the ocean surface mixes into deeper waters, deep sea biodiversity is likely to be at greater risk because the organisms are adapted to a more stable thermal environment. The final report card describes the introduction of a new containerised winch system to the Department's RV *Algoa*. This has extended the Department's ocean sampling capability from 1 000 m to over 6 000 m, and will allow scientists to unlock critical knowledge hidden in South Africa's deep ocean spaces, and to assess the rate and extent of change in these environments.

Concluding remarks

In the summary for the 2018 Annual Science Report, areas were highlighted, where, based on the content of the report, increased research and monitoring emphasis should be considered. These were climate change-related issues, including ocean acidification, and pollution in the marine environment, especially the emerging issue of plastic pollution. It was pointed out that research with socio-economic implications was lacking, and it was further highlighted, in the perspective of the outgoing Director of Biodiversity and Coastal Research, that monitoring effort on the East Coast was lacking. The latter is still largely the case, but the baseline study of pollution in Durban harbour is promising from this perspective. That study, together with the study of nutrient effects at South Coast estuaries, provides pollution baselines on which to build. Geographically, expansion of monitoring is most in evidence for the Prince Edward Islands, based on reports of several relatively new monitoring studies in this area. This accords with the epithet of "a natural laboratory for climate change studies" that has been attached to these islands in recent years.

Approximately half of the research and monitoring report cards presented here are directly or indirectly concerned with detecting or understanding climate-related changes or climate change effects in the marine environment. While longer-term trends are evident from some EOVs such as upwelling and chlorophyll *a*, the shortness of many of the time series coupled with the highly dynamic and variable nature of South Africa's marine environment, make it difficult at this stage to distinguish longer-term trends from shorter-scale fluctuations. Long-term time series of seabird abundance or diet show much clearer trends, but it is often difficult to distinguish whether the trends are most related to climatic effects or other drivers such as fishing.

If anything, these complexities should motivate the need for continued and greater investment in such projects, given the urgent need to understand change in order to manage or mitigate appropriately for it. This of course would come at a cost. However, at the time of writing, budgets are being considerably reduced to mitigate government costs associated with the Covid-19 pandemic, and the sustainability of both long-term monitoring and shorter-term research projects seems less assured than before. Related to this, and to South Africa’s ambitions of developing her ocean economy, is increasing emphasis on the need for research that is supportive of growth of the ocean economy and understanding the socio-economic dimensions in the distribution of benefits (and costs) associated with this growth. This is an area that is still lacking, from a perusal of this report and the research output listed at the back, and there seems an urgent need to consider this in further strategic planning. The pooling of resources and effort within new and ongoing partnerships should also be encouraged to broaden research and monitoring coverage, cost-effectively.

It must be kept in mind that all projects that assist with better understanding of our marine environment and how it is changing, can support better, sustainable or adaptive management policies and interventions. Mostly, these will be to the benefit of humans, if not with immediate effect, then in the longer-term. Short-term forecasts (3–5 days) on ocean state, made possible by operational ocean modelling that is based on continually collected ocean data, can provide support for operational environmental monitoring, marine search and rescue, fisheries and aquaculture management, risk mitigation (e.g. oil spills) and other offshore industries (e.g. fishing, energy). As regards cost-justification, such capability is almost invaluable to oceans and coast users, especially given the highly dynamic and energetic nature of South Africa’s productive marine environment. As a final example, consider if the iconic African penguin were to go extinct. The demise of penguin-based tourism would affect income and jobs and be a considerable setback to the ocean economy and the tourism industry in the Western Cape, of which it forms an integral part. If, however, the continuing decline of this species can be arrested and reversed through current and planned management interventions, then this would have been made possible by research.

1. LONG-TERM TRENDS IN UPWELLING INDICES FOR THE WEST AND SOUTH COASTS

Upwelling is defined "as an upward movement of water parcels in the water column that is maintained over a reasonably long period of time, long enough to lift water parcels over a vertical distance of 100 m or more". This ocean circulation process is responsible for high productivity levels observed in the Eastern Boundary Upwelling Systems of the world oceans, including the Benguela Upwelling System (Benguela).

Renowned oceanographer Andrew Bakun predicted that warming caused by greenhouse gas accumulation in the atmosphere would alter coastal upwelling forcing mechanisms, leading to either a decrease or increase in upwelling intensity. Even though some of the trend analysis results obtained from model predictions support these claims, there is little consensus on the effects of climate change on upwelling.

In this report, we present results obtained from testing this prediction for the southern part of the Benguela, which coincides largely with the west coast of South Africa, and for another location on the South Coast.

Figure 1: The study area, showing the location of three major upwelling cells in the southern Benguela region, off Hondeklip Bay, Cape Columbine and Cape Point, and a site on the South Coast off Plettenberg Bay

A 20-year long time series of data (1981–2020) obtained for three upwelling locations in the southern Benguela and one site situated on the South Coast (Fig. 1) was assessed for trends in wind-driven upwelling strength. As maximum upwelling normally occurs during the summer months of December, January or February (DJF) in this region, we plotted the average upwelling maximum for each site during these three months, for each year.

The upwelling index was derived from United States Navy Fleet Numerical Meteorology and Oceanography Centre model output on offshore Ekman transport at 1 degree spatial resolution (https://coastwatch.pfeg.noaa.gov/erddap/griddap).

All four selected sites exhibited strong interannual and decadal variability in upwelling (Fig. 2). At the decadal scale, upwelling was generally more intense during the 1990s and over the last decade, compared to the 1980s and early 2000s. The linear trendlines demonstrate a long-term increase in upwelling maxima for Hondeklip Bay, Cape Columbine and Cape Point. Average annual increases of 0.78 $m^3 s^{-1} km^{-1}$, 0.97 $m^3 s^{-1} km^{-1}$ and 1.34 $m^3 s^{-1} km^{-1}$ were estimated for these locations, respectively. In Plettenberg Bay, the trendline was virtually flat (0.05 $m^3 s^{-1} km^{-1}$ increase).

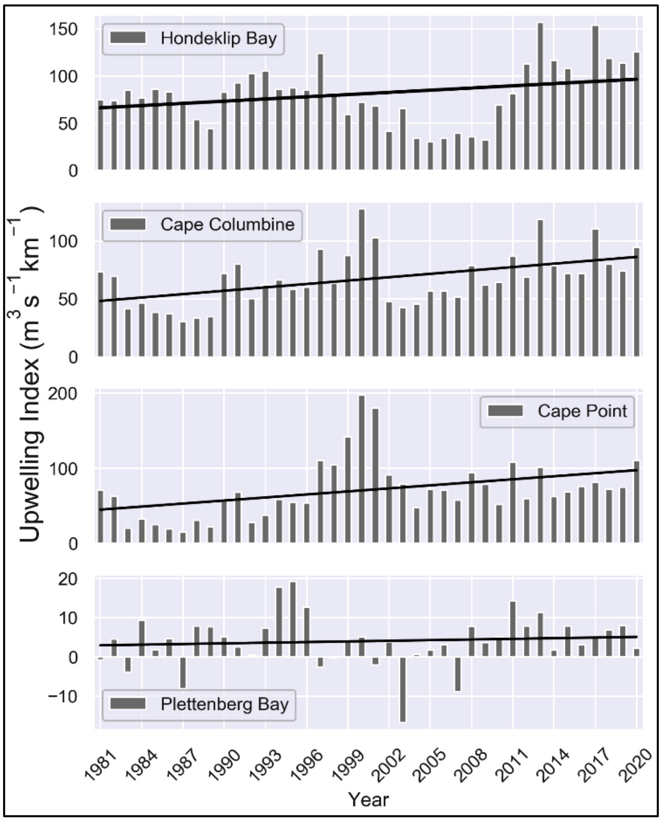

Figure 2: Time series of DJF upwelling index values (grey bars) at four upwelling locations from 1981–2020, showing linear trendlines

The influence of the atmospheric South Atlantic High Pressure Cell (SAHPC) on seasonal variability in upwelling is well established. The long-term poleward migration of the SAHPC has been linked to increased wind stress resulting in coastal upwelling intensification in sub-tropical regions. The influence of wind stress on upwelling on the West Coast is much stronger than on the South Coast, perhaps explaining the apparent lack of long-term change at Plettenberg Bay. More research is required to determine the role of climate change on the observed changes in upwelling on the West Coast.

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2. BOTTOM-WATER DISSOLVED OXYGEN LEVELS ON THE WEST COAST

Marine organisms are dependent on seawater dissolved oxygen (DO) for respiration. Dissolved oxygen concentrations in the ocean can be highly variable and are determined by a combination of factors, including oxygen exchange with the atmosphere and temperature-dependent solubility factors, biological production and respiration, and mixing processes. Dissolved oxygen is recognised as an essential ocean variable because it is relevant to climate change and is relatively cost-effective to measure.

On the west coast of South Africa, the lowest DO levels are typically found in inshore bottom waters, and DO is lowest during the summer and autumn months. This is due to the respiration and subsequent decay of phytoplankton blooms produced in response to seasonal upwelling, which is most intense during spring and summer. Mass mortalities of rock lobster (Fig. 1) and fish strandings on the West Coast have been associated with abnormally low DO events.

Figure 1: Mass mortality of rock lobster on the South African west coast caused by declining oxygen concentrations following the decay of a phytoplankton bloom (photo: R Tarr)

Since 2013, DO measurements have been obtained from bottom water sampled at nearshore stations of West Coast monitoring lines, during regular cruises of the Southern Benguela: Integrated Ecosystem Programme (Fig. 2). This allows for comparison of DO levels between seasons, years and different parts of the coast. Dissolved oxygen levels lower than 2 mg/L, and down to 0.5 mg/L (Fair to Poor in Fig. 3), are associated with hypoxic conditions, in which organisms may begin to show aberrant behaviour due to oxygen stress.

Hypoxic conditions were most prevalent off Kleinsee and in St Helena Bay, with anoxic events (< 0.5 mg/L; Very poor in Fig. 3) occurring most frequently in St Helena Bay. Anoxic events are associated with mass mortalities of marine organisms on the West Coast, and extended anoxic conditions can result in "dead zones" in the ocean. Protracted periods of mainly hypoxic or anoxic conditions were evident at the two deeper St Helena Bay stations (Fig. 3), since 2017 in the case of the 73 m depth station, and since 2015 at 30 m. The deeper of the two nearshore Kleinsee stations was also characterised by mainly hypoxic conditions, throughout the monitoring period. For most stations, DO levels appeared similar between 2018 and 2019, with some improvement since 2017.

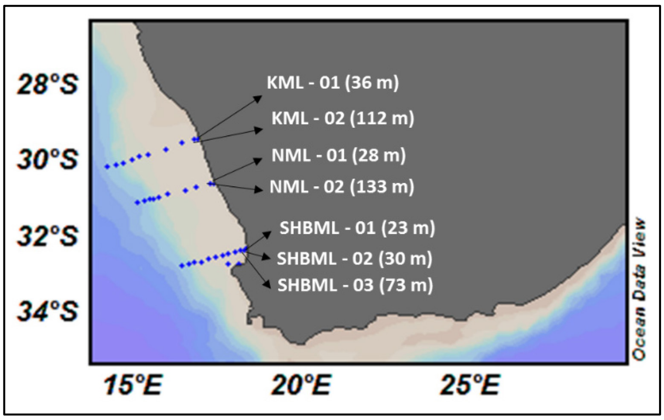

Figure 2: Map showing the Kleinsee (KML), Namaqua (NML) and St Helena Bay (SHBML) monitoring lines of the SB: IEP, and the locations of inshore stations for which oxygen was determined

Dissolved oxygen and temperature have an inverse relationship, and ocean warming can be expected to reduce DO that is essential for respiration of marine organisms. Globally, there has been a decreasing trend in the concentrations of dissolved oxygen over the last few decades, thus continued monitoring is essential to assess longer-term trends on a local scale.

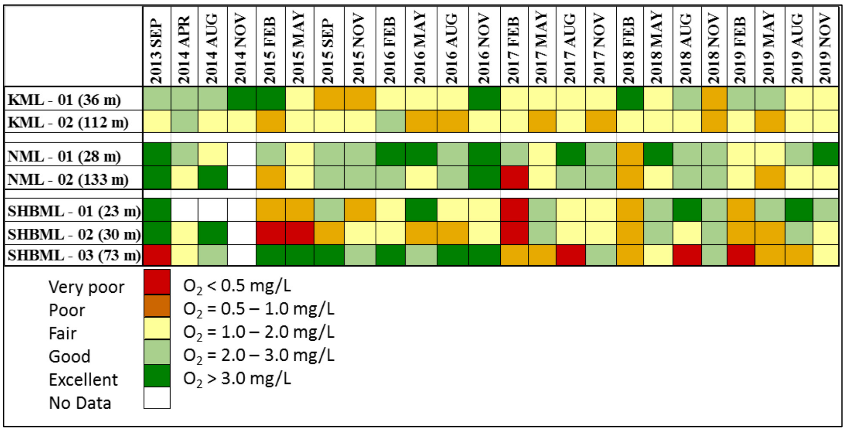

Figure 3: Indicators of oxygen conditions in bottom waters of inshore stations, from 2013–2019

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3. BOTTOM pH ON THE WEST COAST

Oceanic uptake of anthropogenic CO_2 is changing the ocean's chemistry, leading to more acidic conditions (lower pH) and lower chemical saturation states (Ω) for the calcium carbonate ($CaCO_3$) minerals such as aragonite and calcite, which are the "building blocks" for shells or exoskeletons of calcifying marine organisms including corals, pteropods, molluscs (Fig. 1) and foraminifera. If seawater becomes acidic and under-saturated with respect to $CaCO_3$ ($\Omega < 1$), it is more difficult for these organisms to maintain their shells or exoskeletons, or to develop new ones. Reef-building corals provide the basis for biologically diverse and economically important ecosystems, while molluscs such as oysters, mussels and abalone are the basis for subsistence or commercial fisheries. Increasing ocean acidification can therefore severely affect marine ecosystem health and associated ecosystem services, with considerable socio-economic implications.

Figure 1: Mussels (Mollusca)

On the west coast of South Africa, the lowest seawater pH values are known to occur at the lower depths of inshore waters, corresponding with upwelling areas where phytoplankton productivity in the overlaying water is typically highest. Measurements of dissolved inorganic carbon (DIC) and total alkalinity (AT) from water samples taken at inshore stations of West Coast monitoring lines during regular cruises of the Southern Benguela: Integrated Ecosystem Programme (Fig. 2), have allowed for calculation of pH indicators over time (Fig. 3).

Seawater with low pH (< 7.7) occurred frequently in the nearshore environment along all three monitoring lines during 2013–2019. A pH of 7.7 is equivalent to Ω of about 1 which indicates the onset of stress for calcifying organisms. It is not unusual for highly productive upwelling areas, such as the Benguela Upwelling System on the West Coast, to experience low pH levels on a seasonal basis; this is the result of the temperature-dependent solubility of CO_2 and processes such as the respiration of organic matter that produce high CO_2 levels, low pH and a low aragonite saturation state. However, persistently low pH levels, as was evident for inshore stations of the Kleinsee Monitoring Line during 2015–2017 (Fig. 2), pose a threat to calcifying marine organisms. Conditions at Kleinsee and the other monitoring lines improved during the latter part of 2018, but declined again in the 2019 upwelling season. Continued monitoring is essential to determine whether there is a long-term decline in pH levels in the region due to continuous global uptake of anthropogenic atmospheric CO_2; this should be accompanied by *in situ* monitoring of vulnerable marine organisms to assess their condition under varying pH levels.

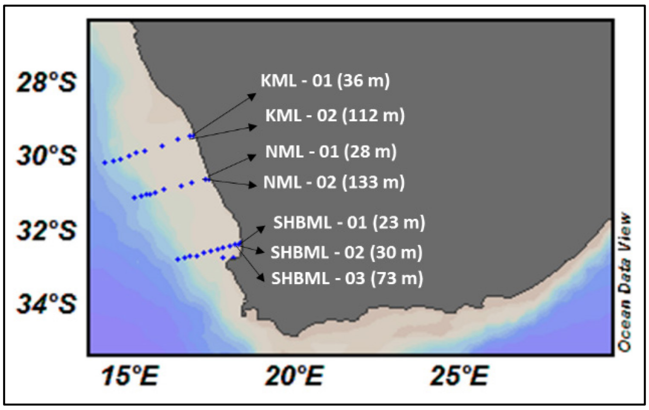

Figure 2: Map showing the Kleinsee (KML), Namaqua (NML) and St Helena Bay (SHBML) monitoring lines of the SB: IEP, and the locations of inshore stations for which pH was determined

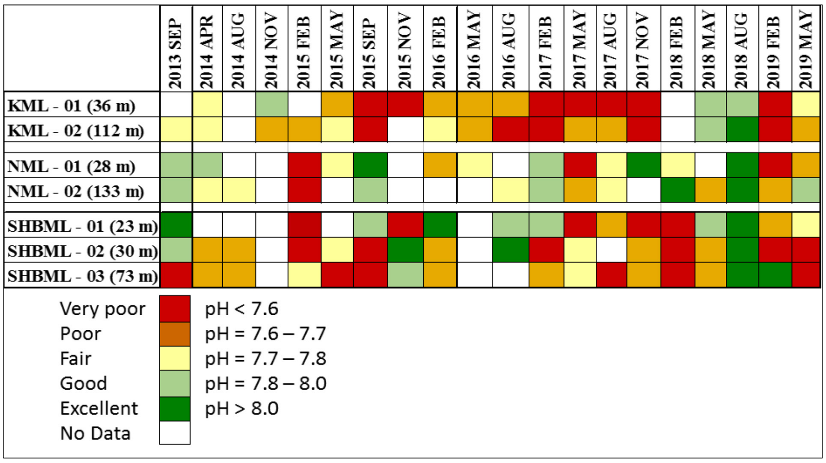

Figure 3: Indicators of ocean pH conditions in bottom waters of inshore stations, from 2013–2019

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4. SURFACE CHLOROPHYLL 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 a number of decades (Fig. 1). It is a well-known retention area with significantly elevated phytoplankton and zooplankton biomass, compared to the rest of the upwelling system off South Africa, and is an important region for pelagic fish, hake, and rock lobster.

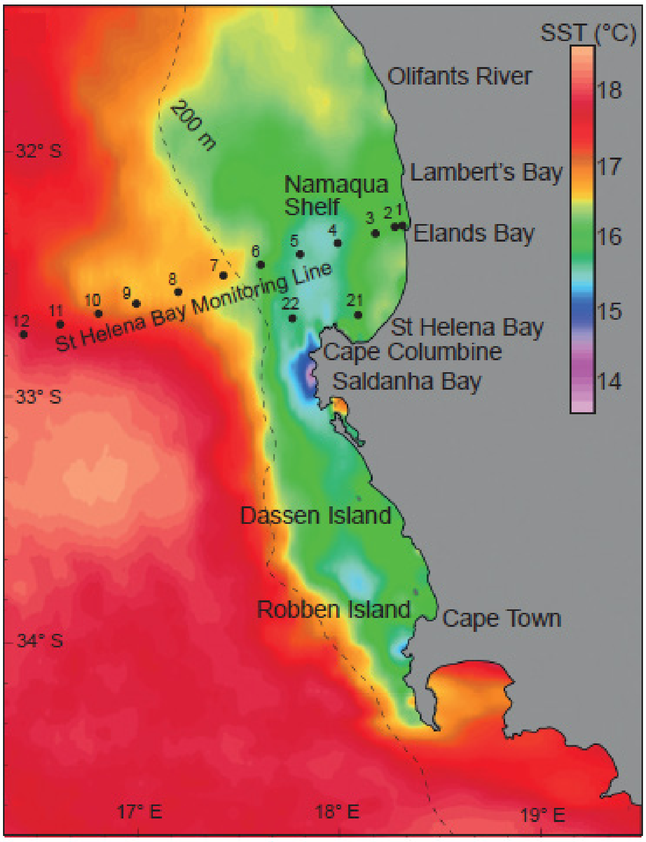

Figure 1: Map of sea surface temperature (SST) illustrating cooler waters typically found inshore and warmer waters offshore, as well as the location of the St Helena Bay Monitoring Line

The upwelling of water along the west coast of South Africa is driven by south-easterly winds which advect surface waters offshore, resulting in deeper, nutrient-rich waters being uplifted to the surface from deeper depths. On a seasonal scale, higher chlorophyll *a* concentrations are coincident with larger amounts of upwelling which occur throughout the upwelling season (October–March) each year. Satellite-derived surface chlorophyll *a* concentrations clearly illustrate this seasonal signal, with maxima in spring/early summer and late summer/autumn (Fig. 2).

Higher values of chlorophyll *a* are 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 the peak upwelling periods. In contrast, lower chlorophyll *a* concentrations indicate lower phytoplankton biomass and a less productive ecosystem, usually associated with lower amounts of upwelling and less nutrient availability in the surface layers during late autumn to early spring (April–September) each year (Fig. 2).

Generally, higher concentrations occur close to the coast and decrease with distance offshore (Fig. 2). During 2015, concentrations > 20 mg m^{-3} occurred close to the coast in autumn (March) and late spring/early summer (September–November). Elevated chlorophyll (> 5 mg m^{-3}) extended approximately 110 km offshore in March – the farthest offshore extension for such high concentrations since March 2010.

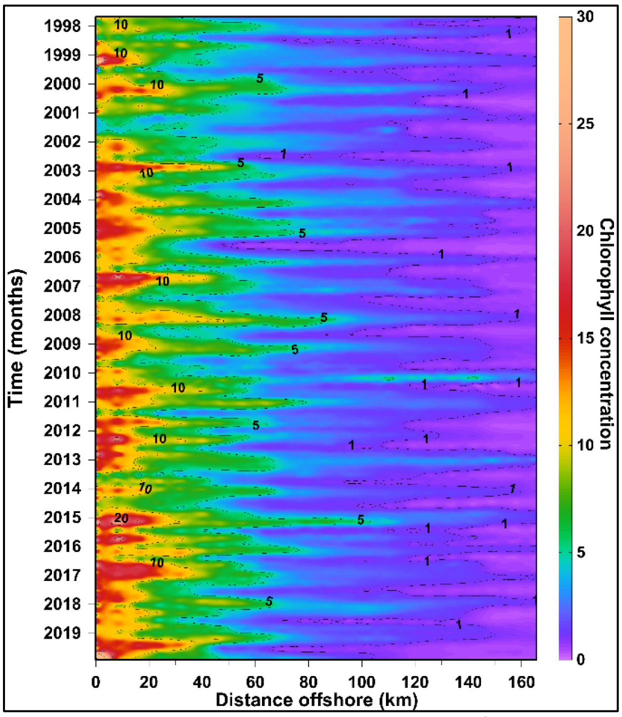

Figure 2: Time series of monthly chlorophyll a (mg m^{-3}) along the St Helena Bay Monitoring Line between 1997 and 2019

In contrast, concentrations > 20 mg m^{-3} were observed closer to the coast between August and October 2016, and only during June, August and December 2017. In 2016, the farthest offshore extent (*ca* 80 km) of values above 5 mg m^{-3} was observed in February and March, while in January 2017, January/February 2018, and February/March 2019, such concentrations extended only *ca* 70 km offshore. Chlorophyll *a* concentrations near the coast in 2017 were overall lower than peak values in 2016, but remained elevated throughout the year. Index values were even lower throughout 2018, suggesting that the ecosystem was less productive. However, higher values throughout 2019 suggests an increase in productivity in the region over the past year. Notably, peak chlorophyll *a* values in 2019 were observed during April–August, suggesting a more productive autumn/winter than usual.

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5. CHLOROPHYLL VARIABILITY ON THE WEST AND SOUTH COASTS

Phytoplankton play a crucial role in a number of key marine processes, such as the modulation of food webs, 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. Satellite ocean colour data is used globally to better understand marine ecosystems, for both research and monitoring purposes. To monitor conditions along the southern African coast, an index of chlorophyll *a* concentration is routinely computed by integrating satellite-derived surface chlorophyll *a* values from the coast to the 1 mg m^{-3} level further offshore (Fig. 1a). Higher values are usually associated with greater phytoplankton biomass and a more productive ecosystem, and lower values, the converse.

Along the west coast of southern Africa, the highest index values are found off Namibia (16–26°S; Fig. 1b). In 2016, higher values suggested a more productive ecosystem than during 2013–2015. Index values in 2017 were similar to those in 2015, except in July when peak values were more similar to 2016. Low values throughout the region in 2018 suggested that this was the least productive year, with the lowest phytoplankton biomass since 2013. During 2019, index values were elevated for most of the year, with peak values found north of 23°S in July and August.

