Oceans and Coasts

Annual Science Report 2022

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REPUBLIC OF SOUTH AFRICA

Oceans and Coasts

Annual Science Report

2022

Department of Forestry, Fisheries and the Environment

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ACKNOWLEDGEMENTS

Most staff members of the Chief Directorate: Oceans & Coastal Research contributed in one way or another to the contents and production of the Oceans and Coasts Annual Science Report, 2022. The Department wishes to express its appreciation to the many other agencies that have contributed to the work presented in this report. The at-sea, ship-based work and many coastal field trips for data collection and community engagements undertaken by the Branch: Oceans and Coasts are facilitated by the Chief Directorate's science managers and made possible by the various units within the Branch's Corporate Management Services and Financial Management Services.

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COVER IMAGE: Compilation created by DFFE, with original photographs provided by DFFE Photo Library and picture of the Research Ship *Algoa* courtesy of Marine Traffic

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SUMMARY AND PERSPECTIVES

Introduction

The Oceans and Coasts Annual Science Report, 2022, presents results of science and science-related activities of the Department's Chief Directorate: Oceans and Coastal Research (OC Research). These activities support the Branch Oceans and Coasts in fulfilling their mandate of managing and conserving South Africa's coastal and marine environment, as well as addressing the country's international and regional commitments to the conservation and sustainable use of the ocean and its biodiversity. The science plan, developed to guide the various science programmes of OC Research for the period 2016–2030, was premised on national and international trends and priorities regarding the state of the ocean, socioeconomic benefits from its resources, and the impacts of human activities and global changes.

The science plan recognises that fundamentally, data collections or observations taken within a long-term context are essential for long-term changes to be disentangled from short- or medium-term variability. A key purpose of OC Research is therefore to develop and maintain programmes that provide continuous or sustained monitoring and descriptions of key aspects of the marine environment, with a very specific emphasis on the establishment of long-term datasets. Shorter-term research projects are also conducted, in search of a deeper, more fundamental understanding of specific areas or ecosystem processes, or to support evidence-based recommendations for ocean policy and management, another key function of OC Research. The science plan also emphasises the need to continually develop new and innovative platforms and technologies, to sustain and enhance ocean monitoring, prediction and management.

The science activities of OC Research take into account the strategic goals, requirements or guidance of multiple regional and international Multilateral Environmental Agreements (MEAs). These include the Benguela Current Convention, the Nairobi Convention, the Antarctic Treaty, the Convention on the Conservation of Migratory Species of Wild Animals, the Paris Agreement and the Convention on Biological Diversity (CBD). The CBD recently concluded the Kunming-Montreal Global Biodiversity Framework (GBF) which sets goals and targets to safeguard and sustainably use biodiversity and support the achievement of the United Nations Sustainable Development Goals (SDGs). The GBF is headlined by an ambitious target to protect 30% of the planet's environment by 2030 (familiarly known as 30x30), including marine and coastal ecosystems. Compared with the previous decade the GBF places greater emphasis on ocean and coasts in its targets for 2030, and in its monitoring framework of indicators to track progress. This will require increased investment, especially for infrastructure, in marine and coastal research and monitoring by Parties such as South Africa.

The GBF was one of two major landmark international agreements that were recently concluded, which focus our attention on the management of the ocean. The other is the Treaty of the High Seas, also known as the Biodiversity Beyond National Jurisdiction Treaty (BBNJ). This Treaty seeks to provide a basis for establishing protection of the High Seas, which make up almost two-thirds of the planet's ocean, and importantly lie outside the national jurisdiction of any country. Across the 30x30 target of the CBD and the BBNJ Treaty, countries are asked to look both within and outside their national jurisdictions to improve conservation and sustainable management of the ocean and coastal ecosystems. Thus, countries are expected to build sustainable use objectives and governance tools, and these will require a knowledge base. Key spaces for ecosystem functioning, biodiversity and species support, including fisheries support, will need to be identified. An assessment of the health of identified areas is needed to determine if restoration, maintenance or protection is required. Science programmes are also needed to determine impacts from various uses on ecosystems and estimate thresholds of such impact, both within sectors and accumulated across sectors. Present or planned uses must not permanently impact the ocean services and contributions to planetary functioning.

Through its research vessels, the SA *Agulhas* II and the RS *Algoa*, the Branch Oceans and Coasts continues to be the primary access point through which South Africa can continue deep ocean science. These at-sea platforms are complemented by the Branch's coastal and shallow water science programmes such as seabird counts, coastal biodiversity and rocky shore monitoring. Because of South Africa's regional and international commitments, the science activities are not restricted to the oceans and coasts of South Africa or its territorial possession the Prince Edward Islands, but also embrace Antarctica, the high Seas including the Southern Ocean, and national waters of other African countries through various partnership programmes. The activities are carried out in partnership with marine research nodes of other departments and universities in South Africa, and from other countries and organisations. The development of human capacity in marine research is integral to the science plan, and the training and development of staff, interns, students and outside researchers is embedded into all programmes and projects.

The science programmes produce coherent and accessible datasets that over time can be used to give indications of how South Africa's marine ecosystems are changing over time. The Oceans and Coasts Information Management System (OCIMS) has been developed as a platform where the collated datasets as well as decision support tools based on these datasets can be accessed. The datasets are produced as the primary output of science programmes. Required secondary outputs are scientific analyses, which are formalised through scientific publications, and policy advice. While it is important that stable and uniform datasets are maintained over long periods, secondary outputs on policy advice must be responsive to present and future users and uses of the ocean. Two such policy issues are highlighted in this Report: Marine Protected Areas and effects of seismic surveys. These occur in parallel to other policy advice such as ongoing work with the Branch Fisheries Management on the interaction between fish, the fishing industry and the African penguin. An Expert Review Panel has been established to review existing science and offer recommendations on managing the intersection of the Small Pelagic Fishing Industry and the biology and conservation of the African penguin, whose population numbers have seen a dramatic decline.

The data, information and knowledge products generated from the science activities are intended not only for the science community, managers and policymakers, but also the broader public. Considerable importance is attached to information pieces and outreach events targeting the public, including young learners who will be the future custodians of our marine environment.

The Annual Science Report is itself a major information product of OC Research that is meant to make the work and findings of OC Research accessible to the public.

The contributions to this report are presented under three main sections. The first two sections, Monitoring Programmes (11 report cards) and Research Highlights (13 report cards), showcasing research achievements for 2022, are similar to previous years' reports. A new section, Science to Policy (2 report cards), is introduced, showcasing where the OC Research activities can influence policy. The previous section on Tools and Technologies/Technological Innovation and Training has been split into two sections, namely Platforms, Technology and Innovation, and Training and Outreach. As in previous reports, a list of scientific outputs for the calendar year is provided at the end, including peer-reviewed publications and other products that reflect both the volume and quality of work accomplished by OC Research in 2022.

Monitoring Programmes

One of the core functions of O&C Research is to establish and maintain long-term measurements in South Africa's coastal and offshore marine environment, to assess ecosystem status and ocean health. Recent warming, acidification and deoxygenation (declining oxygen levels) associated with climate change have greatly affected physical and chemical conditions in oceans. Consequent