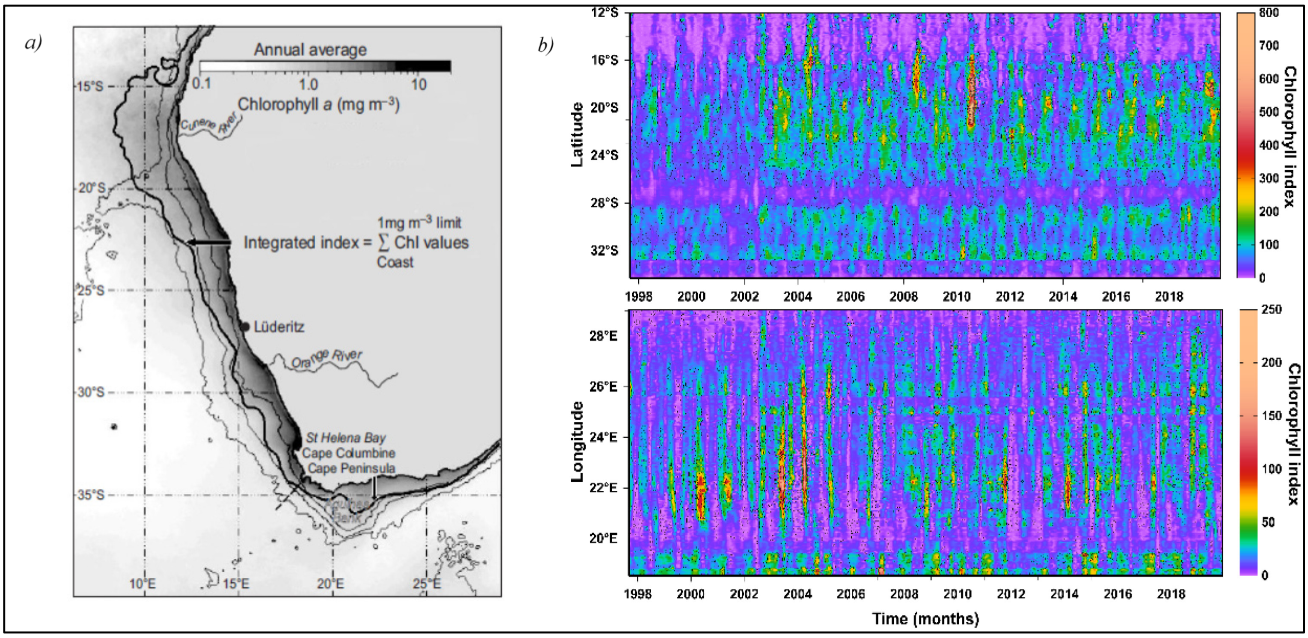

Figure 1: a) Annual average chlorophyll a concentration and location of the 1 mg m^{-3} contour (thick line), b) Monthly chlorophyll indices (1997-2019) for the west coasts of Namibia and South Africa (top panel) and for South Africa's South Coast (bottom panel)

Along South Africa's west coast (28–34°S), elevated index values occur in areas influenced by the Namaqualand, Cape Columbine, and Cape Peninsula upwelling cells. During the first half of 2015, the index was higher than in 2013 and 2014. During 2017, values were lower than those in 2015 and 2016, suggesting a decrease in productivity. Off Namaqualand, the second half of 2018 showed the highest index values since 2013. The 2019 values were only slightly lower than those in 2018, but remained elevated throughout the year.

Along South Africa's south coast (18.5–29°E), chlorophyll index values are generally lower than on the West Coast. During the 2013–2019 period, the highest values were observed at 22°E in January to February 2014. However, the lowest values were observed throughout 2016, suggesting that this was the least productive year with the lowest phytoplankton biomass on the South Coast during the 2013–2019 period. Higher values throughout 2017 suggested an increase in productivity, with maxima occurring in the central part of the region in May and September. Whereas elevated biomass was evident in the western portion of the region between January and May 2018, with much lower values across the rest of the region, values were high across most of the central and eastern part of the South Coast during November 2018. During 2019, high values extended across the central and eastern part of the region during the first half of the year, with much lower values observed during the second half of 2019.

The apparent large increase in index values on the West Coast since mid-2002 is due to a platform change from SeaWiFS to MODIS Aqua sensor. When accounting for this change, there is a small but significant long-term increase in chlorophyll *a* off Namibia, with a decrease observed off the west coast of South Africa and on the Agulhas Bank. Nevertheless, these trends are much smaller than the seasonal and interannual variations that occur in these regions, and substantially more years of data are required to properly distinguish long-term trends from seasonal and interannual variations.

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6. ZOOPLANKTON ESSENTIAL OCEAN VARIABLES FOR THE SOUTH COAST, 1988–2019

The Global Ocean Observing System (GOOS) is a collaborative system of sustained ocean observations around the global ocean in support of climate, operational services and marine ecosystem health. A key component is the focus on Essential Ocean Variables (EOVs), which are based on relevance to the above themes, technical feasibility and cost-effectiveness.

Plankton form the foundation of most marine food webs, and zooplankton provide a crucial source of food for higher trophic levels, including important commercial species, marine mammals and sea birds. Because of the relatively short life spans of plankton, their abundance and composition respond quickly to local and global environmental changes and they can serve as sentinel organisms of environmental and water quality changes. Due to these as well as other important functions, 'Zooplankton biomass and diversity' was identified by GOOS as an EOV in 2018. Sub-variables include total zooplankton biomass, and biomass or abundance (or presence/absence) by taxon, functional group or size class.

Annual sampling of zooplankton off the south coast of South Africa during spring to early summer (October–December) was initiated in 1988, during acoustic surveys of pelagic fish biomass. A monitoring line off Mossel Bay (MBML, Fig. 1) was selected to explore suitable variables to characterise long-term changes in zooplankton biomass and diversity. There was a four-year hiatus in surveys, and hence sampling, from 2012 to 2015.

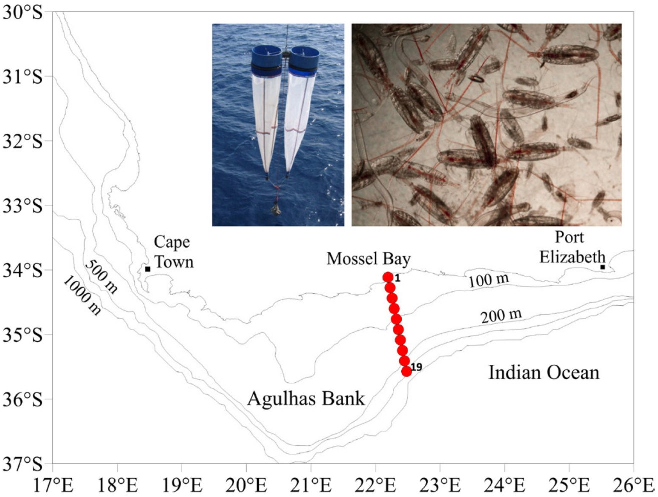

Figure 1: Location of sampling stations 1-19 along the Mossel Bay monitoring line (MBML) on the Agulhas Bank. The inserts show a Bongo net used for sampling, and copepods

There are different measures of zooplankton biomass, including biovolume, wet weight, dry weight and carbon weight. Biovolume is a rapid and non-destructive method, but is considered the least accurate measure, while dry weight and carbon weight are destructive measures but more accurate. Copepods tend to dominate zooplankton communities and may comprise up to 90% of total zooplankton biomass. Here, copepod biomass is calculated using length-weight regressions for each species and life-history stage.

Between 1988 and 2011 there was a significant decline in total copepod biomass, including the biomass of *Calanus agulhensis* which is the dominant large copepod and favoured prey of pelagic fish, along the MBML (Fig. 2). There was a similar trend in total zooplankton biovolume, but in some years (e.g. 1996) zooplankton biovolume was considerably higher relative to copepod biomass due to high abundances of salps, which are relatively large and have a high water content. Biomass of small calanoid copepods also declined over this period, but not as dramatically.

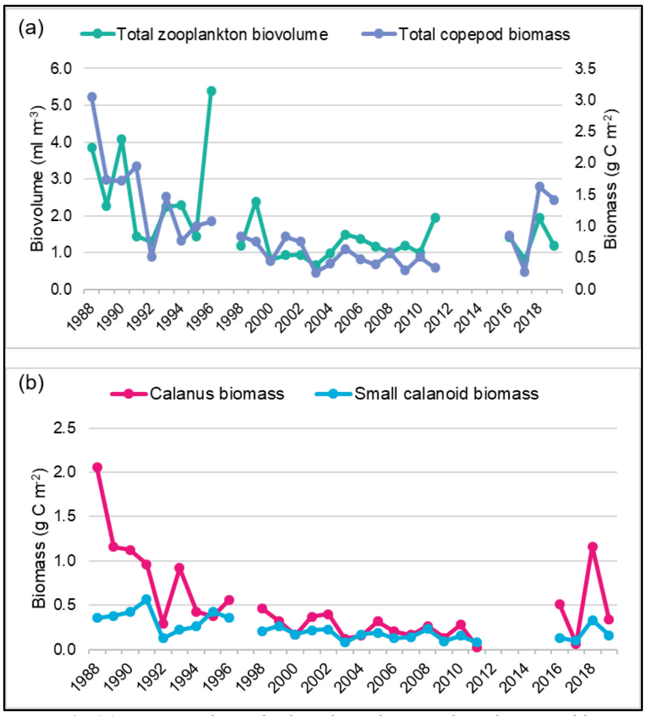

Figure 2: (a) Mean total zooplankton biovolume and total copepod biomass; (b) mean biomass of Calanus agulhensis *and small calanoid copepods along the MBML*

Since sampling recommenced in 2016, there have been marked fluctuations in total copepod biomass and that of *C. agulhensis*, with the highest recent values occurring in 2018. Total copepod biomass in 2018 was 1.63 g C m^{-2}, while that of *C. agulhensis* was 1.16 g C m^{-2}, similar to levels in 1989 and 1990. While zooplankton variability may reflect environmental variability, changes in copepod biomass and composition on the Agulhas Bank are thought to be largely driven by predation from pelagic fish. The recent increase in copepod biomass, particularly of the large species preferred by plantivorous fish, suggests reduced "top-down" predation by small pelagic fish, likely due to a decrease in pelagic fish biomass.

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7. AFRICAN PENGUINS TRENDING DOWN TOWARDS EXTINCTION

The African penguin *Spheniscus demersus* is the only extant penguin species in Africa, where it is endemic to both South Africa and Namibia. In the past it was South Africa's most abundant seabird, possibly exceeding one million individuals in the 1920s, but by 2012 numbers had dwindled to less than *ca* 23 500 pairs (Fig. 1).

Figure 1: Comparison of African penguin numbers at Whale Bay, Dassen Island (above) in 1970 and (below) in 2011

In 2010 the conservation status of the species was classified as Endangered in terms of the IUCN criterion of a greater than 50% decline over its three most recent generations (30 years).

More recent counts in South Africa indicate a continuing decline to about 13 250 pairs in 2019, the lowest value ever recorded. An updated Red List assessment for South Africa showed an almost 70% decrease over the three most recent generations, indicating an acceleration in the rate of decline. Notwithstanding this situation, the assessment result did not support the upgrade of the threat category to Critically Endangered as of yet (Fig. 2).

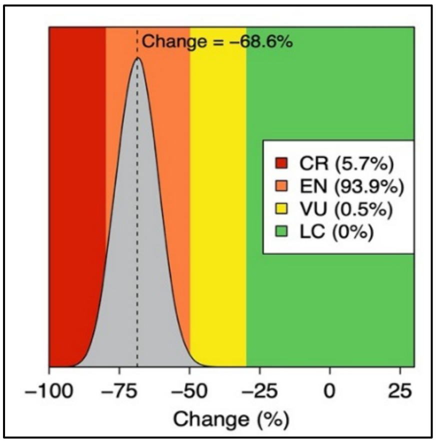

Figure 2: The median change (%, dashed line) in the breeding population of the African penguin in South Africa over three generations, and corresponding posterior probability (grey polygon) for that change, overlaid on the IUCN thresholds for the Red List criterion

On the West Coast, the former stronghold of the species in South Africa, numbers have declined by 10% per annum over the last two decades (Fig. 3). The decline has been attributed to food scarcity caused by congruent eastward shifts in distribution and lowered availability of their two main prey species, sardine and anchovy.

As a consequence of the decreases in the west, the percentage of South Africa's penguins breeding in the Eastern Cape has risen to 50, from 27% in 1989 (Fig. 3c). Food availability is considered to be the main driver of the trend in African penguin numbers in South Africa, with the other main threats including oil pollution and predation by seals. As management goals, it is considered that enhancing food availability for penguins and mitigating the impacts of any oiling will have the most beneficial impacts for the population, and require urgent attention.

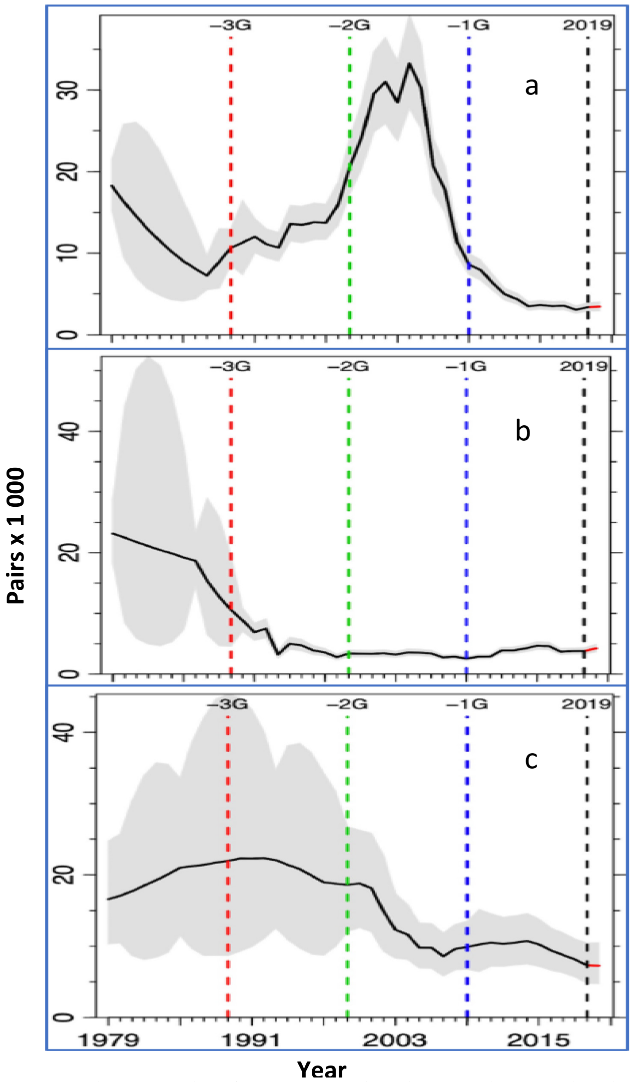

Figure 3: Changes in the African penguin breeding population within three regions of South Africa over several generations (G): (a) the West Coast region (Western Cape colonies north of Cape Town), (b) the south-west Coast region (Western Cape colonies south and east of Cape Town, and (c) the Eastern Cape

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8. A REGIONAL CONSERVATION STATUS ASSESSMENT OF THE CAPE GANNET IN THE BENGUELA ECOSYSTEM

The Cape gannet *Morus capensis* is one of seven seabird species that are endemic to the Benguela Ecosystem off the south-west coast of Africa. Between the 1950s and 1960s the Cape gannet bred in higher numbers in Namibia than in South Africa, but by 1978 their numbers were spread evenly between the two countries. Since 1997, more than 80% of the overall population of Cape gannets has bred in South Africa.

Redistribution of the species from the north-west to south-east of its range has continued and currently *ca* 70% of the breeding population occurs at Bird Island, Algoa Bay, on the eastern border of the Benguela Ecosystem. This is reflected in the long-term increase in breeding pairs at this colony (Fig. 1), while Namibian colonies have been in long-term decline and South Africa's west coast colonies, Bird Island in Lambert's Bay and Malgas Island, have decreased since the 1990s. Overall, the breeding population declined by *ca* 52% over three generations (18.3 years per generation) between the 1950s and the present.

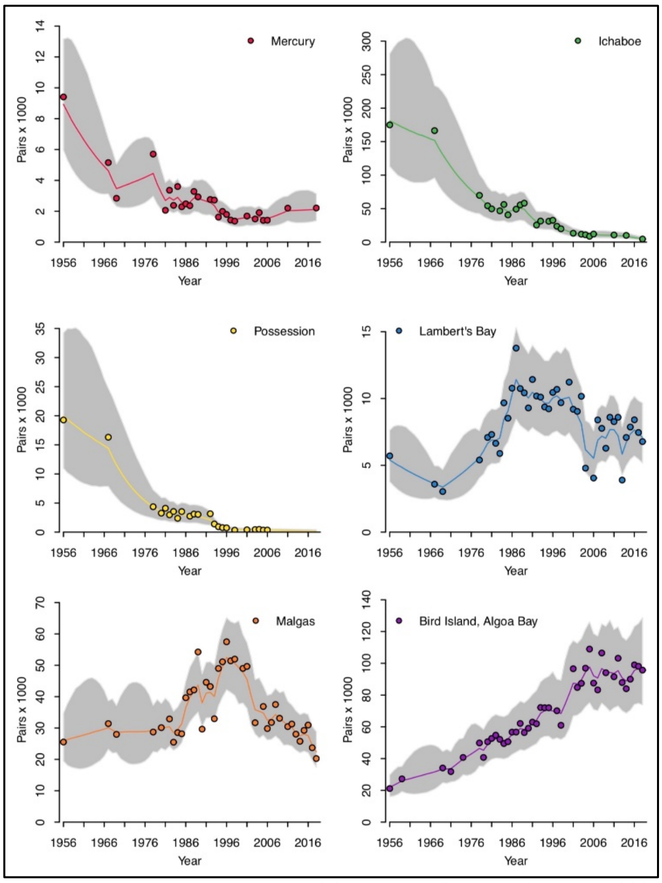

Figure 1: Bayesian state-space model estimates (lines) and 95% credible intervals (grey polygons) of the number of Cape gannet breeding pairs at the six extant colonies, 1956/57–2018/19

Application of JARA (Just Another Red-List Assessment – a Bayesian state-space tool for IUCN Red List assessment) to updated demographic data for the Cape gannet population, indicates that the species should have Vulnerable status (Fig. 2).

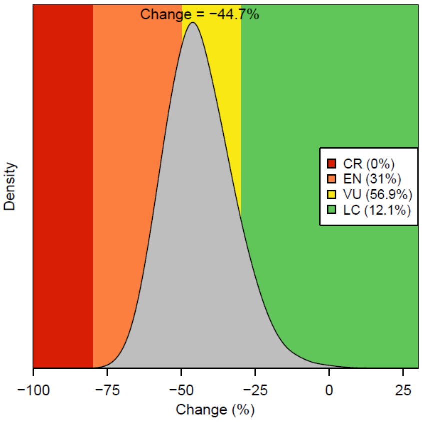

Figure 2: Percentage change of the overall breeding population of the Cape gannet over three generation lengths. IUCN Red List categories: CR = Critically Endangered; EN = Endangered; VU = Vulnerable; LC = Least Concern

The rate of decrease of Cape gannets in their most recent generation exceeded that of the previous generation, primarily as a result of large decreases at Bird Island, Lambert's Bay, and Malgas Island (Fig. 1). This is attributable to the decrease in availability of their preferred prey off the West Coast, namely sardine *Sardinops sagax* and anchovy *Engraulis encrasicolus*. While the Cape gannet is able to utilise alternative prey species such as saury *Scomberesox saurus* as well as hakes *Merluccius* spp. and other demersal species discarded by trawlers, these prey are less nutritious than sardine and anchovy**.**

Other key threats to the Cape gannet populations, apart from the reduction of their preferred prey, include heavy mortality of eggs, chicks and fledglings at and around colonies by Kelp Gulls *Larus dominicanus dominicanus*, Great white pelicans *Pelecanus onocrotalus* and Cape fur seals *Arctocephalus pusillus pusillus*, substantial disturbance by seals that come ashore at some colonies including to prey on gannets, oiling and disease. It is critical to manage such threats, which can be more easily addressed than shifts in prey distribution and abundance.

Further information

Sherley RB *et al.* 2019. The status and conservation of the Cape Gannet *Morus capensis*. *Ostrich* 90: 335–346.

Authors: Makhado AB, Masotla MJ, Crawford RJM (O&C Research)
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9. SCAT-BASED DIET ANALYSIS OF CAPE FUR SEALS FROM LAMBERT'S BAY, 2014–2018

The Benguela Ecosystem is characterised by considerable environmental variability and is considered to be highly vulnerable to effects of climate changes. In the southern Benguela, which largely adjoins the west coast of South Africa, eastwards shifts of the forage fish species sardine *Sardinops sagax* and anchovy *Engraulis encrasicolus* have been attributed to environmental changes in the system. Reduced availability of these prey species on the West Coast has had well documented negative impacts on the feeding ecology and population trends of higher predators especially seabirds such as the African penguin *Spheniscus demersus* and Cape gannet *Morus capensis*. The effects of such changes on another important higher predator, the Cape fur seal *Arctocephalus pusillus pusillus,* is less well known.

Monitoring of seal diet is useful for investigating how seals adapt to ecosystem changes. A relatively cheap and effective method of doing this is to collect samples of seal scats (faeces) from breeding colonies, and to retrieve undigested prey items from the scat material. Items such as fish otoliths and squid beaks can be used to identify and enumerate prey species in the diet. As part of an Honours' study (UNISA), scats collected from the seal colony in Lambert's Bay (32°05'S, 18°18'E) on a monthly basis between 2014 and 2018, were processed and analysed. Prey items were retrieved from the scats using water and sieves, identified using microscopes, reference materials and identification manuals, and quantified.

Fish was by far the main prey species, with fish remains occurring in 90.3% of all scats collected (n = 872). Other prey types were cephalopods and seabirds, which occurred in 3.5% and 6.5% of scats, respectively. Twenty fish prey species were identified, of which commercially important anchovy was dominant (Table 1), both in terms of the number of scats in which they occurred (frequency of occurrence – FO) and in terms of the numbers present (numerical abundance – NA). The contributions of the six most important fish species in the diet, which also included lantern fish *Lampanyctus* spp., pelagic gobies *Sufflogobius bibarbatus* and others, was relatively consistent between the five years of study (Fig. 1). Sardine, historically an important prey item for seals and other higher predators on the West Coast, occurred in less than ten percent of scats, indicating low availability. This is consistent with recent results of the Department's small pelagic spawner biomass surveys, which indicate that sardine currently occurs in very low densities on the West Coast.

Table 1: The six most important fish prey species in the diet in terms of frequency of occurrence (FO) and numerical abundance (NA), expressed here as percentages of the total numbers of scats and fish individuals, respectively

Prey species	Common name	%FO	%NA
Engraulis encrasicolus	Anchovy	74.7	73.7
Lampanyctus spp.	Lantern fish spp.	21.4	6.2
Sufflogobius bibarbatus	Pelagic goby	21.1	6.4
Trachurus capensis	Atlantic horse mackerel	16.1	4.8
Merluccius capensis	Cape hake	11.9	2.8
Cynoglassus capensis	Sand tonguefish	11.7	1.8

A previous study at the same colony (2010–2014), identified only eleven fish species in the diet, indicating a possible increase in the dietary range of the colony. This could be a response to the shortage of preferred prey such as sardine. While seals are generalist predators, the need to supplement their diet with prey that are less nutritious than sardine (and possibly less accessible), has potential implications for their energy budget and life history, including reproductive success. Indeed aerial surveys of breeding numbers have shown declines at the study colony and at other colonies to the north of Lambert's Bay, which may be linked to the feeding conditions. Continued monitoring of seal diet using this low budget technique is recommended to track the seals' responses to ecosystem changes and complement other monitoring data including temporal and spatial trends in numbers.

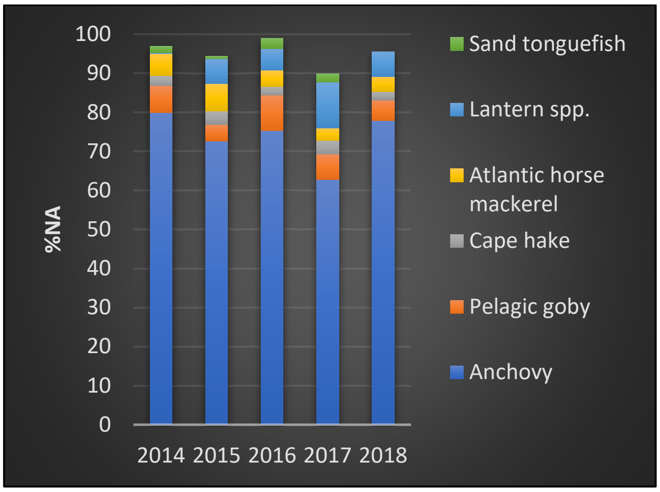

Figure 1: Percentage numerical abundance (%NA) of the six most prominent fish prey species, during each year of study

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10. A BASELINE STUDY OF MICROPLASTICS IN THE PORT OF DURBAN

The Port of Durban occupies a natural bay that has been utilised as a harbour since 1824. Over the years the harbour has expanded and it is currently the busiest port in southern Africa. Thirteen storm water drains and three polluted rivers flow into the harbour, and there is active discharge of harbour sediment into the bay to prevent sediment build-up in the port channels. Therefore it is likely that the harbour serves as a conduit for pollutants, including plastic debris, from land to sea (Fig. 1).

Figure 1: Pollution that leads to the ocean and coastal environment (photo: DEFF)

Microplastics, defined as plastic particles of < 5 mm in diameter, have been found on beaches and in coastal zones, in the open-sea and in deep-sea sediments, worldwide. The detrimental effects of microplastics on the marine environment have been widely reported, including ingestion by marine species and the sorption and spreading of harmful contaminants.

The South African Water Quality Guidelines currently do not include microplastic standards due to insufficient data. The guidelines recommend that once enough data are available, measurable guideline values be incorporated to protect the country's marine habitats, organisms and people. Under request from the Department's Integrated Coastal Management group, a collaboration between the Department's Research group and CEFAS (UK) conducted a microplastics survey during 2019 in the Port of Durban (Fig. 2). This study falls under the Department's larger pollution endeavour, the Source to Sea initiative.

Surface water samples were collected from seven locations using a pump, which filtered 2 000 litres through four different sieve sizes, to identify the quantity and size distribution of microplastics. Sediment samples were collected, using a grab, from 25 locations. Accompanying environmental data were collected at each station using a hand-held CTD.

Results indicate a greater abundance of microplastic particles entering the harbour from storm water drains than via the harbour entrance or from the riverine sources (Fig. 3). Accordingly, storm water drain management should be prioritised with regard to plastic input into the harbour and ocean. These data are available when required for contribution to water quality guidelines. The full dataset will be freely accessible at the end of June 2020 on the Department's (www.ocean.gov.za) and CEFAS (www.cefas.co.uk) websites.

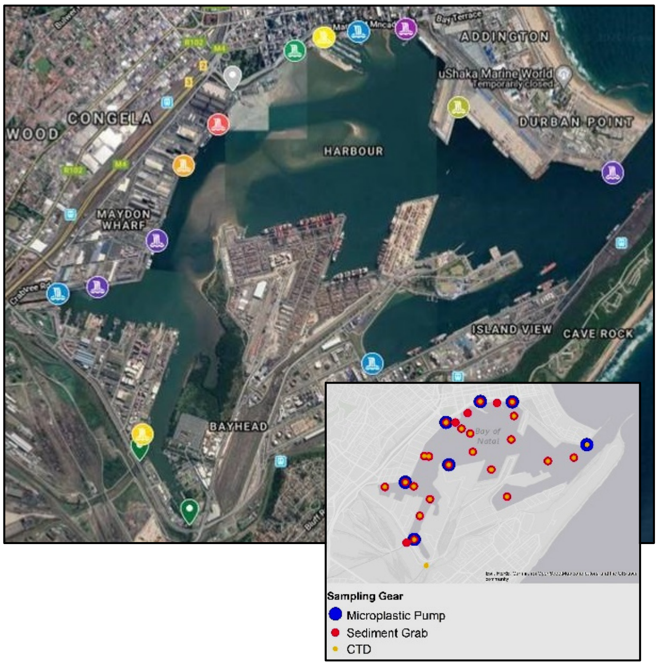

Figure 2: Durban harbour showing storm water drains (circles) and river input (drop points); inset: sampling stations and gear

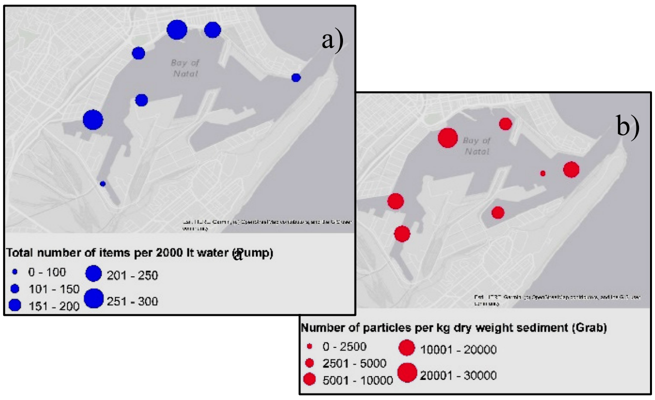

Figure 3: Quantities of microplastic items retrieved from (a) water and (b) sediment samples

This work has opened a door to multi-institutional collaboration, which is essential in this field given the plethora of methodologies leading to potentially incomparable data. Under the CEFAS-DSI-CSIR workshop, 16 participants from 11 SA institutes completed a training exercise at the Department's microplastic laboratory. Three Departmental staff members and two SAEON employees were trained in the CEFAS methodology.

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11. SEASONAL VARIABILITY OF SURFACE HYDROGRAPHIC CONDITIONS AROUND THE PRINCE EDWARD ISLANDS

The Prince Edward Islands (PEIs), consisting of Marion Island and Prince Edward Island, have been part of the South African official territory since 1948 and were declared a MPA in April 2013. The islands experience a very low anthropogenic influence, making them ideal locations to investigate climate signals. Previous research has demonstrated a strong interaction between the oceanography and the biological communities at the PEIs. In order to advise the integrated and ecological management of this MPA, it is important to have a clear understanding of the seasonal variations in oceanographic conditions around the PEIs. However, oceanographic parameters have been severely under-sampled around the PEIs, with monitoring limited to long-term *in situ* observations from a single location at Marion Island, and more recently, daily observations from two moorings on the shelf between the two islands. Satellite data offer the opportunity of investigating the surface hydrographic conditions over a much larger area than the *in situ* observations and are also available over a much longer time scale. In this study, we have used daily gridded satellite products, with a spatial resolution of 0.25 degrees, from January 1993 to December 2018, to characterise the seasonal cycle of geostrophic velocity and sea surface temperature (SST) around the PEIs. Monthly climatological mean sea surface height contours were used to define the locations of the northern, middle, and southern branches of the sub-Antarctic Front and the Antarctic Polar Front.

Throughout the year, there is an overall eastward movement of water around the islands, associated with the eastward flow of the Antarctic Circumpolar Current (Fig. 1). There is a clear meridional gradient of lower geostrophic velocities (< 0.2 m s^{-1}) in the north, and higher velocities (> 0.2 m s^{-1}) in the southern part of the region. Although the greater part of the flow was observed to pass south of the islands, a bifurcation of the current was observed upstream of the islands, resulting in a portion of the flow being directed to the north of the PEIs before it merges again with the main flow further downstream (Fig. 1). Directly east of the islands, currents are relatively weak throughout the year, likely because the bathymetry of the PEIs acts as a barrier to the general eastward flow. Seasonal variation in the geostrophic currents was weak in the north and more distinct toward the south. At a latitude of *ca* 48°S, the highest geostrophic velocities (0.35 m s^{-1}) were observed during austral winter (July), while the lowest values (0.20 m s^{-1}) occurred in austral summer (Fig. 1). This variability may be associated with the seasonal cycle of westerly winds, which are known to be strongest during winter and weakest in summer at the latitude of the PEIs.

The middle (M-SAF) and southern (S-SAF) branches of the sub-Antarctic Front are usually deflected north of the PEIs, while the northern (N-APF) and middle (M-APF) branches of the Antarctic Polar Front are found south of the islands (Figs 1, 2). The M-SAF is observed in the north-western corner of the study region only during austral autumn and winter (March–August), while the M-APF is only seen at the southern limit of the study region from the end of winter to mid-spring (August–October). The S-SAF and N-APF are located closer to the PEIs, and are clearly evident within the study region throughout the year. At shorter time scales (days to weeks), these fronts are known to exhibit substantial northward/southward meandering. The S-SAF seems to show some seasonal variation in its location, being located closer to or south of the PEIs during winter, while it is positioned further away and north of the PEIs during the rest of the year. In contrast, the N-APF does not show much seasonal variability in its position (Figs 1, 2).

The distribution of SST around the PEIs (Fig. 2) showed the opposite meridional pattern to that of geostrophic velocity. Higher SSTs (> 6°C) were observed in the northern part of the region, with lower values (< 6°C) occurring in the south. This meridional pattern results from the latitudinal differences in the amount of solar radiation reaching the earth's surface, which decreases poleward. From the end of spring to the end of autumn (November–May), warmer water (4–10°C) occurs within the area of study. From the beginning of winter to mid-spring (June–October), this warm water recedes northwards and cooler water (2–5°C) from higher latitudes moves closer to the PEIs. Also, in contrast to the pattern of geostrophic velocity, the SST shows no obvious large-scale spatial differences between the regions upstream and downstream of the islands.

Previously published research, based on measurements between 1949 and 1998, demonstrated seasonal changes in SST from 4.3°C at the end of winter to 6.4°C at the beginning of summer. In this study a much larger seasonal range of SST values was found (2–10°C) (Fig. 2). This difference may be an artefact of differences in the spatial and temporal scales of the data used in the different studies but it may also be indicative of long-term change in the variability of oceanographic conditions in the PEI region. Ongoing research will be needed to elucidate this.

Authors: Toolsee T (UCT); Lamont T (O&C Research)

(Figures 1 and 2 on the next page)

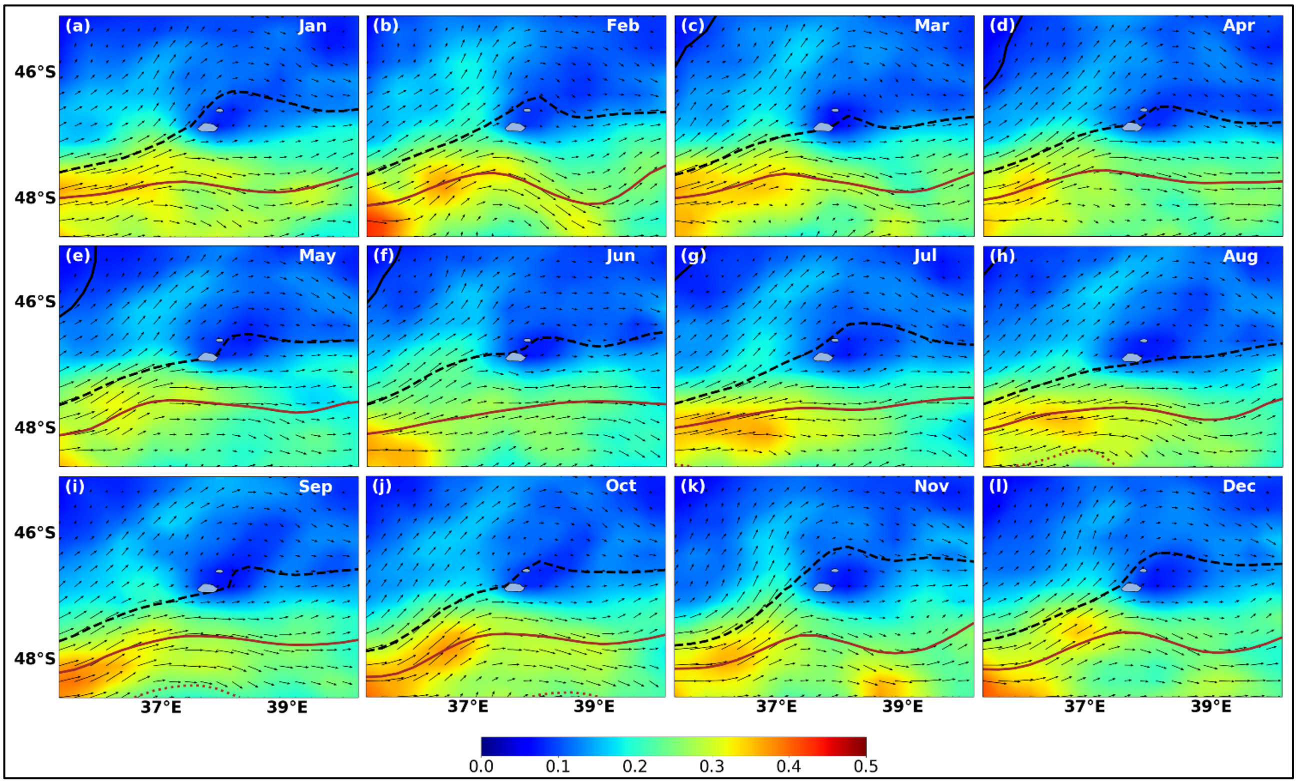

Figure 1: Monthly climatology of geostrophic velocity (m s^{-1}), with vectors indicating the direction of flow, around the PEIs. The solid/dashed black lines show the positions of middle/southern branches of the sub-Antarctic Front (M-SAF/S-SAF), and the solid/dotted brown lines indicate the northern/middle branches of the Antarctic Polar Front (N-APF/M-APF)

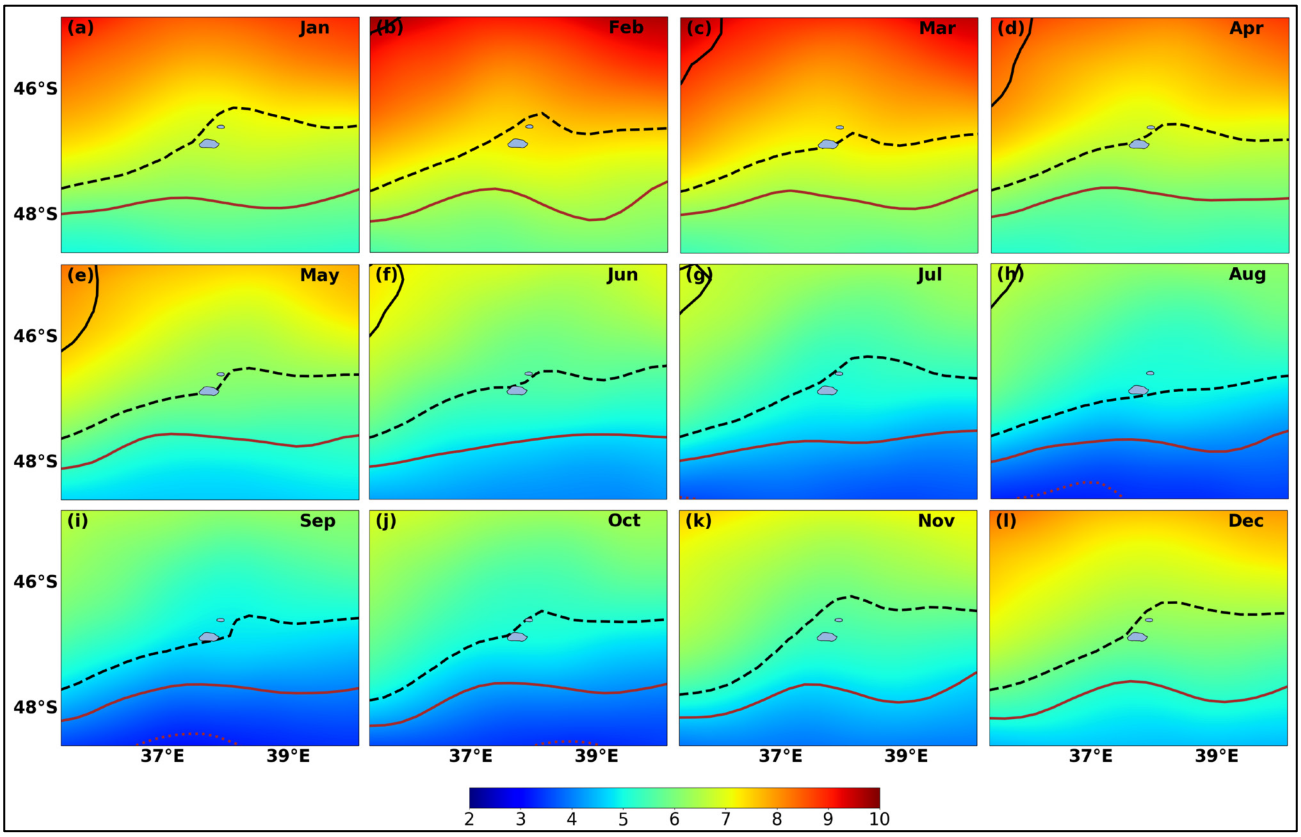

Figure 2: Monthly climatology of sea surface temperature (°C) around the PEIs. The solid/dashed black lines show the positions of middle/southern branches of the sub-Antarctic Front (M-SAF/S-SAF), and the solid/dotted brown lines indicate the northern/middle branches of the Antarctic Polar Front (N-APF/M-APF)

12. LARGE-SCALE HYDROGRAPHIC CONDITIONS AROUND THE PRINCE EDWARD ISLANDS DURING THE 2013–2019 ANNUAL SURVEYS

As physical conditions of marine ecosystems change in response to global climate variations, there are likely to be dramatic shifts in species diversity and structure of biological communities. At the Prince Edward Islands (PEIs) archipelago in the Southern Ocean, where there is a strong link between oceanographic and biological variability, substantial changes have already been observed. To enhance observational coverage in the data-poor Southern Ocean, and to improve understanding of the mechanisms that sustain and drive changes in productivity of the PEI ecosystem, hydrographic sampling has been conducted at and around the PEIs annually since 2013.

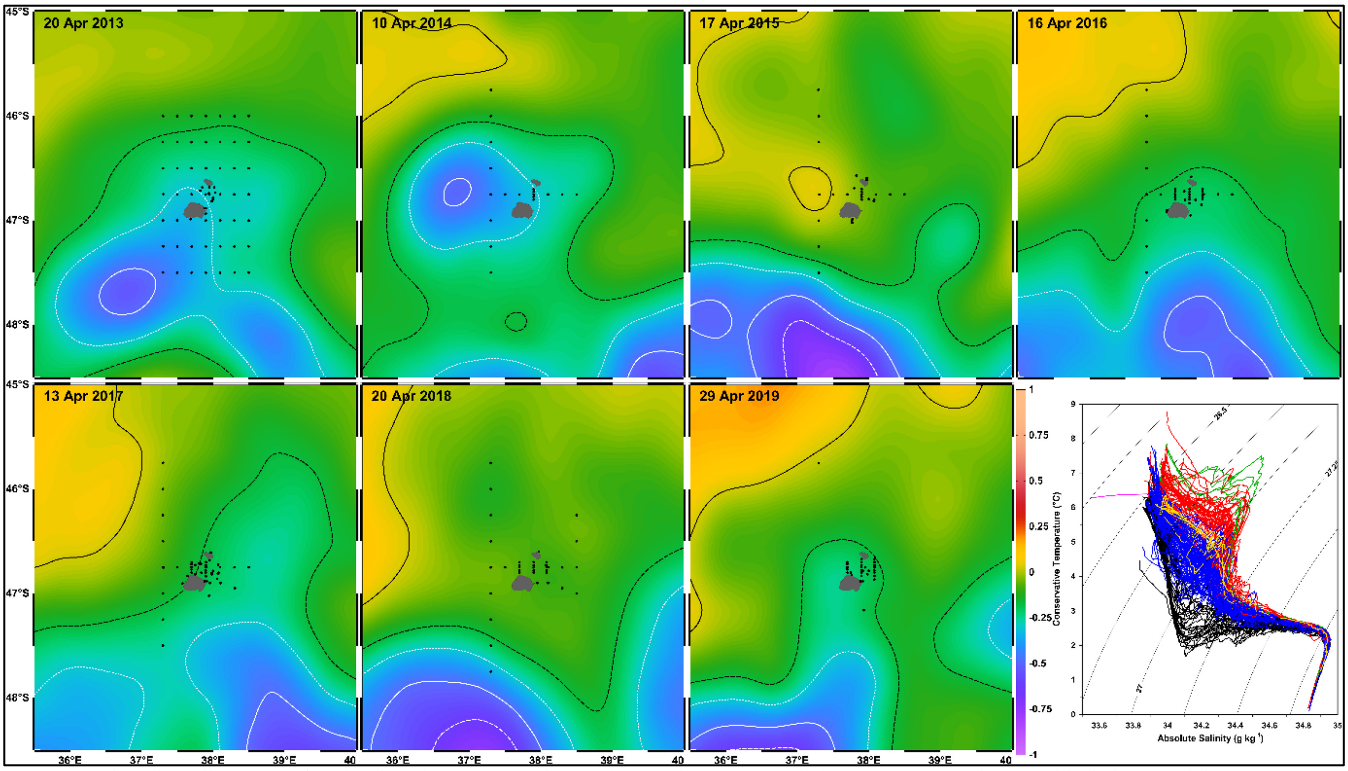

Figure 1: Selected satellite sea surface height (m) maps coinciding with annual cruise periods (station positions shown as black dots), and the Temperature-Salinity (TS) relationship for all stations from 2013 to 2019. Solid black contours show the middle branch (M-SAF), and dashed black contours indicate the southern branch (S-SAF) of the sub-Antarctic Front; dotted white contours show the northern branch (N-APF), and the solid white contours show the middle branch (M-APF) of the Antarctic Polar Front

During 2013, the southern branch of the sub-Antarctic Front (S-SAF) was located north of the PEIs and a cyclonic eddy was influencing the islands (Fig. 1). A similar situation occurred in 2014, but the middle branch of the sub-Antarctic Front (M-SAF) was closer to the PEIs. In contrast, the S-SAF was south of the islands in 2015, with an anticyclonic eddy impacting the islands. During 2018, the S-SAF was also south of the islands, but a dissipating cyclonic eddy was located north-west of the PEIs. Substantial northward/southward meandering of the S-SAF occurred in 2016, 2017 and 2019, and no eddies were evident during these surveys.

During each survey, water mass analysis indicated distinct distributions resulting from the varying oceanographic features. Shallow salinity and temperature maxima, characteristic of sub-Antarctic Surface Water (SASW), were observed at stations north of the S-SAF (red TS curves), and even larger subsurface temperature and salinity maxima were seen north of the M-SAF (green curves). These waters were also associated with the anticyclonic eddy west of the PEIs in 2015. Shallow temperature and salinity minima (black TS curves), typical of Antarctic Surface Water (AASW), were found south of the northern branch of the Antarctic Polar Front (N-APF), and were also seen in cyclonic eddies during 2013, 2014 and 2018.The region between the S-SAF and N-APF showed a mixture of these two water masses (blue and yellow TS curves). The yellow TS curves showed slightly larger proportions of SASW and were seen at stations located closer to the S-SAF. A single station (pink TS curve), sampled off the north-eastern edge of Marion Island in 60 m water depth, showed substantially lower salinities in the upper 10 m, indicating fresh water run-off from the island (Fig. 1).

The large-scale CTD sampling yielded data that are crucial to contextualising the conditions observed on the shallow PEI shelf, confirming the sources of the waters which were advected onto the shelf. These data were also vital in corroborating the meso-scale features and frontal positions identified from satellite altimetry.

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

Despite their small size, the Prince Edward Islands (PEIs) play an important role in providing 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. Historically, hydrographic observations in the region have largely been limited to April/May each year, during annual relief voyages to re-supply the research base. However, since April 2014, two moorings on the inter-island shelf (Fig. 1) have been providing the first set of continuous measurements of bottom temperature in the region.

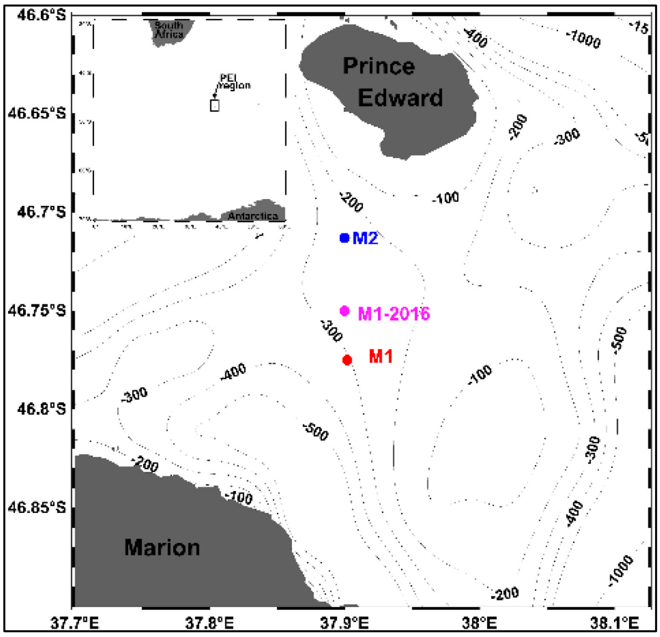

Figure 1: Bathymetry on the PEI shelf. Mooring positions M1 and M2 are shown in red and blue, respectively. The pink dot shows the location of M1 between April 2016 and April 2017

As mooring M2 (deployed at a depth of 260 m) was located deeper in the water column than M1 (174 m), bottom temperatures were consistently lower at M2 than at M1 (Fig. 2). Nevertheless, both moorings showed similar daily variability, with few occasions when temperatures showed opposite patterns for more than a few days at a time. The moorings also showed similar seasonal cycles, with the highest temperatures generally observed during austral autumn (March–May), and the lowest values typically seen during spring (September–November).

The data indicate substantial intra- and interseasonal, as well as interannual variability in bottom temperature (Fig. 2). Each temperature peak/trough indicated warming/cooling events of around 0.5–2°C in the inter-island region, which satellite altimetry indicated were associated with the close proximity of anticyclonic/cyclonic eddies, as well as the southern branch of the sub-Antarctic Front (S-SAF) and/or the northern branch of the Antarctic Polar Front (N-APF).

Both moorings also indicated extensive periods where temperatures were either consistently lower or higher than the long-term mean (Fig. 2). These periods corresponded to meridional meanders of the S-SAF. When the S-SAF was located north of the islands, bottom temperatures were generally lower due to stronger influx of cooler Antarctic waters. In contrast, when the S-SAF was south of the islands, bottom temperatures were generally higher due to the larger proportions of warmer sub-Antarctic and even sub-tropical waters.

Water temperatures influence the characteristics of biological communities through the water column, including the prey species on which the vast numbers of seabirds and marine mammals breeding at the PEIs are dependent. Thus, by influencing geographical distributions of preferred prey species, temperature variations are 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, the survival of young that are dependent on foraging adults, and ultimately for the reproductive success and numerical trends of the populations.

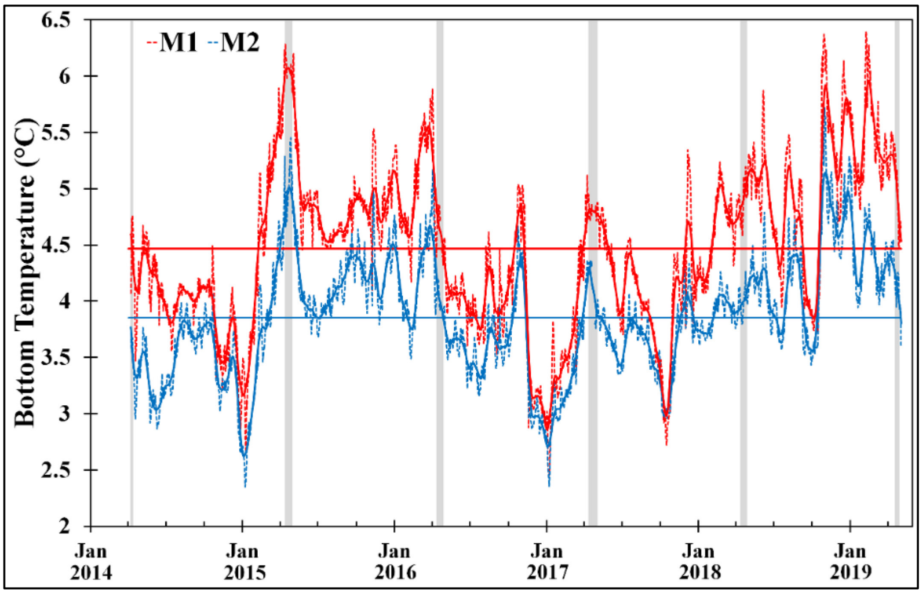

Figure 2: Daily mean bottom temperature (°C) at moorings M1 (red) and M2 (blue). Dashed lines indicate measurements while solid lines show low-pass filtered values. Horizontal lines show mean temperatures for each time series. Cruise periods are indicated by grey shading

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14. 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 the first set of continuous measurements of water column current speed and direction in the region.

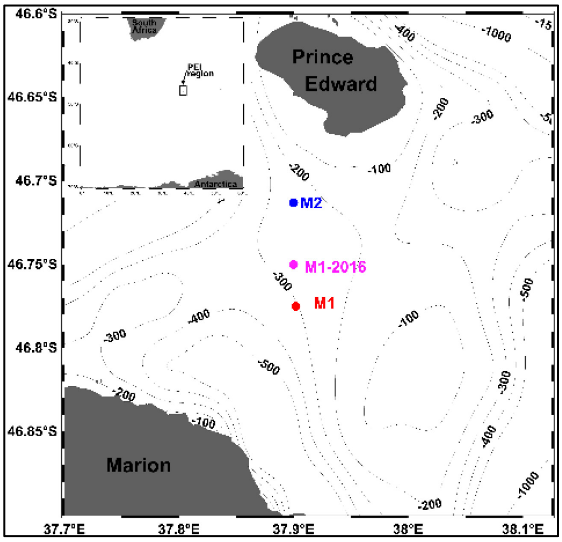

Figure 1: Bathymetry on the PEI shelf. Mooring positions M1 and M2 are shown in red and blue, respectively. The pink dot shows the location of M1 between April 2016 and April 2017

Daily mean current speeds at moorings M1 and M2 ranged from 0.01 to 50.90 cm s^{-1}, and zonal (west/east) flow was substantially larger than meridional (north/south) flow, due to the strongly zonal nature of the Antarctic Circumpolar Current. At M2, currents in the upper layers varied between south-easterly and south-westerly flow, but below *ca* 230 m, flow was predominantly south-westward. In contrast, flow in the upper layers at M1 was mainly north-westward, while roughly equal amounts of north-westerly and south-westerly flow was observed at the bottom (Fig. 2).

Many of the variations between easterly and westerly flow were associated with the interaction of passing cyclonic and anticyclonic eddies with the PEI shelf, as well as meridional meanders of the southern branch of the sub-Antarctic Front, and the northern branch of the Antarctic Polar Front. Nevertheless, there were numerous occasions where westerly flow could not be linked with either eddies or frontal meanders. Persistence of westerly flow in the bottom waters at M2, and throughout the water column at M1, suggests the presence of a Taylor column (a stationary anticyclonic circulation over the shelf). Such a feature may thus be more permanent than previously thought, and may be enhanced when fronts or eddies are located close to the islands.

A Taylor column is likely to play a critical role in the retention of nutrients and biota, thus maintaining enhanced productivity on the shelf. In the absence of interactions of eddies and fronts with the shelf, a Taylor column would also account for the continued persistence of an ecosystem able to sustain high concentrations of marine biota. With our data restricted to two locations, it is not clear whether such a structure exists around the entire PEI plateau, or if it is constrained to Marion Island only. As satellite altimetry cannot resolve flow in the inter-island region, more extensive long-term in situ observations across the plateau are required to fully resolve the flow structures and their variability.

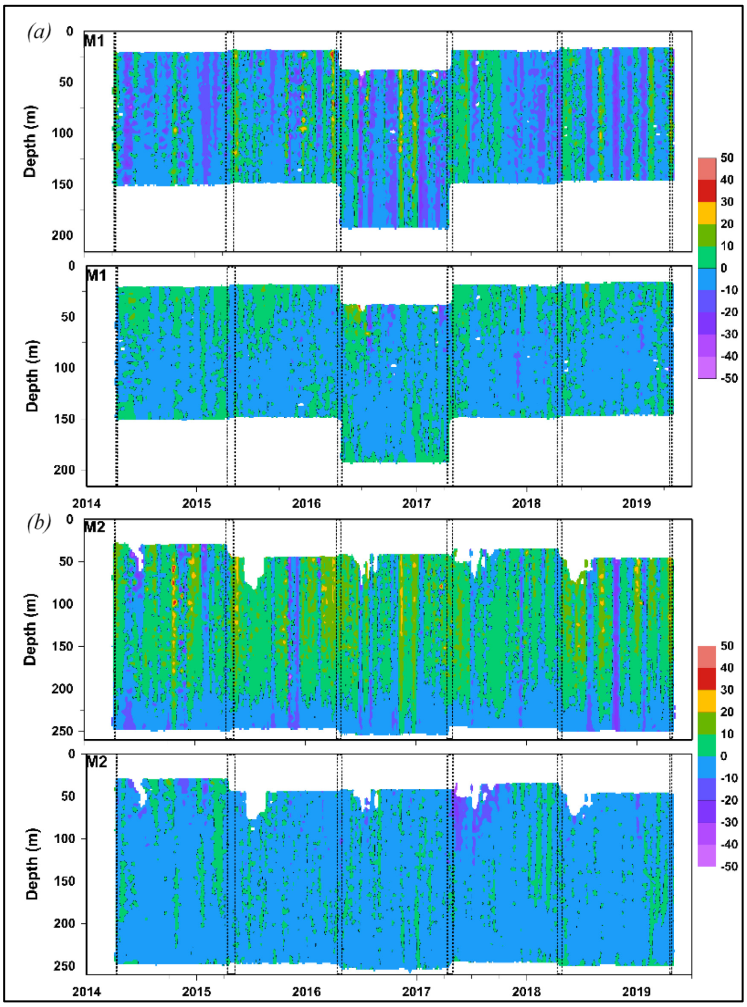

Figure 2: Daily mean zonal (top panel) and meridional (bottom panel) current components (cm s^{-1}) at (a) M1, and (b) M2. Positive values denote eastward (zonal) and northward (meridional) flow; negative values denote westward (zonal) and southward (meridional) flow. Cruise periods are indicated by dashed black lines

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15. CARBONATE CHEMISTRY IN THE SOUTHERN OCEAN IN SPRING 2019

Atmospheric carbon dioxide (CO_2) has increased from about 280 parts per million (ppm) since the beginning of the industrial age to the current value of 412 ppm. This has mostly been attributable to the burning of fossil fuels. Of the CO_2 emitted into the atmosphere, approximately a third is absorbed by the ocean. The Southern Ocean is considered one of the most important CO_2 sinks, absorbing approximately 50% of the world's total ocean CO_2 flux. However, the uptake of anthropogenic CO_2 has led to a decrease in surface pH and in the concentration of carbonate ions in the ocean, globally. Projected further decreases will potentially be detrimental for marine organisms that have skeletons or shells made of carbonate minerals (e.g. lobsters, molluscs and corals) and for industries that utilise such organisms (e.g. aquaculture).

This report provides highlights of carbonate chemistry measurements performed during the "Southern oCean seAsonaL Experiment" (SCALE; www.scale.org.za). Key objectives of SCALE include advancing our understanding of the climate sensitivity of the Southern Ocean through a better understanding of seasonal cycle dynamics in the upper ocean, and to observe decadal changes in ocean interior storage of carbon, geotraces and heat. Carbonate system variables, namely dissolved inorganic carbon (DIC) and total alkalinity (AT), were measured along both the Good Hope and the marginal ice zone (MIZ) transects in the Southern Ocean, during spring of 2019 (Fig. 1). The surveys were conducted on the *SA Agulhas II*. CO_2 was extracted from seawater samples using a VINDTA 3C system, and DIC and AT measurements were obtained. The pH, partial pressure of CO_2 (pCO_2) and the saturation state of the carbonate mineral aragonite (Ωarag) were calculated.

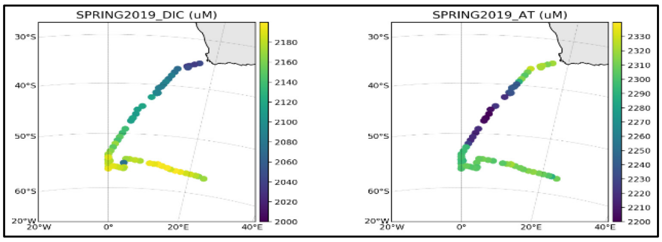

Figure 1: Raw Dissolved Inorganic Carbon (µmol/kg) and Total Alkalinity (µmol/kg) of surface water samples collected along the vessel's track

A gradual decrease in temperature in the upper 500 m layer, as the survey progressed southwards, was accompanied by an increase in DIC and a decrease in pH and Ωarag (Fig. 2). Northward flow of Antarctic Intermediate Water (AAIW), the core of which has been shown to move towards the Cape Basin where it meets with Indian Ocean AAIW injected via Agulhas Rings, was apparent between 1 000–2 000 m. The core of the AAIW carried DIC of *ca* 2 250 µmol/kg, a pH of *ca* 7.8, O_2 of *ca* 2.9 ml/L and an aragonite saturation of 1. As a result of upwelling of Circumpolar Deep Water (CDW), the aragonite saturation horizon shifted from a depth of 1 000 m in the north of the survey area, to *ca* 500 m around 50°S.

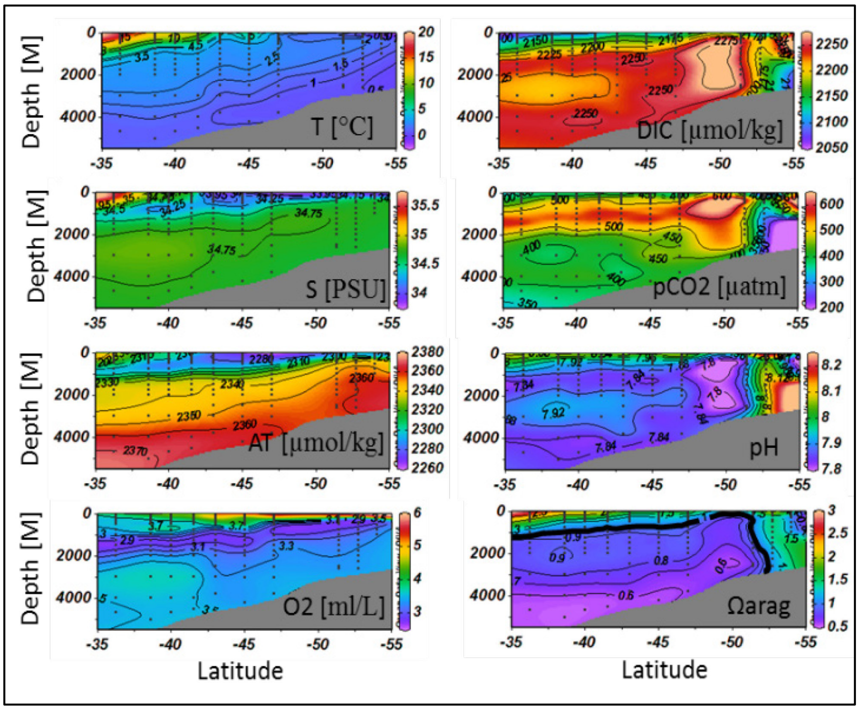

Figure 2: Vertical sections of temperature (T), salinity (S), total alkalinity (AT), dissolved oxygen (O_2), dissolved inorganic carbon (DIC), partial pressure of CO_2 (pCO_2), pH and aragonite saturation (Ωarag). The aragonite saturation horizon is marked by a thick black line. The marginal ice zone started at about 55°S

These results contribute to further understanding ocean chemistry patterns and processes in the Southern Ocean that will help to assess climate sensitivity and predict changes under different scenarios. The spring SCALE together with winter and summer surveys will assess the SCALE hypothesis that changes in seasonal modes of variability are a more sensitive indicator of long-term trends than changes in the magnitude of annual means. SCALE furthermore provided interdisciplinary post graduate student training with advanced skills development in various oceanographic fields and innovative observational technology.

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Contributor: Mdokwana BW (O&C Research)

SCALE
Southern oCean seAsonaL Experiment

16. LONG-TERM VARIABILITY IN THE DIET OF MACARONI AND ROCKHOPPER PENGUINS AT SUB-ANTARCTIC MARION ISLAND

Breeding penguins are central place foragers, limited by their need to forage and return to their colonies to relieve their partners and/or feed their chicks. Long-term diet studies of seabirds while breeding provides important insights to their feeding ecology, their responses to ecosystem changes, and shifts in prey availability.

At Marion Island, macaroni and rockhopper penguins, *Eudyptes chrysolophus* and *Eudyptes chrysocome* (Fig. 1), breed sympatrically and can therefore be expected to exhibit ecological segregation to reduce competition. Over the past 25 years (1994–2018/19), there have been marked declines in the populations of both species: macaroni penguins have decreased by 49% and rockhoppers by 66%.

Figure 1: The two crested penguins that occur at Marion Island: the rockhopper penguin (left) and the macaroni penguin (right)

Diet samples of both species have been collected at the island during the breeding season, also over the past 25 years. Their diets were shown to comprise a variety of crustaceans, cephalopods and fish, in different proportions (Fig. 2).

Crustaceans were dominant in the diet of both species, but more so in rockhoppers. The crustaceans *Thysanoessa vicina* and *Euphausia vallentini* (both krill species) were the two most important prey species in the diet of both penguin species in terms of mass, comprising 59% of macaroni and 79% of rockhopper diet.

Fish was more prevalent in the diet of macaroni penguins and the size of the fish that they ate was significantly larger than those in the rockhopper's diet. There was also a wider range of fish species in the diet of macaroni penguins than in the rockhoppers' diet, with *Krefftichthys anderssoni*, *Protomyctophum tenisoni* and *Electrona carlsbergi* (all lanternfish species) being the most abundant species (Fig. 3). Small amounts of cephalopod (squid) remains were also recorded. The low occurrence of cephalopod remains in scats may have been due to accumulation of squid beaks in folds of the stomach.

Whereas rockhopper penguins exhibit a relatively specialised feeder strategy, with crustaceans dominating their diet in all the 25 years sampled (Fig. 3), macaroni penguins were more generalised in their feeding, with alternating dominance between different fish and crustacean species over the years (Fig. 3). The fish prey have higher calorific contents than the other prey types, and the higher incidence of fish in the macaroni penguin diet may contribute to their slower rate of decline, compared with the rate of decline in rockhopper numbers at the island. An apparent decline in the contribution of fish to the diet of rockhoppers over the past 25 years may indicate that they have had increasing difficulty in catching fish. However, the ongoing, long-term decline of both species indicates an overriding driver, such as climate change.

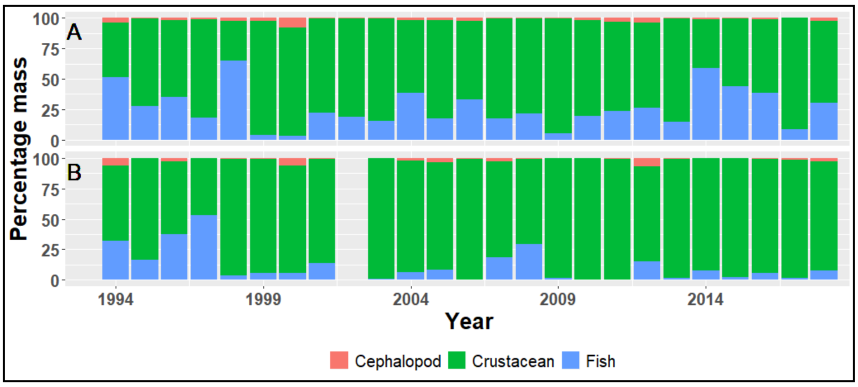

Figure 2: The estimated relative contributions by mass of fish, crustaceans and cephalopods to the diets of macaroni (A) and rockhopper penguins (B) at Marion Island

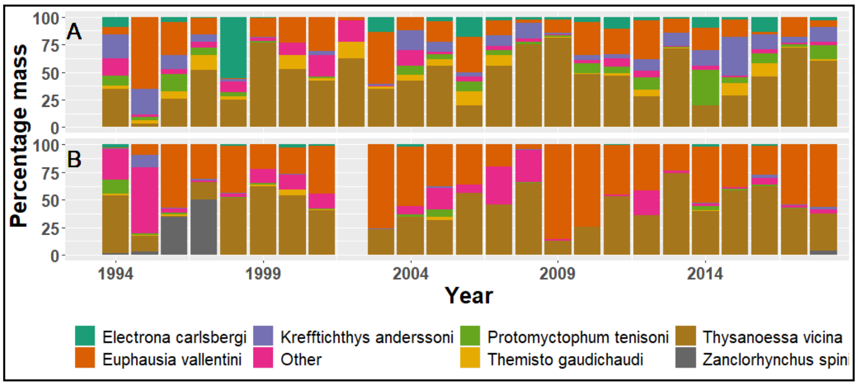

Figure 3: The relative contributions by mass of the dominant prey species in the diet of macaroni (A) and rockhopper penguins (B)

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Contributors: Crawford RJM, Dyer BM (O&C Research)

17. SEASONAL CHANGES OF THE MIXED LAYER DEPTH IN THE SOUTH-EAST ATLANTIC OCEAN

The mixed layer in the open ocean is the upper ocean layer (adjacent to the air-sea interface) that is well mixed, with vertically uniform profiles of temperature, salinity and density. On seasonal time scales, the two primary drivers of mixing within this homogeneous layer are wind stress and radiation (heat loss and gain) at the sea surface that are transferred through the water column. The intensity and duration of these processes influences the mixed layer depth (MLD). The MLD is critical to many physical (e.g. heat exchange), chemical (e.g. exchange of oxygen and carbon dioxide), and biological (e.g. photosynthesis and vertical distribution of plankton and fish) processes in the ocean.

In comparison with several other ocean regions, understanding of seasonal changes in the MLD within the south-east Atlantic Ocean (SE Atlantic), which encompasses the Benguela Ecosystem off the west coast of southern Africa, is relatively lacking. This has mainly been due to a lack of *in situ* oceanographic data on which studies of seasonal change could be based. However, data provided by Argo floats (Fig. 1) from the Argo Array Programme (www.usgodae.org/argo/argo.html) were used to conduct a baseline study to describe seasonal variation of the MLD in the SE Atlantic (25°–45°S, 0°–25°E), for the period 2008–2018. The Argo data were analysed using MATLAB software and a temperature-based criterion algorithm to determine monthly and seasonal MLD values across the region.

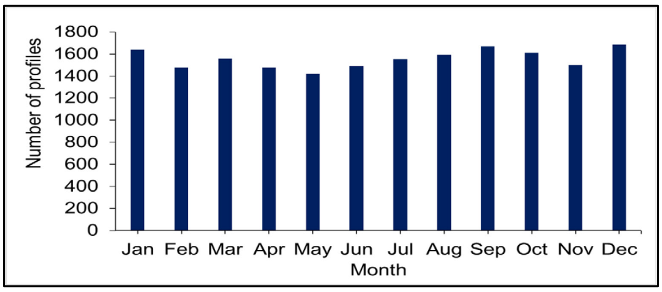

Figure 1: The monthly total of the number of Argo profiles that were used over the study period (2008-2018)

Results from individual floats showed that the MLD ranged from 4–546 m, while the mean monthly MLD ranged from 30–120 m (Fig. 2). The calculated mean MLD was at its deepest during winter, peaking in August, and the shallowest MLD was observed in summer (December). The increased solar heating on the sea surface during summer leads to a more stable, stratified water column, which decreases the penetration of wind-driven mixing and results in shallower MLD values. In winter, however, the cooling of the sea surface limits the stability of the stratified layer, resulting in deeper penetration of wind-driven turbulence, which in turn induces further mixing to greater oceanic depths. MLD in the global ocean can be less than 20 m in summer, while reaching more than 500 m in winter particularly in the sub-polar latitudes. During spring, occurrences of deep MLD (> 500 m) in the latitudinal band between 27°S and 35°S were apparent, indicating that deep MLD can occur in sub-tropical oceans (Fig. 3). The distribution of deep MLDs suggests that their occurrence is possibly related to strong vertical mixing associated with localised oceanic meso-scale turbulence that is known to dominate the region.

This baseline study, which was the basis of a postgraduate degree at CPUT, demonstrates the usefulness of Argo data for the investigation of MLD in data-scarce regions such as the SE Atlantic. These datasets will be explored further, in conjunction with other datasets (modelling and ship-based), to develop forecasting capabilities of the MLD processes and their potential influences on the marine environment.

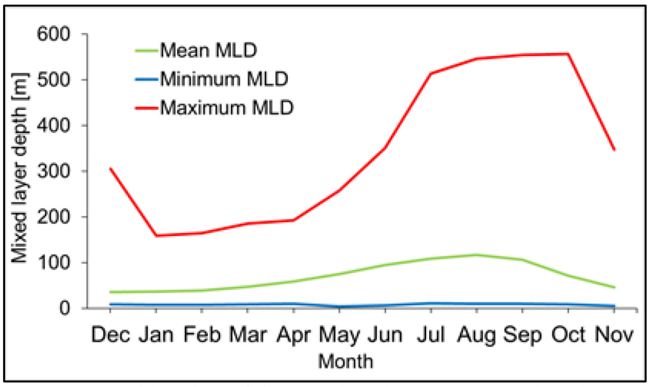

Figure 2: Monthly values of the MLD based on temperature-based criteria obtained from Argo floats

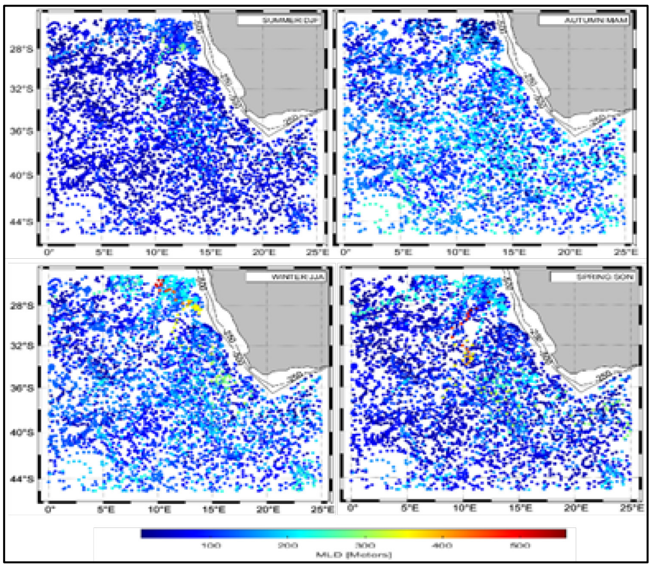

Figure 3: Individual Argo profiles within the SE Atlantic showing seasonal variation of the MLD for summer (top left), autumn (top right), winter (bottom left) and spring (bottom right). High MLD values (orange and red) are observed in winter, with few in spring, whilst lowest MLD values (dark blue) are observed in summer

Authors: Gulekana M, Mbongwa S (O&C Research); Rasmeni B, Halo I (CPUT)

18. ENTRAPMENT? PLANKTON DISTRIBUTION AND COMPOSITION WITHIN A RECENTLY FORMED CYCLONIC EDDY OFF SOUTH-WESTERN MADAGASCAR

Meso-scale eddies are major features in ocean dynamics that significantly influence ocean production, depending on their polarity (cyclonic or anticyclonic), status (intensifying or decaying), location and time of formation. Eddies in the south-west Indian Ocean have been the focus of many studies, especially in the Mozambique Channel where southward-moving cyclonic and anticyclonic eddies feed into the Agulhas Current. However, eddies formed south of Madagascar that move westwards towards the coast of South Africa have been much less studied, despite their significant contribution to the Agulhas Current. It has recently been hypothesised that these eddies may act as vectors of genetic material between Madagascar and the South African coast, trapping organisms of local (Madagascan) origin and transporting them across the ocean, known as the “suitcase hypothesis”.

In July 2013, sampling was conducted on the Madagascar shelf and along a transect through an eddy that had formed recently (roughly one month previously) off the south-west coast of Madagascar (Fig. 1). Aims were to understand how zooplankton were distributed within the eddy, and to explore the possibility of entrapment of zooplankton by the eddy from its region of formation.

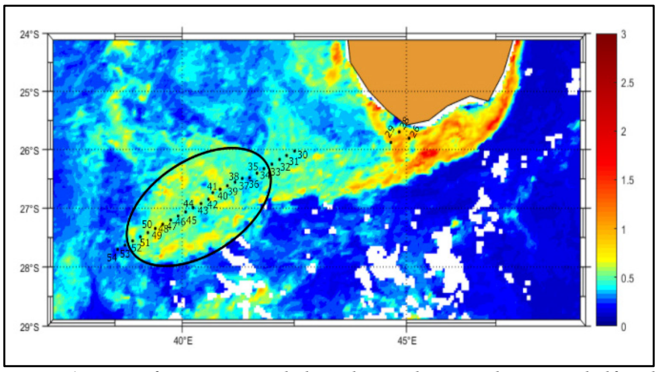

Figure 1: Map of stations sampled on the southern Madagascar shelf and transecting a cyclonic eddy during July 2013, superimposed on a seven-day (13–20 July 2013) composite of Chlorophyll a concentration from MODIS. The black ellipse indicates the approximate boundary of the eddy

A patch of enhanced Chlorophyll *a* concentration was found at four stations (44–47) in the eddy (Fig. 2a), homogeneously distributed vertically in the upper mixed layer (UML) and characterised by a higher proportion of diatoms compared to the other stations (Fig. 2b). Abundances of picoplankton, nanoplankton, ciliates and dinoflagellates were very similar within and outside the eddy. Cyclonic eddies typically have enhanced nutrients from upwelling in their cores, but this eddy was still intensifying and nutrient concentrations were low, so it is possible the diatoms may have originated on the shelf.

Zooplankton in the eddy followed a contrasting pattern with higher biomass at four stations (48–51) just west of the high diatom patch (Fig. 2c). Multivariate analysis revealed that the mesozooplankton communities at these four stations possessed greater similarities in species composition with the Madagascar shelf than with the other stations, suggesting a link between the shelf and the western side of the eddy. The periphery of the eddy seems to have been primarily influenced by a strong geostrophic current propagating from the southern shelf of Madagascar, which then wrapped itself around the eddy. This filament may be the source of the high zooplankton biomass in the eddy periphery, which would account for the similarities in community composition between the eddy periphery and the shelf. This study confirms that eddies can entrain plankton from the Madagascar shelf and transport organisms into the open ocean. Whether or not they can reach the African continent, is the focus of ongoing modelling and genetic studies.

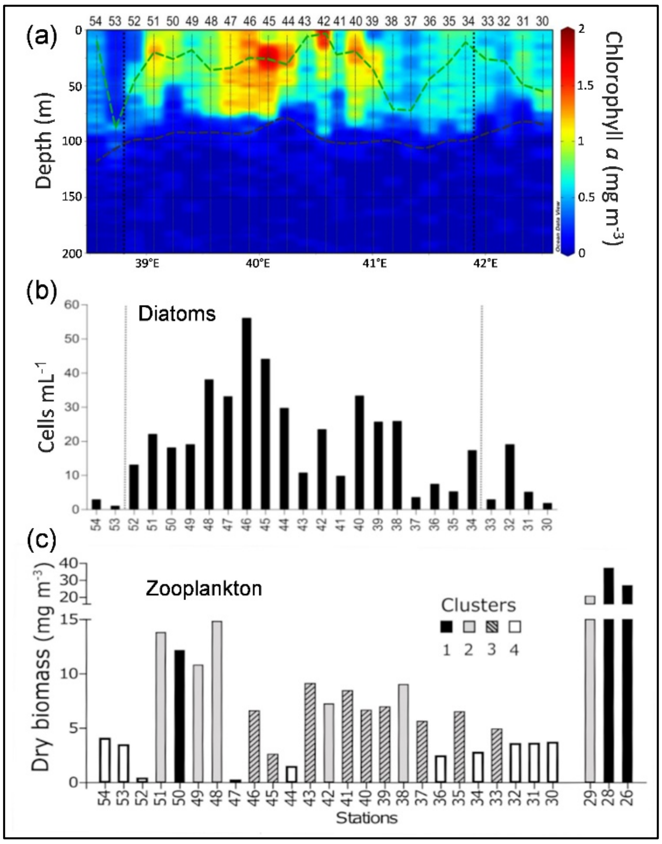

Figure 2: (a) Chlorophyll a *concentration (mg m^{-3}) along the transect across the eddy (stations 30 to 54). The dark dashed line corresponds to the depth of the mixed layer and the green dashed line to the maximum Chlorophyll* a *concentration. The two vertical dotted lines indicate the eddy perimeter; (b) Concentration of diatoms (cells mL^{-1}) from the surface for all stations crossing the eddy; (c) Zooplankton dry biomass (mg m^{-3}) for all stations crossing the eddy and the three shelf stations (29, 28, 26). The clusters (1 to 4) originated from multivariate analyses*

Authors: Noyon M (NMU); Huggett J (O&C Research); Morris T (SAWS); Walker D (CPUT)

19. GIANTS AND TITANS: THE SPREAD OF TWO INVASIVE ALIEN BARNACLES ON KWAZULU-NATAL ROCKY SHORES

Invasive alien species are globally recognised as one of the most serious threats to biodiversity. Coastal ecosystems are particularly prone to species introductions, with alien species primarily arriving on hulls or in ballast water of ships, or escaping from aquaculture facilities. Intertidal rocky shores in South Africa have been severely impacted by invasive species, most notably by the Mediterranean mussel, the bisexual mussel and the Pacific barnacle, which are all limited to the cold waters of the West and South Coasts. Prior to this study, no invasive species have been recorded on rocky shores of the warm East Coast.

The South African National Rocky Shore Monitoring Programme was established by the Department in 2015, and has since been implemented in all coastal provinces. During a monitoring survey in KwaZulu-Natal (KZN) in 2018, an unknown and conspicuously large barnacle was detected and collected. It was identified by an expert taxonomist as the giant purple barnacle *Megabalanus tintinnabulum.* This provided the impetus for a survey to be undertaken of the entire South African east coast in 2019 (Fig. 1), to establish how far this globally known invasive species has spread and how it is impacting natural intertidal ecosystems. During this survey, a second large invasive barnacle, the titan barnacle *Megabalanus coccopoma* was detected (Fig. 2).

Figure 1: Map of the South African east coast, showing the locations of sampling sites. Purple markers indicate the presence of giant purple barnacles, pink markers the additional presence of titan barnacles, and grey markers the absence of either species

Neither of the two species was detected when a comprehensive rocky shore biodiversity survey was last conducted, in the late 1990s, suggesting that their arrival and spread along the South African coast occurred within the past 20 years. In 2010, however, both species were collected from a buoy outside Richards Bay harbour, and on barges shortly after they were scuttled at a depth of 35 m. This indicates that breeding populations of the two species had become established by that time, and may already have spread into natural subtidal habitats.

Figure 2: The two alien invasive species that were detected on KZN rocky shores for the first time in 2018–19: The giant purple barnacle (left) and the titan barnacle (right). As their names indicate they are large and conspicuous, with the giant growing up to >10 cm in height, while the titan is slightly smaller

The 2018 and 2019 surveys first confirmed the arrival and spread of the two invasive barnacles in natural habitats of South Africa. The latter survey showed that *M. tintinnabulum* has become a common inhabitant of the lower intertidal zone of rocky shores, where it grows up to >10 cm in height and provides a habitat for numerous other species that colonise its shell plates. The slightly smaller *M. coccopoma* was only sporadically encountered alive in the intertidal zone, but its bright pink shells were commonly encountered washed up on KZN beaches, indicating that there is a well-established subtidal population of this barnacle, which has not been sampled at this stage.

It is very difficult to control the spread of invasive marine species once they have become established and spread. Eradication is futile, since their dispersing larval stages are planktonic and the mere removal of adult barnacles would yield no long-term success. Management effort must therefore be focused on preventing new introductions, including through monitoring and control of aliens in the ballast waters of ships, and of fouling communities on hulls of vessels.

Authors: Pfaff MC (O&C Research); Mvula P (UKZN); Biccard A (Anchor Environmental Consultants)
Contributors: Mushanganyisi K (O&C Research); Olbers J (Ezemvelo)

20. A HITCHHIKER'S GUIDE TO DISTINGUISHING COASTAL FROM OPEN-OCEAN FORAGING SEA TURTLES

The loggerhead sea turtle *Caretta caretta* is a migratory species that occupies a wide array of marine habitats throughout its life. Understanding its habitat use provides important information for the design of effective conservation strategies for this threatened species. This study combined two approaches to examine habitat use patterns of individual female loggerheads nesting in the iSimangaliso Wetland Park (KwaZulu-Natal), namely (a) the community composition of turtle epibionts, which are organisms that "hitchhike" on turtles (Fig. 1), and (b) isotopic analysis of turtle skin tissue. The latter involves identifying chemical signatures, which reflect an organism's role in the food web. In particular, we investigated nitrogen isotopes (δ15N), which indicate the trophic level of a turtle, and carbon isotopes (δ13C), which point to the source of primary production a turtle has consumed in the months prior to sampling.

Figure 1: A nesting loggerhead turtle is sampled for its epibiont community during the routine annual monitoring that forms part of the tagging programme in the Isimangaliso Wetland Park (KZN)

Of the isotope types, only carbon showed a pattern, with two distinctive turtle foraging groups identified based on relative enrichment/depletion of δ13C (Fig. 2). One was characterised by feeding in coastal habitats (enriched δ13C) and the other in open-ocean pelagic habitats (depleted δ13C).

Twenty-four species of epibionts were identified and counted on 80 loggerhead females, and their community composition differed significantly between the two foraging groups (Fig. 3). The open-ocean pelagic goose barnacles *Lepas spp.* occurred in higher abundances on individuals with depleted δ13C, while the three coastal amphipods *Hyale grandicornis*, *Hyachelia tortugae* and *Podocerus africanus* were more common on turtles with enriched δ13C. The turtle barnacle *Chelonibia testudinaria* commonly occurred on individuals of both groups and is thus not a reliable indicator of turtle feeding habitat.

The combination of isotope and epibiont data applied in this study suggests that nesting loggerheads of the south-west Indian Ocean exhibit a bimodal foraging strategy, feeding in either coastal or open-ocean habitats. This study demonstrates that epibionts can inform conservation planning, since habitat use patterns of their hosts are easily generated at low cost for a large number of individuals. While used here for turtles, this method is likely also applicable to other migratory species.

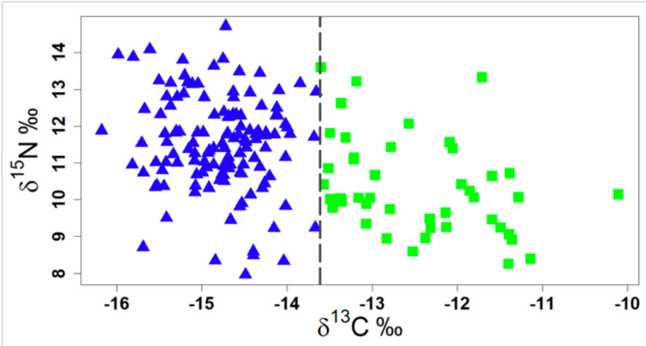

Figure 2: Distribution of carbon (δ13C) and nitrogen (δ15N) stable isotope signatures from nesting loggerhead turtles. Two clusters emerged based on carbon isotope ratios, a depleted cluster (blue triangles), and an enriched cluster (green squares), which reflect open-ocean vs coastal feeding, respectively

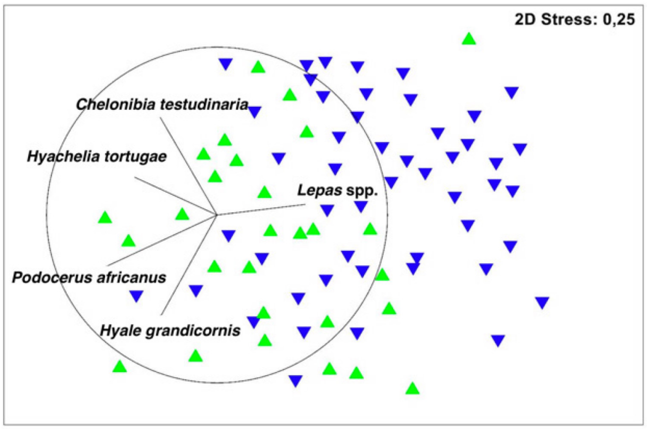

Figure 3: An ordination plot showing differences in turtle epibiont communities between coastal (green) and oceanic foraging turtles, where each point represents a turtle and the proximity between points reflects how similar their epibiont communities were. The black lines indicate in which direction these differences were influenced by the five most diagnostic epibiont species

Authors: Nolte C, Nel R (NMU); Pfaff MC (O&C Research)

21. PHYSIOLOGICAL RESPONSES OF COASTAL MARINE ORGANISMS TO CHANGING CLIMATES: A CASE STUDY OF A LOCAL ABALONE SPECIES

Throughout time, there have been organisms that have been able to adapt to practically every climatic situation on Earth. Presently, a multitude of anthropogenic stressors including commercial exploitation, pollution, acidification and warming, pose considerable challenges to the capability of organisms to adapt, because of their unprecedented rates of increase and their cumulative impacts. Furthermore, warming (and increases in some other climate-related stressors) are not attributable merely to constant change, but to an increased frequency and intensity of extreme climatic events. Marine heat waves, for example, are occurring more frequently and for longer periods causing catastrophic events globally.

To better understand how marine organisms respond to gradual or extreme climatic changes, we evaluated physiological responses of selected taxa. Here we present impacts of long-term hypercapnia (low pH) on the thermal response of an endemic abalone species of considerable ecological and economic importance, *Haliotis midae*. The abalone were housed in sub-replicate tanks for 18 months and exposed to Hypercapnic (pH = 7.3) or Normocapnic (pH = 8) conditions produced in header tanks (Fig. 1A). Abalone exposed to Hypercapnic conditions had significantly slower growth rates (Fig. 1B). Critical Thermal Maxima (CT_{max}) – the point where organisms respond with uncoordinated movement, but are able to recover fully thereafter – was then measured by attaching the abalone to plates and increasing temperature by 2°C/hour until they became detached. This was followed by measurements of acid-base regulation to determine if abalone could regulate pH levels within their haemolymph (blood equivalent).

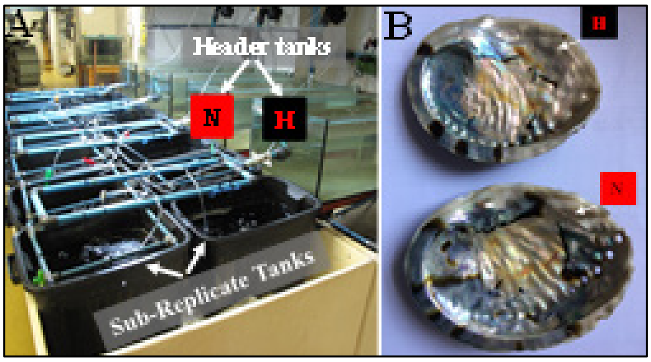

Figure 1: A) Header and sub-replicate tanks for controlling of pH conditions. B) Shells of a Hypercapnic (H) versus Normocapnic (N) abalone at the same development stage

Pre-exposure to low pH conditions did not affect thermal tolerance of abalone (*ca* 28°C; Fig. 2). However, measurements of acid-base indicated that abalone are unable to compensate for hypercapnia (Fig. 3), and this is likely impacting their physiological performance, as reflected in the slower growth rates. While, the biggest threat to abalone in South Africa is illegal trade, changing climatic conditions may be additionally impacting this already slow growing species. For example, in coastal areas, pH levels are predicted to decline by 0.3 to 0.5 units by 2100 and marine heat waves are increasing and occur on average at least once a year. While pre-exposure to low pH conditions did not affect thermal responses, knowledge of the temperatures at which abalone experience acute heat stress is useful to avoid aquaculture mortalities, and better understand how they will fare in their natural habitat under temperature stress.

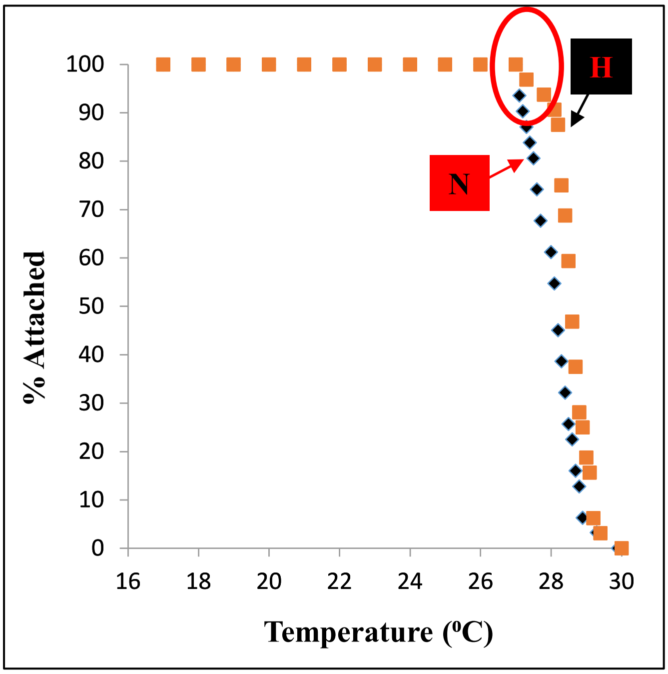

Figure 2: The percentage of Normocapnic (N) and Hypercapnic (H) individuals that remained attached to plates as the rate of temperature increased

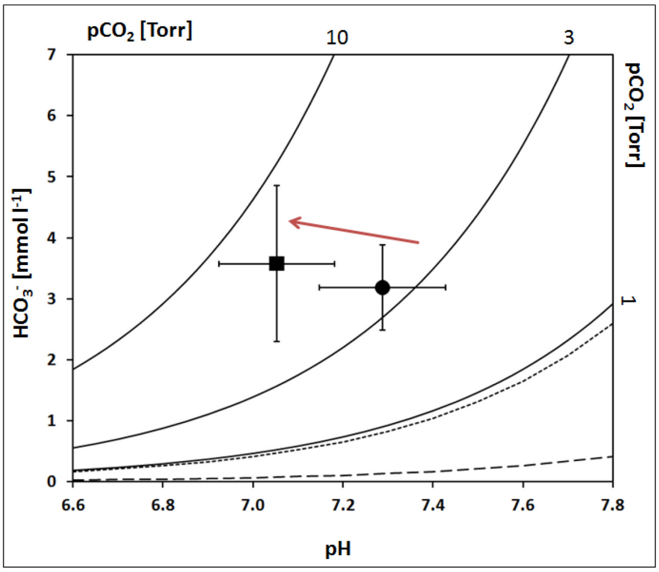

Figure 3: Henderson-Hasselbalch (pH-bicarbonate) diagram for haemolymph of Normocapnic (●) and Hypercapnic (■) seawater. Values are means ± SD (n = 12). The red arrow indicates a non-compensated respiratory acidosis, i.e. no relevant elevation of bicarbonate ion (HCO_3^-) levels to retain internal pH at pre-incubation/Normocapnic levels

Author: Haupt T (O&C Research)
Contributors: Novak T, Auerswald L (Fisheries Research); Naylor M (HIK Abalone Farm – Hermanus)

22. SPATIO-TEMPORAL VARIATION IN THE DIET OF BANK CORMORANTS IN SOUTH AFRICA

The bank cormorant *Phalacrocorax neglectus* is endemic to the Benguela Ecosystem off the south-west coast of Africa (Fig. 1). It is classified as Endangered on account of a recent large reduction of its numbers. Diet samples (pellets) have been collected from bank cormorant colonies in South Africa since the 1970s. This report assesses decadal-scale shifts in the diet composition of the species.

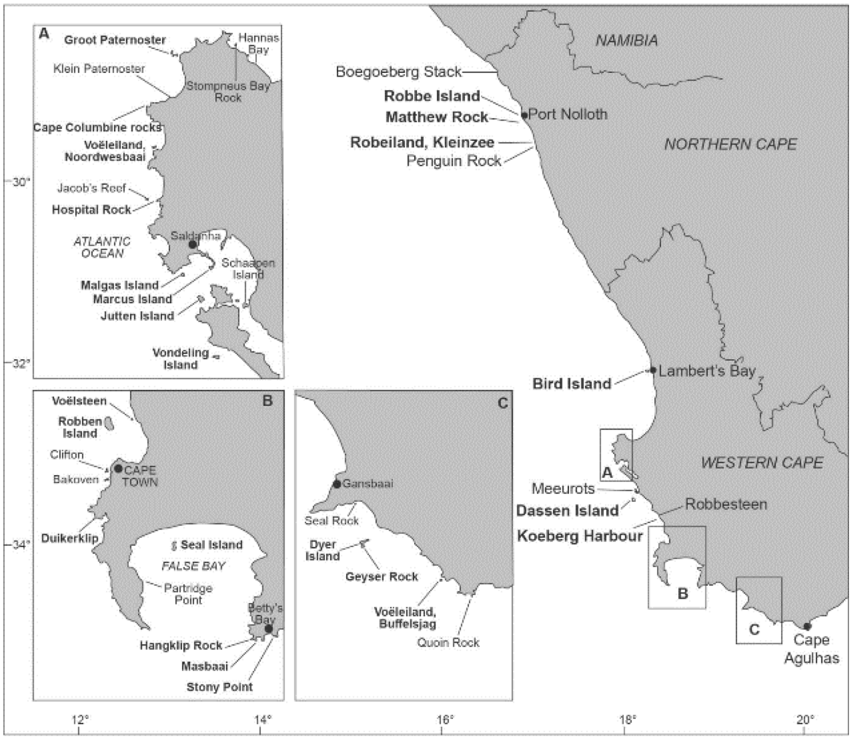

Figure 1: Map of the locations where bank cormorants are known to have bred in South Africa. Colonies where pellets were collected in the present study are highlighted with bold font

The diet of bank cormorants varied considerably between 1975–1985 and 1995–2002, with a widespread decrease in the proportions of West Coast rock lobster, octopus and cuttlefish *Sepia* spp. between the two periods, and an increase in fish species (Fig. 2).

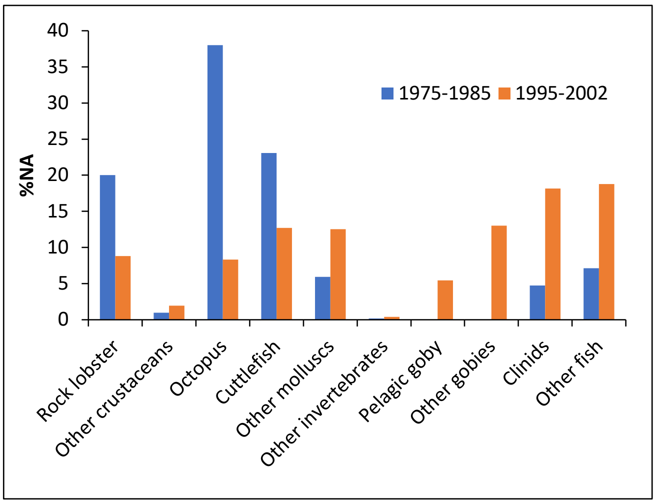

Figure 2: The relative contribution by number (%NA) of ten prey categories to the diet of bank cormorants in 1975–1985 (n = 3 235 diet samples) and in 1995–2002 (n = 11 642)

The decline in West Coast rock lobster in the diet corresponded with a shift to the southeast in the distribution of this species in South Africa, leading to an increase in the proportion of the stock that occurred to the east of Cape Point, and a concomitant decline in the commercial catches of this species on the West Coast. West Coast rock lobster is a preferred prey species of the bank cormorant, with a considerably higher energy content than other prey in the diet.

The shifts in the distribution of this prey species were most likely accountable for the decline in bank cormorant numbers that occurred over these periods, and for the increase in the proportion of the population breeding to the east of Cape Point.

The lengths of the majority of West Coast rock lobster carapaces retrieved from diet pellets over the study period were less than 60 mm, with a peak at 55 mm (Fig. 3). No specimens exceeded 80 mm, which is the legal minimum size limit for the fishery, indicating negligible overlap between the diet and catches.

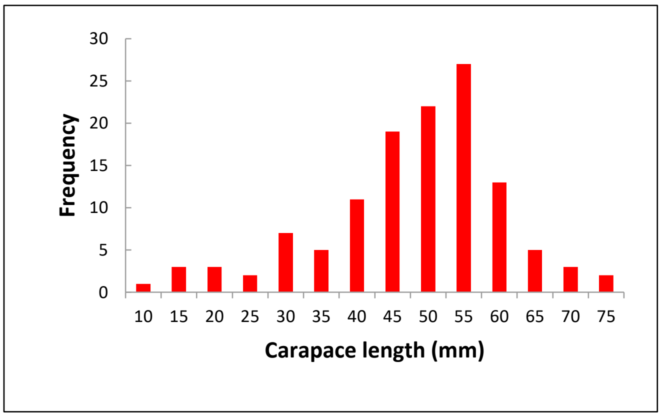

Figure 3: Frequency of carapace lengths in different size classes of West Coast rock lobster found in pellets regurgitated by bank cormorants in South Africa, 1975–2002

Authors: Makhado AB, Dyer BM, Crawford RJM (O&C Research)
Contributors: Masotla MJ, Upfold L (O&C Research)

23. DIVE BEHAVIOUR AND PHYSIOLOGICAL LIMITS OF CAPE FUR SEALS

The Cape fur seal *Arctocephalus pusillus pusillus* population has recovered considerably following past over-exploitation, and is currently estimated at 1.5–2 million animals. The population is a major component of the top predator biomass in the Benguela Ecosystem. While the diet of *A. p. pusillus* has been well studied, research on their foraging behaviour has lagged behind that for other fur seals, such as the conspecific Australian fur seal *A. p. doriferus*. For these, information derived from dive data loggers (e.g. dive shape, depth, duration and frequency, in relation to environmental variables and physiological limits, have been useful for determining ecological responses of populations to environmental changes.

To address this gap in *A. p. pusillus*, data loggers were deployed on 32 adult female seals at Kleinsee on the West Coast (Fig. 1). The loggers were retrieved (Fig. 2) when the seals returned after a subsequent foraging trip, and data were downloaded. Previous diet studies and preliminary dive data have indicated that *A. p. pusillus* feeds predominantly in the upper water column (epipelagic zone). It was thus unsurprising that most recorded dives were in the depth range of epipelagic prey and at night, reflecting a reliance on small, vertically migrating, schooling prey found mostly < 50 m deep. However, most females also performed benthic dives (feeding along the sea floor), and this was surprisingly prevalent in some individuals. The smaller of the two groups in Figure 3 was characterised by increased benthic diving (occurring mainly by day compared to pelagic diving) and correspondingly, longer dives to greater depths.

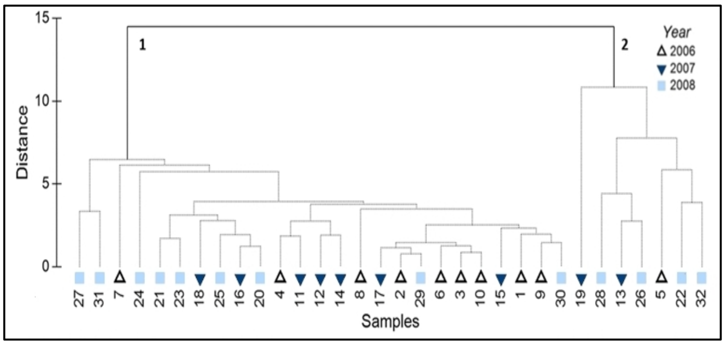

Figure 3: Cluster analysis plot based on the diving and foraging trip characteristics of study animals, showing two distinctive groups of individuals

Figure 1: Location of the Kleinsee seal colony

Figure 2: Removal of a data logger from an anaesthetised study animal

There are costs associated with this behaviour. Fur seals are breath-hold divers, capable of storing a lot of oxygen in their blood so they can hunt below the surface. When diving, their metabolism (the rate they use energy) is not very different to when resting, and they are capable of doing many short dives with little energy expenditure. If longer dives are necessary, they can prolong their time underwater by slowing their heart rate, and reducing or shutting down blood flow to peripheral organs (e.g. kidneys) and muscles. When stored oxygen resources are exhausted, however, muscles will have to function anaerobically, causing a build-up of lactic acid, and fatigue. Thus, after a long dive, a seal will have to remain longer at the surface to flush out lactic acid before it can dive again. More time at the surface implies less hunting time.

From the relationship between the durations of dives and the periods between dives, we estimated the Aerobic Dive Limit (ADL – the dive duration beyond which blood lactate levels rise above resting metabolic levels) for individuals. As a rule, benthic dives exceeded ADL but pelagic dives did not (Fig. 4). This highlights the greater costs of benthic diving in *A. p. pusillus*, which the study confirmed are generally reliant on pelagic prey. Declines in availability of pelagic prey species in the Benguela Ecosystem, which have had well documented detrimental impacts on seabird populations, may thus be expected to have adverse effects on reproductive success of *A. p. pusillus* females, by reducing foraging efficiency. Further study is needed to assess the degree to which benthic diving is associated with changing conditions, and the nutritional content of prey consumed during such dives.

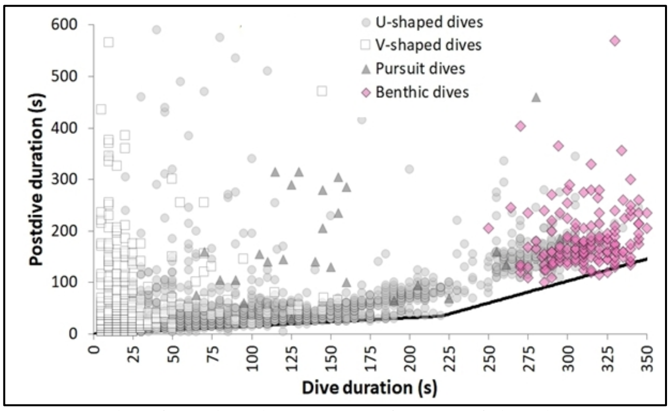

Figure 4: Plot of postdive duration as a function of dive duration in an individual seal, showing the estimated Aerobic Dive Limit (ADL) at the break between the two regression lines. All benthic dives exceeded the ADL (the other dive types in the legend are pelagic dive types)

Further information

Kirkman SP *et al.* 2019. Dive behaviour and foraging effort of female Cape fur seals *Arctocephalus pusillus pusillus. Royal Society Open Science* 6: 191369.

Authors: Kirkman SP (O&C Research); Arnould JPY (Deakin University, Australia)
Contributors: Costa DP, Harrison A-L (UCLA, USA); Kotze PGH, Oosthuizen WH (O&C Research); Weise M (Office of Naval Research, USA); Botha JA (NMU)

24. SOCIAL ORGANISATION OF THE INDIAN OCEAN HUMPBACK DOLPHIN ON THE SOUTH COAST OF SOUTH AFRICA

The Indian Ocean humpback dolphin *Sousa plumbea* has a discontinuous distribution along the south and east coasts of South Africa, favouring shallow waters < 20 m deep and < 500 m from shore, usually in the surf zone. As such it faces numerous threats associated with coastal areas, including entrapment by shark nets, pollution, boat traffic and others. *S. plumbea* occurs in small groups and its abundance in South Africa is low (estimated at 500 to 1 000 individuals); it is currently considered to be the most Endangered marine mammal species in the country. In Plettenberg Bay, declines in both abundance (from 112 to 80 individuals) and group size (from 7 to 4 individuals) were documented from 2003–2016.

As social mammals, declines in abundance and group size of *S. plumbea* can affect the population's social organisation, increasing its vulnerability. Understanding dolphin social organisation is relevant for conservation strategies, but to date there has been little research on the social structure and group dynamics of *S. plumbea* locally. In this study, photo-identification data were used to assess the social organisation of *S. plumbea* on the South Coast.

The study area was the inshore waters of South Africa's south coast (Fig. 1). Photographs were taken of the dorsal fins of *S. plumbea* individuals encountered during boat-based surveys conducted during 2014–2015. A photo-identification catalogue was created comprising 65 individuals (Fig. 2). Individuals that were sighted at least 3 times (n = 29) were used to assess the strength of associations between individuals, using an Association Index (AI) which provides values ranging from 0 (two dolphins never seen together) to 1 (two individuals always seen together). Further analyses included cluster analysis based on the AI to determine whether distinctive groups of individuals could be identified.

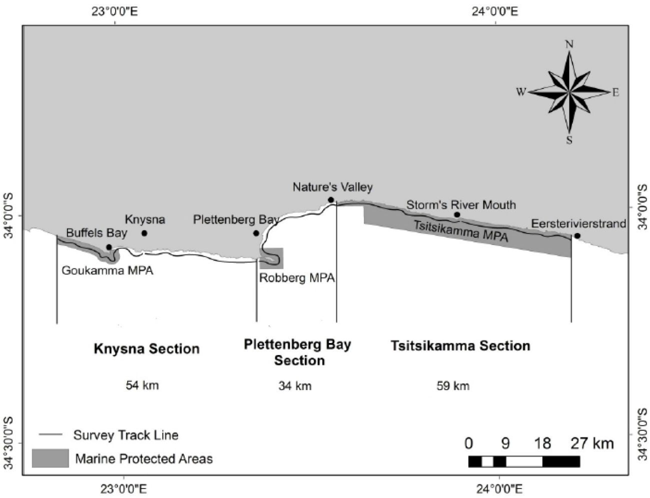

Figure 1: The study area showing three survey sections, the locations of marine protected areas and the approximate survey track line

Figure 2: Examples of dorsal fin images of known S. plumbea *individuals from the photo-identification catalogue (photos: D Conry)*

Results showed that about half of associations between individuals (n = 14) were strong (AI > 0.5; Fig. 3). This included four pairs of individuals that had very strong (AI > 0.8) associations between them, entailing that the individuals of these pairs were almost always recorded together. Strong divisions were also apparent in the sampled population, resulting in four distinctive groups (Fig. 3). Two of these groups were geographically widespread (C and D in Fig. 3); the other two were more localised and appeared to be geographically isolated from each other.

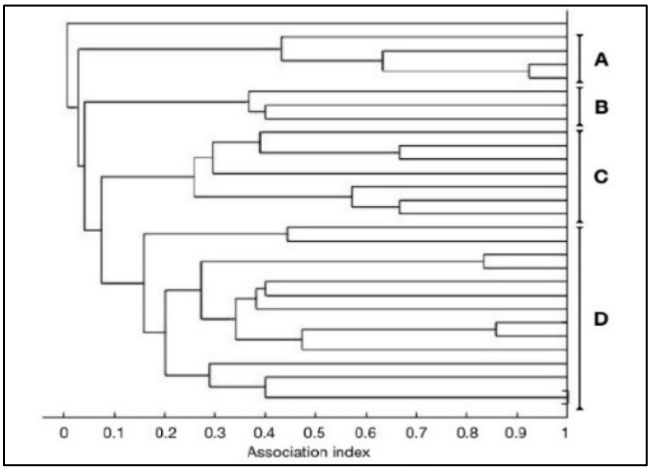

Figure 3: Hierarchical cluster analysis of S. plumbea *individuals based on the Association Index between individuals, showing four distinctive clusters of individuals (A–D) identified*

The fact that only 29 of an estimated population of 80 were observed enough times for inclusion in the analysis implies some limitations to this study – further research is needed to enlarge on these findings. Nevertheless, this study provided important findings for the population, especially considering a lack of knowledge on its social organization, and its Endangered species status. Most importantly, the strong associations observed within four pairs of individuals is considered to be atypical for the genus, and may reflect a behavioural response to the observed decline in mean group size in the study area. As a possible driver, increased individual risk of predation associated with reduced group size may reinforce the social bonds between individuals of groups. It is key for the conservation of the *S plumbea* population to avoid further fragmentation of the population and to preserve and protect intercommunity interactions as much as possible along the coast.

Further information

Bouveroux T *et al.* 2019. Social organisation of the Indian Ocean humpback dolphin (*Sousa plumbea*): A preliminary study along the south coast of South Africa. *Canadian Journal of Zoology* 97: 855–865.

Authors: Bouveroux T, Conry DS (NMU); Kirkman SP (O&C Research)
Contributors: Vargas-Fonseca OA, Pistorius PA (NMU)

25. A RARE SIGHTING OF AN ANTARCTIC BLUE WHALE OFF THE COAST OF SOUTH AFRICA

The blue whale *Balaenoptera musculus intermedia* is very rarely sighted in South African waters. Whaling during the twentieth century had reduced the blue whale population from *ca* 239 000 to *ca* 360 by 1973. There has been some recovery of the population since the cessation of commercial whaling but the current population is estimated to still be < 1% of the pre-whaling population. In terms of IUCN Red List criteria, the species has been assessed as Endangered globally, and as Critically Endangered in South Africa.

Despite there being some recovery in their numbers, sightings of blue whales have remained extremely scarce, both in polar waters and in their over-wintering range, which includes South African waters. No blue whales were sighted during a dedicated cruise conducted in September 2019 by the Department's Top Predator Research Programme. However, during a quarterly cruise of the Department's Southern Benguela: Integrated Ecosystem Programme, an adult and a calf blue whale were sighted and photographed (Fig. 1) on 22 November 2019. The pair, presumably a cow and calf, were spotted *ca* 250 km from shore, due west of the Namaqua National Park area in the Northern Cape (Fig. 2). The location of the sighting was off the continental shelf in 1 670 m water depth. No clear behavioural signs of feeding by the cow or suckling of the calf were observed. The pair spent some time at the surface and appeared to be relaxed, turning on their sides and lifting their tails (fluking) occasionally. The cow raised her head out of the water and the calf arched its back before both dived and were not seen again.

Figure 1: blue whale calf dorsal fin with the mother's head appearing (photo: S McCue)

This was only the third known blue whale sighting in South African waters in the post-whaling era. The previous known sighting, which was *ca* 10 km off Saldanha Bay, was recorded in 2002. Although this was the first sighting in 17 years, more blue whales have been detected off the coast using acoustic receivers. The 2018 research cruise, although unsuccessful from the point of view of blue whale sightings, was instrumental in refining a research design for searching for the species. A follow up cruise is planned for 2021/2022, providing opportunity for the Department to procure specialised equipment and secure collaborations with local and international specialists on blue whales in the interim.

Blue whales act as vertical and horizontal vectors for nutrients in polar waters. They have been demonstrated to promote Southern Ocean productivity through defecating iron-rich faeces. Further to this critical ecosystem role in waters of South African interest (i.e. Antarctica/South Ocean), South Africa has committed through the IWC and CCAMLR that it shall contribute to improved conservation status of whales. Therefore, further investment by the Department into assessing their numbers, their migration routes and calving grounds, should be prioritised.

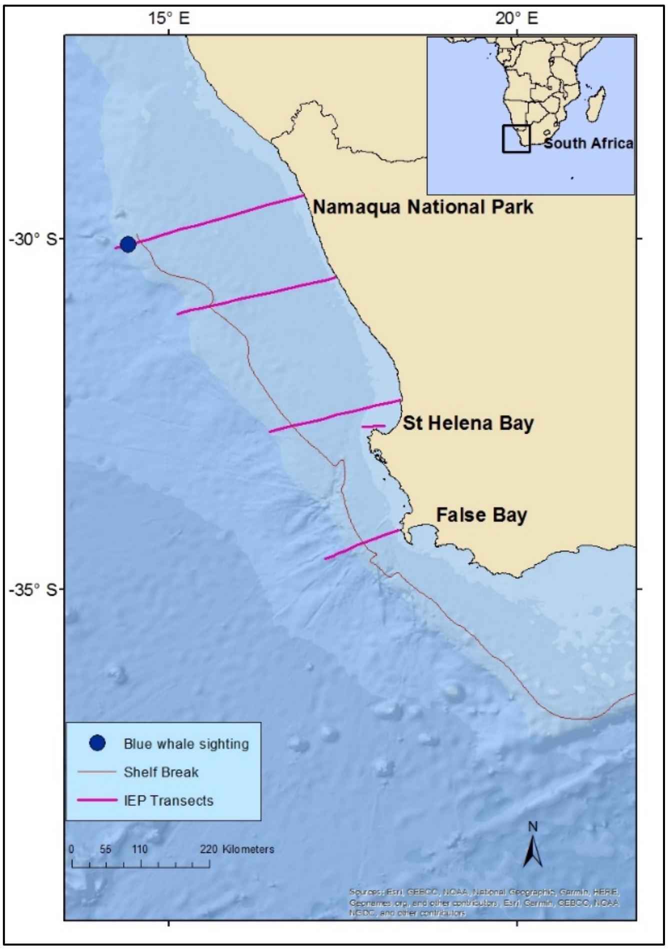

Figure 2: Location of the blue whale sighting along the northernmost transect of the SB: IEP cruise in November 2019 (map: M Seakamela)

Authors: McCue S, Sibiya N, Kotze D, Gumede N, Seakamela M (O&C Research)

26. SEDIMENTOLOGY OF THE PASSIVE CONTINENTAL MARGIN AND THE CAPE CANYON HEAD – INSIGHTS FROM BENTHIC GRAB SAMPLING

The ocean bottom is the most widespread habitat on earth, and is covered in sediment. There are various sources of seafloor sediment, resulting in sediment types that differ in properties such as particle size and texture (e.g. mud, sand or gravel) and mineral type(s). The different types of sediment constitute different types of habitat for benthic (bottom living) species, giving rise to one of the most diverse species pools in the ocean. However, due to the challenges of exploring the seafloor, offshore sediment profiles remain poorly understood.

Qualitative analyses were performed on 23 grab samples collected during 2017 over the shelf at the Cape Canyon head off the West Coast, onboard the Department's RV *Algoa*. The sampling design comprised eight transects that ran east-west and north-south, covering approximately 8 000 km^2, between 37–359 m.

Physical and biological properties of samples were investigated. Particles were separated according to their magnetic properties (using magnets) and particle sizes were analysed (using a laser particle analyser). The magnetic particles were separated out (i) to determine the volume percentage of magnetic particles compared to non-magnetic particles, and (ii) to aid in unearthing of biological organisms, in particular foraminifera.

A variety of foraminifera species, such as *Elphidium* cf. *alvarezianum, Ammonia parkinsoniana,* were recorded amongst the minerals of magnetite and ilmenite (Fig. 1). Overall, the sediments were predominantly composed of sandy mud or muddy sand with a smaller proportion of silty sand. A north-west to southeast gradient in particle size was observed: the north-west was characterised by coarse- and medium-grained sand and the south by finer sand particles. In the central part of the study area, silt (Fig. 2A) and clay (Fig. 2B) were predominant. The magnetic data, which shows the distribution of minerals, followed a similar trend to the medium sand distribution, with greatest mineral concentration in the north-western part of the study area (Fig. 2C).

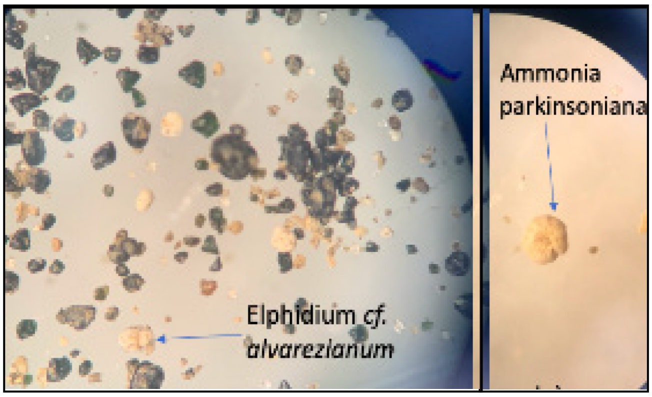

Figure 1: Magnetite and ilmenite minerals (black grains) with the foraminiferan Elphidium *cf.* alvarezianum *(left); and the foraminiferan* Ammonia parkinsoniana *(right)*

The observed pattern is attributable to physical forces, namely current and wave actions, which tend to be more erratic on the shelf (< 200 m) than in deeper areas, resulting in a scattered distribution of the sediment grain size and magnetic minerals.

These findings will contribute to finer-scale descriptions of benthic habitat types in marine ecosystem classification mapping, which is central for marine conservation and management planning.

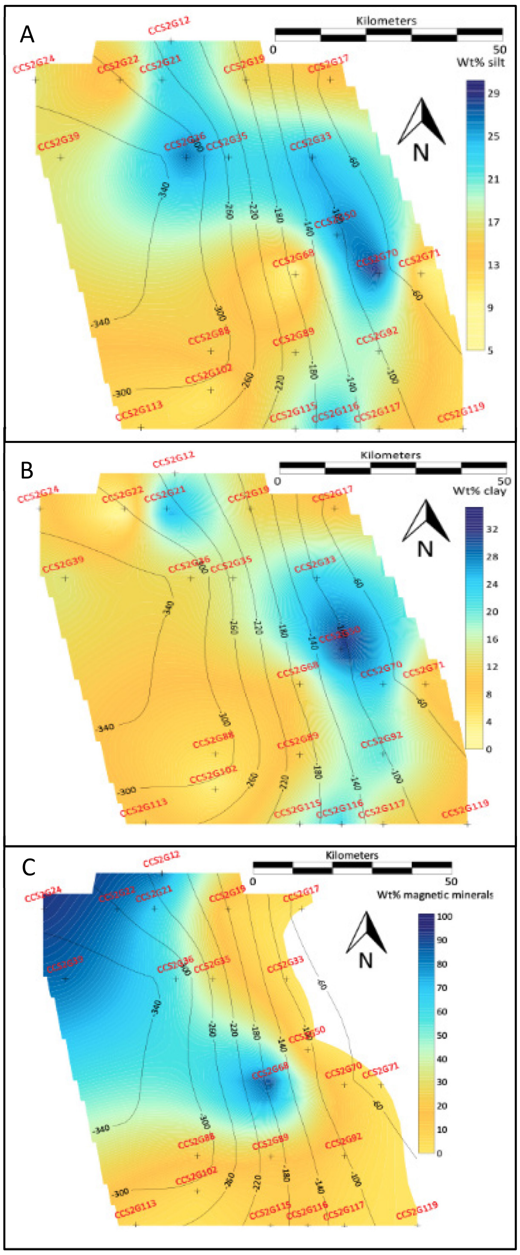

Figure 2: Contoured maps showing the percentage distributions of (A) silt, (B) clay and (C) minerals, in the study area

Authors: Adam A, Tonnelier N (NMU); Cawthra H (Council for Geoscience); Filander Z (O&C Research)

27. BENTHIC COMMUNITY STRUCTURE OF TWO TEMPORARILY CLOSED ESTUARIES IN THE SOUTHERN CAPE IN RESPONSE TO INCREASED NUTRIENT INPUT

The South African coastline has approximately 290 estuaries of which more than 70% are classified as temporarily closed estuaries. During periods of low river flow conditions, a sandbar develops at the mouth due to wave-driven sediment movement, closing off the estuary from the ocean for varying lengths of time. Mouth closure and nutrients from expanding urban environments and agricultural runoff cause hyper-nutrification and eutrophication, with impacts on estuarine biota.

The large Goukamma and Hartenbos estuaries, situated in the Gouritz Water Management area on the south coast of South Africa (Fig. 1), regularly undergo temporary mouth closures. Previous studies indicate that these estuaries have experienced increasing nutrient input from wastewater treatment plant discharges and diffuse pollution from agriculture and urban areas. Intensified nutrient input often results in increased phytoplankton biomass and algal blooms which most often cause oxygen depletion through night-time respiration and decay. By providing additional food and shelter for higher trophic levels in food webs, blooms can alter trophic relationships in estuaries and hence alter the structure and composition of biotic communities. This study investigated differences in benthic communities of the Goukamma and Hartenbos estuaries which are exposed to different sources of nutrient inputs, namely urban area and waste-water treatment plant discharges (Hartenbos), and agriculture (Goukamma).

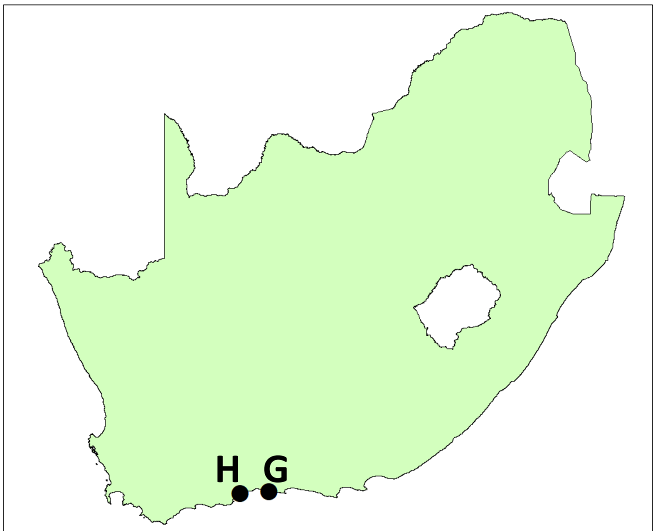

Figure 1: Location of sampled estuaries, Hartenbos (H) and Goukamma (G)

Benthic invertebrates were sampled using a van Veen grab at six stations in each estuary during May 2019. The lower reaches of the Goukamma Estuary were dominated by classes Gastropoda and Malacostra but these were completely absent from the upper reaches of the estuary (Fig. 2A). Dominance by these classes, which are sensitive to environmental changes, including pollution, indicates that the lower reaches are in a good state. Their absence in the middle and upper reaches of the estuary can be attributed to increased nutrient concentrations and resultant hypoxia due to seepage from farmlands, and the severe reduction of the riparian buffer zone.

The Hartenbos Estuary is repeatedly subject to waste-water spills, high ammonia levels, anoxic events, harmful algal blooms and fish kills. The benthos was dominated by the class Polychaeta (Fig. 2B), with the most abundant species being *Capitella capitata.* The latter is widely used as an indicator of pollution because it is known to respond positively to many forms of organic loading or disturbance. It usually dominates the benthic biomass at sewage outfalls.

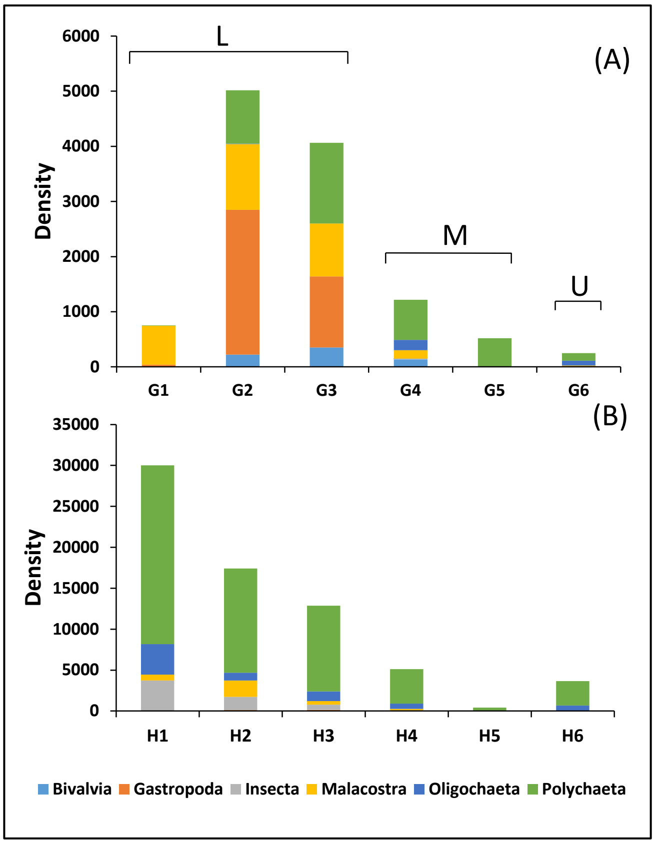

Figure 2: Densities (abundance/m²) of benthic invertebrate classes at the Goukamma (A) and Hartenbos estuaries (B); L = Lower reaches, M = Middle reaches and U = Upper reaches

The results of the study indicate that the Hartenbos Estuary is in a poorer state than the Goukamma Estuary. However, remedial action at the latter can be relatively easily achieved by addressing the point sources of pollution. The Hartenbos Estuary urgently requires management intervention to facilitate better compliance with the discharge permit for its waste-water treatment works. This would help reduce nutrient input to acceptable levels and restore estuarine ecosystem function.

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Contributors: Bebe L, Mushanganyisi K (O&C Research); Erasmus C, Lamberth S, Williamson C (Fisheries Research)

28. ARE MARINE PROTECTED AREAS EFFECTIVE? THE CASE OF TABLE MOUNTAIN NATIONAL PARK

Efforts to establish MPAs as a tool to conserve marine biodiversity and allow recovery of harvested stocks, have been stepped up in recent decades, with over 1 300 MPAs by now in existence, worldwide. In 2019, 20 new marine areas in South Africa were declared as protected (including new MPAs and expansions to some of the 25 MPAs that were already in existence). This took the total number of MPAs in South Africa's territorial waters and exclusive economic zone (excluding the Prince Edward Islands) to 41. However, given the rising demands on ocean space by resource users, there is a growing need for outcomes-based studies that can provide evidence of MPA effectiveness and justify their use as management tools.

This study evaluated the effects of no-take zones (protected from harvesting) in the Table Mountain National Park (TMNP) MPA, on the local population of the commonly harvested limpet *Cymbula granatina*, and on the rocky shore communities it is associated with. This was addressed by comparing densities and sizes of *C. granatina*, and the species composition of the rocky shore communities, between sites in a no-take zone (no-take sites) and corresponding sites where harvesting is permitted (harvested sites). The study design also took into account the effect of substrate type (granite or sandstone).

No-take areas had elevated densities of *C. granatina* on sandstone rock ledges, whereas granite rock ledges had remarkably low densities at either protection level (Fig.1). In addition, larger individuals were found inside no-take areas regardless of rock type (Fig. 2); this is attributable to harvesters targeting larger individuals. Community composition in harvested areas was dominated by corticated and ephemeral algae, while no-take areas were characterised by a higher representation of algal crusts and limpets (Fig. 3). In the eastern part of the MPA (Agulhas ecoregion), filter feeders were more abundant in harvested areas, while the opposite was observed in the west (Southern Benguela ecoregion). The abundance of algal crusts in no-take areas reflects the positive influence of grazing limpets on this group, which compete with other algae for space.

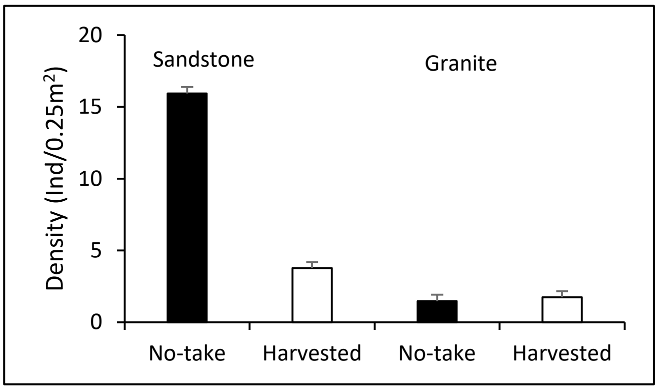

Figure 1: Differences in mean densities (+SE) of C. granatina *in relation to protection level and rock type*

The study provided evidence of how harvesting in the TMNP MPA transforms rocky shore communities to become overgrown by algae, due to the removal of grazing limpets, while limpets and algal crusts remain dominant in no-take zones. Most importantly, the study showed that no-take areas are effective in maintaining high densities of limpets upon favourable substrate (sandstone).

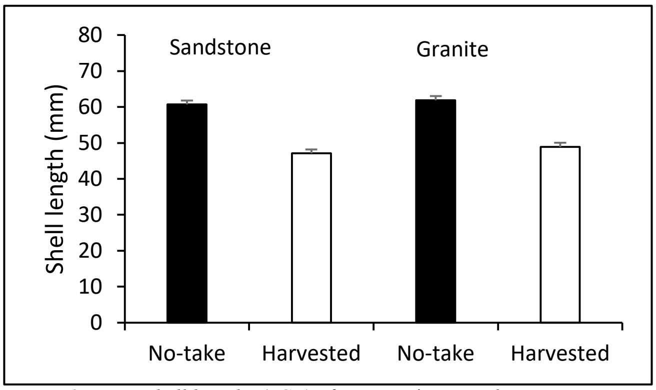

Figure 2: Mean shell lengths (+SE) of C. granatina*, in relation to protection level and rock type*

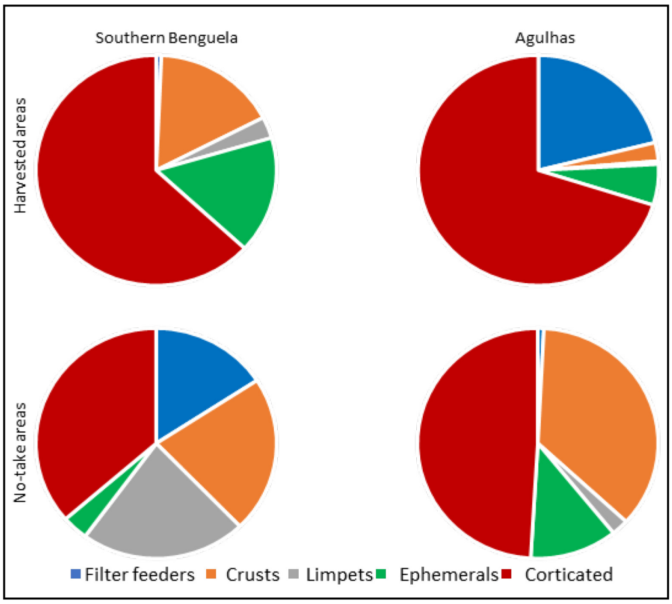

Figure 3: Differences in community composition between harvested vs. no-take areas of the Southern Benguela and Agulhas ecoregions, which make up the western and eastern parts of the MPA, respectively

Authors: Baliwe N, Pfaff MC (O&C Research, UCT); Branch G (UCT)

29. EXPANDING PROTECTION IN SOUTH AFRICA'S MARINE REALM

The first MPA in South African waters, Tsitsikamma, was declared in 1964. By 2011, 25 MPAs had been declared, covering 23% of coastline's length but < 0.6% of the territorial seas and exclusive economic zone (EEZ) of the country (including Southern Ocean territory). In 2013, the Prince Edward Islands MPA was declared in the Southern Ocean, increasing overall protection of South Africa's ocean space to *ca* 12%. However, shortcomings of the MPA network, at that stage in terms of offshore ecosystem representation and biodiversity protection levels around mainland South Africa, had already been well documented, including by SANBI's periodic National Biodiversity Assessment (NBA).

Through systematic conservation planning, priority areas were identified to address gaps in protection. These priorities were the basis for a proposed MPA expansion which was taken forward in 2014 under Operation Phakisa as a strategic initiative to support sustainable ocean economic opportunities. After considerable planning and negotiation, this led, in 2019, to the declaration of 20 new marine areas for protection in terms of the National Environmental Management: Protected Areas Act and the National Protected Areas Expansion Strategy. These 20 areas included new MPAs and expansions to existing ones. The number of MPAs in the mainland's territorial seas and EEZ was increased from 25 to 41 and the area under protection from 0.6% to 5.4%, with the addition of 51 477 km^2 of protected area estate (Fig. 1).

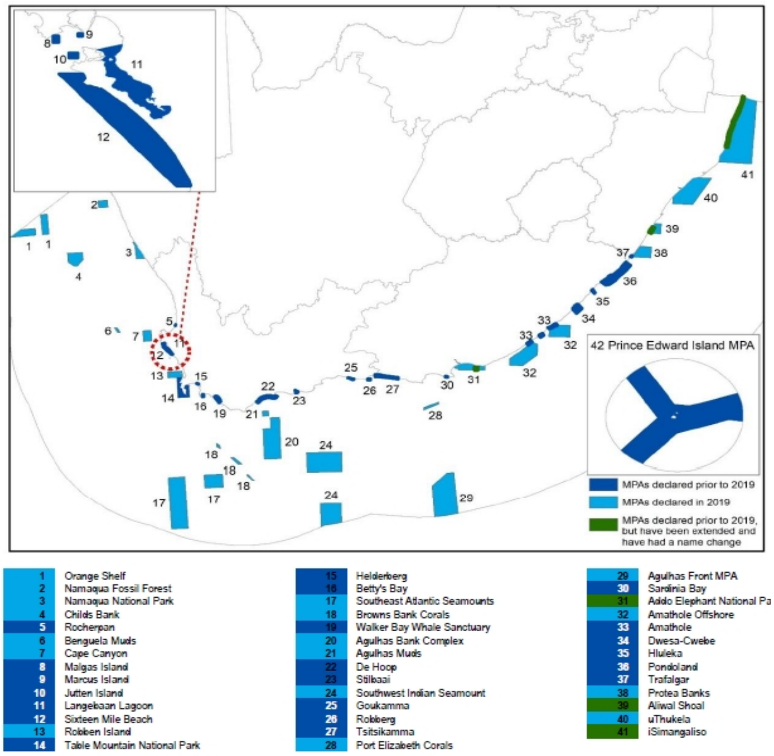

Figure 1: South Africa's expanded MPA network, as of 2019. Also shown is the Prince Edward Islands MPA in the Southern Ocean. (map: Sediqa Katieb, SANBI)

Final boundaries and zoning of the newly protected areas were informed by offshore research conducted by the Department, including in cooperation with the African Coelacanth Ecosystem Programme (ACEP) focusing on the under-explored East Coast regions. The research was conducted using the Department's RV *Algoa*, and through application of the ACEP Remotely Operated Vehicle and other platforms. Also useful, was at-sea tracking information obtained for marine top predators (turtles, seabirds) by the Department and partners. Coastal MPA zonation was informed by research from several other institutions such as SA National Parks, Ezemvelo KwaZulu-Natal Wildlife, SA Association of Marine Biological Research, SA Environmental Observation Network, SA Institute for Aquatic Biodiversity, Rhodes University, and others.

The improvement in South Africa's marine protection through this expansion is showcased by the increase in ecosystem protection levels – a biodiversity indicator that is used in the NBA to assess representation of ecosystem types under protection. Ecosystem types are classified as either well protected, moderately protected, poorly protected or unprotected, depending on the proportion thereof that overlaps with an MPA in relation to pre-set protection targets, and also taking into account the condition of ecosystems. This indicator was calculated for each of the 150 marine ecosystem types that were classified for the most recent NBA, to compare protection levels before and after the expansion of the MPA network.

Representation of all ecosystem types in MPAs is now 87% (previously 53%) and all six marine ecoregions are represented (previously the two most offshore ones were unprotected). Of 70 ecosystem types that were unprotected previously, 51 received first protection in 2019, reducing the percentage that are unprotected from 47% to 13%. Overall marine protection (mainland and Southern Ocean) is currently at 15.5%, placing South Africa in a better position to address post-2020 national protection targets and to support and link with future high seas spatial protection as envisaged by the United Nations process for Biodiversity in Areas Beyond National Jurisdiction (ABNJ). Further expansion towards such targets should take into account remaining unprotected ecosystem types, increase protection of poorly or moderately protected ecosystem types, and build greater resilience and connectivity into the MPA network, including linkages with conservation areas of other countries and ABNJ.

Further information

Sink KJ *et al.* (eds). 2019. *South African National Biodiversity Assessment 2018 Technical Report Volume 4: Marine Realm*. South African National Biodiversity Institute, Pretoria.

Authors: Sink K, (SANBI); Oosthuizen A (SANParks); Livingstone T (Ezemvelo); Boyd AJ, Kirkman SP (O&C Research)

Acknowledgement: Several other MPA researchers, managers and legal advisors for their considerable contributions

30. INTRODUCING THE OCEANS AND COASTAL INFORMATION MANAGEMENT SYSTEM

The Oceans and Coastal Information Management System (OCIMS) was initiated through Operation Phakisa in 2014, with the intention of developing a locally relevant and globally cognisant technological solution that supports effective governance for oceans and coasts in South Africa. In addition, the need to advance earth observation capacity was also identified to improve marine domain awareness.

The CSIR was appointed as the development partner in 2015, contributing an array of expertise, co-funding and human capital development, such as studentships that support the development of decision support tools (DeSTs).

OCIMS comprises multiple independent systems (DeSTs) that are accessible from a central website (www.ocims.gov.za) as well as a document library and data portal. The data portal itself does not store data, but rather hosts a metadata harvester that searches other systems and sources based on the user search criteria. This mechanism allows datasets to be ‘discovered’ through OCIMS, whereby users are able to view the metadata record while the data owners retain their responsibilities and custodianship over their data.

The OCIMS is currently concluding the first development phase, whereby nine DeSTs, at varying levels of operational maturity, have been developed, namely:

- Harmful Algal Blooms (HABs)
- Coastal Operations at Sea
- Coastal Flood Hazard
- Integrated Vessel Tracking
- Coastal Viewer
- Marine Spatial Planning
- Water Quality
- Oil Spill / Bilge Detection
- Fisheries Support

Each DeST has a dedicated technical advisory group, comprising subject experts who guide the functionality and tool development processes. In addition, and when given the opportunity, DeSTs are ground-truthed. For example, the HAB DeST is tested when algal blooms are detected to ensure that what is being observed ‘on the ground’ is also reflected on the DeST. A HAB detected in False Bay on 19 November 2018, shown in Figure 1, can be seen reflected on the HAB DeST in Figure 2.

While OCIMS currently resides on CSIR computing infrastructure, the second phase, commencing on 1 April 2020, will see the transition of DeSTs to the Department. In preparation, the scope of the Department’s own Marine Information Management System (MIMS) has been increased to include hardware which will support the operational requirements of OCIMS.

Figure 1: Algal bloom in False Bay on 19 November 2018

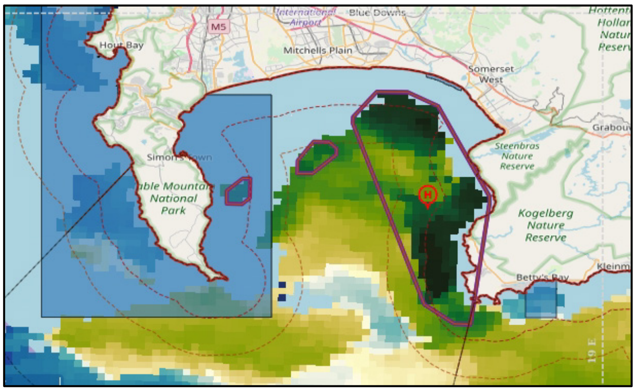

Figure 2: Algal bloom detected on the HAB DeST

Author: Williams L (O&C Research)

31. INTRODUCING THE MARINE INFORMATION MANAGEMENT SYSTEM

Since the 1950s, marine environmental data in South Africa have been collected routinely during voyages and field work. The significant value of these data has been increasingly recognised, taking into account not only the potential usefulness of the data but also the considerable investments of funding, resources and manpower that have gone into the collection and processing of the data. This motivated the creation of a system to preserve these datasets, while making it accessible for the broader community to utilise.

The development of the Department's Marine Information Management System (MIMS) commenced in 2014, with the purpose of providing a long-term archival data repository to safeguard these valuable time-series data. The MIMS is supported by a dedicated team of data curators, system administrators and developers who ensure that the system conforms to international ISO standards pertaining to data management and hardware. This includes ensuring that the stored data are protected against loss or unauthorised alteration by having the relevant redundancies in place. Also, the data must be discoverable and citable by the broader community through having appropriate metadata in place, the data must be in accessible formats and there need to be transparent governance practices through institutional data policies. The data flow process is illustrated in Figure 1.

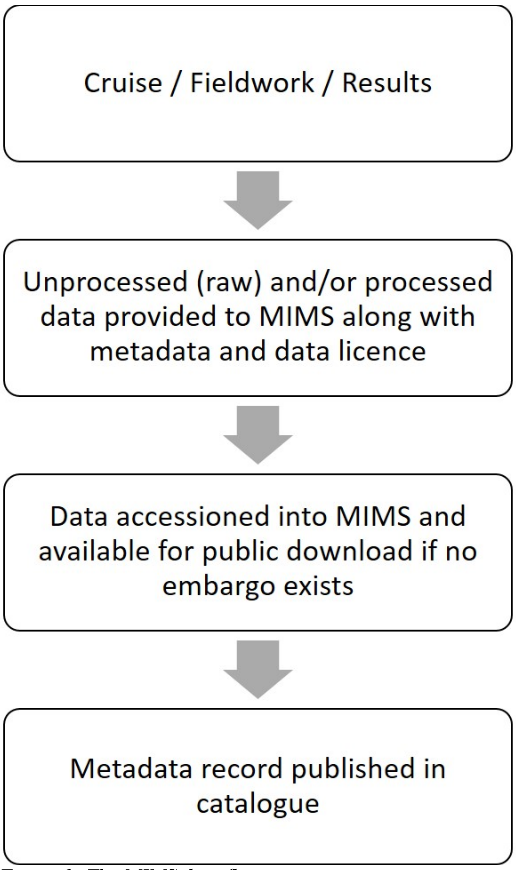

Figure 1: The MIMS data flow process

For safeguarding, data, along with metadata and licence agreements, should be submitted to MIMS as soon as possible after collection. Data are not made available to the public until authorised by the data owner; however, in terms of international standards, all metadata should be in the public domain. In cases where data are embargoed, they will reside on MIMS for safeguarding and only the metadata will be made publically available. All data requests pertaining to the dataset are directed to the data owner.

Currently, the MIMS is primarily hosting datasets created by the Department through research cruises, fieldwork, or the deployment of data generating instruments (e.g. Fig. 2), as well as the entire South African Data Centre for Oceanography repository. However, in future the MIMS scope will be increased to house data from external institutions.

Figure 2: Data retrieved from the Elands Bay buoy is stored on MIMS (photo: D Anders)

In addition to the existing MIMS infrastructure, provision is being made for the procurement of additional hardware to improve the data storage capacity as well as the acquisition of additional servers for high performance computing. These will support the development of operational ocean models and provide the infrastructure to house the Oceans and Coastal Information Management System (OCIMS).

The available MIMS datasets can be accessed via the internet (www.ocean.gov.za).

Author: Williams L (O&C Research)

32. IDENTIFYING SUITABLE SATELLITE PRODUCTS FOR MONITORING SEA SURFACE TEMPERATURE AROUND SOUTHERN AFRICA

Sea surface temperature (SST) is crucial to numerous research applications and operational oceanography systems, which in turn are used to inform academic research, industry, the government sector and the general public. The demand for routinely-available satellite SST data and products has led to the development of numerous freely-available SST datasets worldwide, but these datasets are known to have inherent differences, since they have been developed using a variety of input data sources and processing methods. These differences can result in large discrepancies in the performance of SST products, which in turn are likely to impact the quality of research and/or operational outputs. While the performance of SST products has been evaluated on a global scale, the few comparative studies within the southern African region have all been focused on much smaller areas, and only considered a small number of products. Here, we have evaluated and compared a total of 25 daily satellite SST products (6 low, 8 medium, and 11 high spatial resolution) in order to determine those best suited for research and monitoring applications of the oceans surrounding southern Africa.

The variance, representing the spread of SST values from different datasets about the mean value for a given location and time, was used as an indication of the differences between the various datasets (Fig. 1). High values of the variance (> 0.4) indicate that the SST products showed substantially different values at the same location, on the same day. In contrast, a low variance indicates that the products observed similar SST values at the same location, on the same day.

There was good agreement between SST products for most of the southern African marine region including the South African east coast, Mozambique Channel and offshore regions of the South African west coast. The variance in SST values was generally < 0.4 for these regions. However, strong disagreement between SST products (variance > 0.4) was observed at the Angola-Benguela front, Lüderitz upwelling cell, the Cape Peninsula upwelling cell, the upwelling region at Port Elizabeth and in the retroflection region of the Agulhas Current.

The disagreement in these regions was consistent across the various low-, medium-, and high-resolution products, demonstrating that the SST differences were not a function of the spatial resolution. These areas are all characterised by intense SST gradients, and rapidly changing environmental conditions. A good correlation between SST gradients and the high SST variance in each of these regions suggested that the gradients and high temporal variability of conditions strongly influences the observed differences between SST products.

For the vast majority of the southern African marine region, the choice of SST product is unlikely to have a significant influence on the quality of and conclusions derived from research or operational outputs. However, the choice of SST product is likely to strongly influence such outputs for above-mentioned regions of high SST variance, suggesting that additional *in situ* measurements are required to supplement satellite observations in these ecologically and economically important regions.

Authors: Carr MD (SAEON, O&C Research); Lamont T (O&C Research)
Contributor: Veitch J (O&C Research, SAEON)

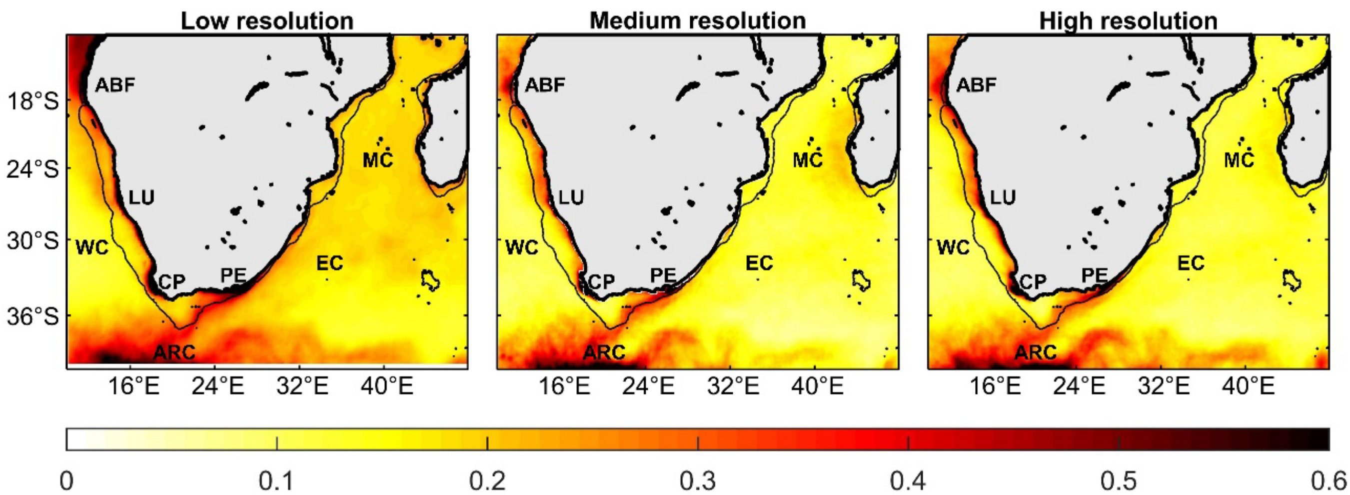

Figure 1: The variance between low (0.25°), medium (0.1°), and high (0.05°) spatial resolution SST products for the southern African marine region (ABF = Angola-Benguela front, ARC = retroflection region of the Agulhas Current, CP = Cape Peninsula upwelling cell, EC = South African east coast, LU = Lüderitz upwelling cell, MC = Mozambique Channel, PE = upwelling region at Port Elizabeth, WC = offshore regions of South Africa's west coast)

33. INTEGRATION OF UNDERWATER TEMPERATURE RECORDER DATA INTO THE MARINE INFORMATION MANAGEMENT SYSTEM

Water temperature data are useful in marine science for a range of applications such as monitoring of Climate Change, recording temperature fluctuations and forecasting of weather. The Department participates in a multinational network of underwater temperature recorders (UTRs) that are deployed along the southern African coastline. A UTR is a device that collects water temperature data while deployed at a location of interest. Devices of this nature are usually fitted with batteries and deployed for extended periods of time. They are intended to operate autonomously, without real-time communication with a remote office, and therefore need to be retrieved to access their stored data. Deployment and retrieval is typically done during diving operations.

The temperature data that are collected are valuable to various research projects, and it is important that the data are stored and managed appropriately. In this regard, the Department's recently developed Marine Information Management System (MIMS) provides a means of managing marine data that is aligned with global initiatives, and has the capabilities to store data in a universally accessible manner (provided that the dataset passes the criteria required for integration into the MIMS database).

After device retrieval and data downloading, the data need to be validated, processed and assessed according to a number of criteria. A UTR processing tool that was developed within the Department allows for easy processing of the raw data to produce an open-format Network Common Data Form (NetCDF) file. Once in NetCDF format, the data are ready to be integrated into the MIMS database.

The UTR processing tool is a new software product that enables an operator with minimal computer programming experience to apply oceanographic-based criteria on a raw dataset. The tool presents a Graphical User Interface (GUI) to the operator to accomplish this. The output is a quality-controlled dataset that meets all the scientific and software requirements for incorporation into the MIMS. The tool was developed in Python ver3, a freely available programming platform, and uses non-proprietary software libraries. Open Source software and Open Format container files were used to facilitate collaboration and dissemination between team members throughout the development process.

Figure 1 highlights the use of the processing tool, based on a UTR deployment off Knysna on the South Coast (Fig. 1a, b). Data from the retrieved UTRs (Fig. 1c) were processed using the tool (Fig. 1d, e). The tool displays a time-series on the screen and allows a user to highlight bad data points, with an option to permanently remove them (as shown by red crosses in Fig. 1e). The measured temperature as well as a filtered time-series thereof, calculated using a 10-day running average, can be produced (Fig. 1f). Histograms of temperature (Fig. 1g) which can also be produced, are useful for highlighting data outliers and in assisting interpretation of temperature value distributions.

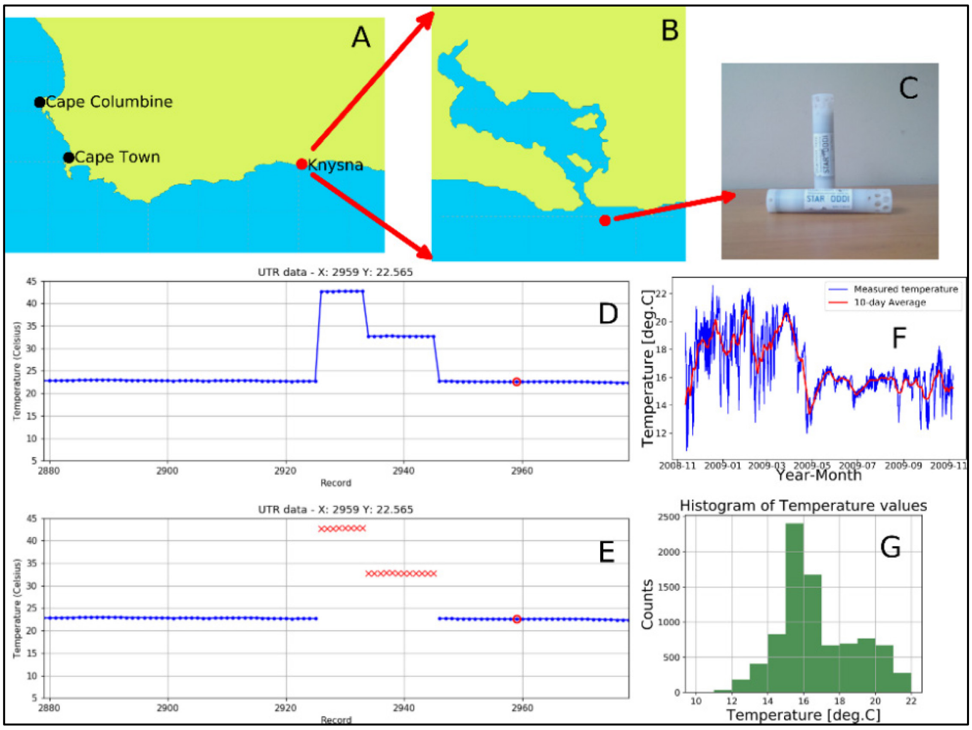

Figure 1: The deployment location (A, B) of a UTR device (C). Screen shots of the data processing using the tool (D, E); and examples of derived scientific data products (F, G)

UTR data that are processed and quality controlled as described above are being added to the MIMS database on a routine basis, providing marine researchers with access to valuable datasets. This will contribute to a more in-depth understanding of the physical processes and changes in the marine environment.

Authors: Bergman S, Ismail H, Lamont T (O&C Research)
Contributors: Anders D, van den Berg M, Boezak A (O&C Research); Maitland J, Cooper K, Singh P (SAEON)

34. LOCATING THE AGULHAS CURRENT CORE AND EDGES: A NEW TOOL TO MONITOR AGULHAS CURRENT VARIABILITY

The Agulhas Current (AC) is the strongest Western Boundary Current in the Southern Hemisphere, and flanks the eastern and southern shelf systems of South Africa. The AC forms a key component in the transport of heat, salt, and water volume, which govern the global climate system. Within a local context, variations in the position of the AC have a direct influence on nutrient availability and subsequent biological responses of adjacent shelf ecosystems. In order to improve our understanding of the functioning of shelf ecosystems along South Africa's east and south coasts, it is crucial to monitor variations in the position and intensity of the AC.

The AC is a narrow and fast-flowing current, characterised by strong velocity and temperature gradients, making it ideal to map from space. The Location of the Agulhas Current Core and Edges (LACCE) product has been developed as a new monitoring tool for the National Oceans and Coastal Information Management System (OCIMS), with the primary aim of monitoring variations in the position of the AC and its edges. At present, the LACCE product is aimed at daily, near-real time operational use, including navigation and MPA monitoring, among others, but it is anticipated that this product will also improve the fundamental knowledge on AC variability and its impacts on shelf ecosystems.

The product is computed using near-real time altimetry data. The AC core is defined by the local maximum speed, while the edges are defined by the maximum speed gradient on either side of the AC core. This product successfully captures a variety of features inherent to the AC, and is unique in that it is able to identify the core and edges of the greater AC system as a whole, including the AC, the AC Retroflection, and the AC Return Current (Fig. 1a).

Agulhas Current meanders, more commonly known as Natal Pulses, are well-defined by the LACCE product (Fig. 1b). These offshore meanders of the AC are associated with substantial uplift of deeper nutrient-rich waters onto the shelf. LACCE provides a simple way of tracking their southward progression along the east coast of South Africa.

The AC typically retroflects (i.e. changes direction from south-westerly to easterly flow) between 16–22˚E, however it has occasionally been observed to retroflect eastwards of 22˚E. Such "early" retroflections, which can now be easily monitored using LACCE (Fig. 1c), have important implications for inter-ocean heat and salt exchange, since they are usually accompanied by the shedding of large Agulhas Rings into the Atlantic Ocean. These events can also have substantial effects on the South Coast shelf ecosystem, such as the loss of spawning products to the surrounding deep ocean, resulting in potentially detrimental impacts on biological communities.

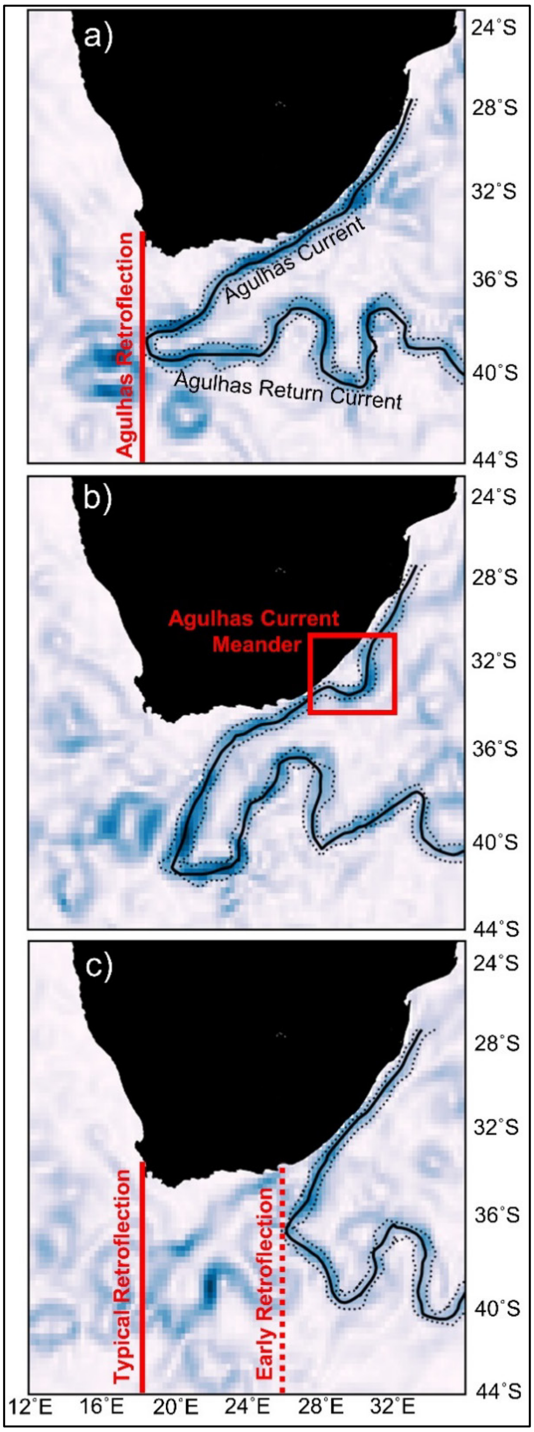

Figure 1: a) Typical position of the Agulhas Current (AC) system. b) Passage of an AC meander along the South African east coast, and c) Early Retroflection of the AC

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35. SOMISANA: A SOUTH AFRICAN APPROACH TO SUSTAINABLE OCEAN MODELLING

Operational ocean forecasting was highlighted as a top priority for the national Oceans and Coastal Information Management System (OCIMS), a tool to provide information and decision support for effective management of South Africa's oceans and coasts. Operational ocean forecasting is the systematic and routine production, interpretation and dissemination of information about future conditions of the ocean and is typically achieved using a numerical model. Such capability is particularly valuable in South Africa given the nature of its adjacent oceans: the Agulhas Current is one of the most energetic currents in the world and the Benguela is one of the most productive. Short-term forecasts (3–5 days) of the state of the ocean can provide support for marine search and rescue, operational environmental monitoring, fisheries and aquaculture management, risk mitigation (e.g. oil spills) and offshore industries (e.g. fishing, energy).

Ocean modelling expertise is currently sub-critical in South Africa and operational ocean forecasting is virtually non-existent. SOMISANA (Sustainable Ocean Modelling Initiative: a South African Approach) is a joint strategy between the Department and SAEON to develop local modelling and technical capacity in parallel with an operational ocean forecast system. The vision of SOMISANA is therefore to "facilitate the local development and sustainability of an operational ocean current forecast system for the South African exclusive economic zone and to do so in a transformative fashion*"*. As part of the SOMISANA initiative, a high-resolution ocean modelling strategy has been produced in order to support the development of risk mitigation protocol for the offshore industries in the region of Algoa Bay. The ongoing offshore bunkering (fuel transfer) operations in the anchorage areas of the Port of Ngqura, within the bay, pose a threat to ecologically sensitive receptors that include the large penguin colonies at Jahleel and St Croix Islands. The environmental risks involved, the complex dynamics within the bay and at its offshore boundary (Fig. 1) as well as the relatively comprehensive network of measurements in the bay led to it being identified as a pilot site for the development of an operational forecast system.

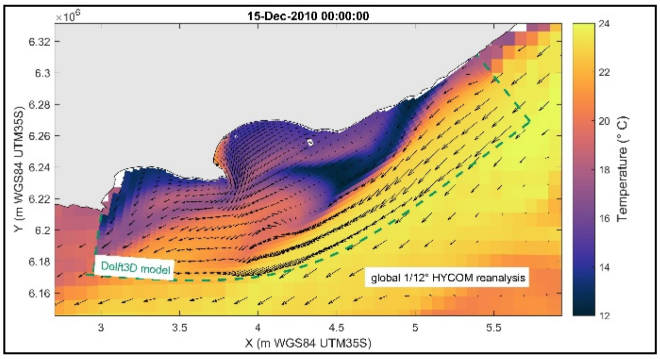

Figure 1: Snapshot of modelled sea surface temperature

The first step is to develop high-resolution, limited duration model simulations of the ocean dynamics (currents, temperature and salinity) for a specified period in the past, chosen to overlap with availability of continuous *in situ* observations in the bay so that these can be used to assess the accuracy of the model. This ocean model is then coupled with an oil spill trajectory model and simulated with various oil spill scenarios to provide an understanding of the potential extent and timing of oil reaching key environmentally sensitive regions within the bay for each case.

Comparisons with temperature recorders at the mouth of the bay and within the bay show that the model is successful at reproducing observed features near the surface and at the bottom. The hypothetical oil spill simulations show that, due to the location of the operations within an enclosed embayment, most of the oil from an accidental spill is likely to impact the shoreline. However, the severity of the impact depends on the size of the spill, the location of the operations within the anchorage area and the season (i.e. summer months lead to higher shoreline impacts than in winter). Fig. 2 shows the probability of impact based on the most extreme oil spill scenario (i.e. a very large spill, during summer months).

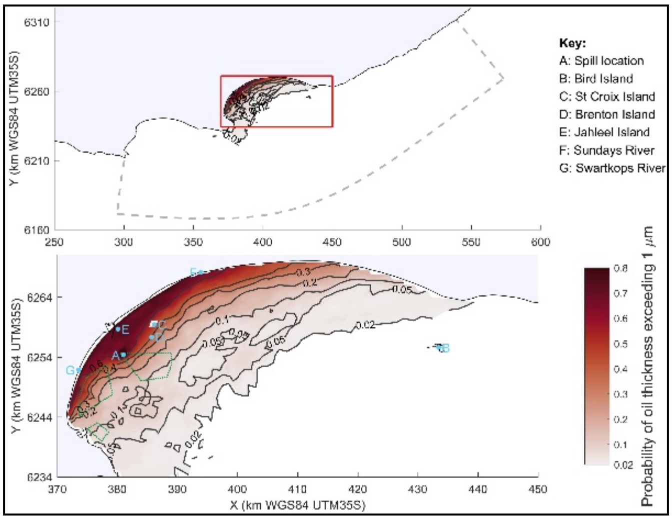

Figure 2: Probability of oil thickness exceeding 1μm as an ecological threshold for smothering seabirds

Nine students are being supported in model-based studies by the SOMISANA initiative, with topics ranging from evaluating global wave forecasts off Cape Point to ocean dynamics of small-scale submarine canyons off the KZN coast. While the next phase of SOMISANA will similarly focus on capacity development, it will also aim to produce an improved model simulation of the ocean dynamics of South Africa's exclusive economic zone spanning the past few decades that can be used for the understanding of environmental variability of our marine ecosystems.

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36. NEW CONTAINERISED WINCH SYSTEM EXTENDS OCEANOGRAPHIC CAPABILITY OF THE RV *ALGOA*

In October 2016, the Department of Environmental Affairs, together with service providers, African Marine Solutions and Basic Hydraulics, embarked on a project to design, build, and test a new containerised winch system (Fig. 1). The winch system was specifically designed to be self-contained, portable between vessels of similar size, and to extend oceanographic sampling capacity to a maximum depth of *ca* 6 500 m. Successful commissioning of this winch system during October 2019 marked the culmination of this three-year project.

Figure 1: The top panel shows a schematic view of the containerised winch system and an image of the container being loaded onto the RV Algoa. *The bottom panel shows images of the control panel and various user interface screens used during winch operations*

The system is comprised of a hydraulic winch with 12 mm, six-core conducting cable, a power pack to control the hydraulics, and an accumulator system to manage tensions on the cable. Sensors mounted on the sheaves measure the length and speed of cable being deployed, as well as the load on the cable. The winch is electronically controlled, using custom-designed software that enables the operator to remotely manipulate the winch.

The operator is able to manually pay-out and heave the cable at selected speeds, but is also able to automate these operations over pre-selected cable lengths. Digital cameras provide real-time relay of imagery to the remotely-operated electronic control unit, allowing the operator to remotely monitor cable spooling, thus improving safety of the operations.

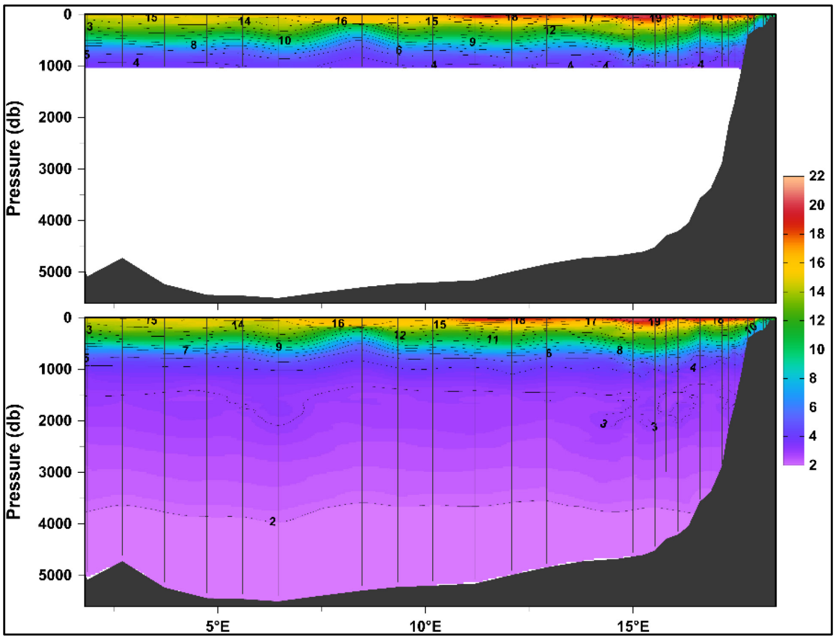

Figure 2: Vertical temperature (°C) section along 34.5°S, to a maximum depth of 1 000 m (top panel) and 5 300 m (bottom panel). Station positions are indicated by vertical black lines

Historically, the RV *Algoa* has been limited to conducting oceanographic sampling to maximum depths of *ca* 1 000 m due to limitations of the onboard winch systems. As illustrated in Fig. 2, the new system allows for much deeper sampling which will greatly improve our understanding of the deeper waters surrounding southern Africa, their impacts on the shelf ecosystems, and their role in global thermohaline circulation.

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<u>Contributor</u>: Tutt GCO (O&C Research)

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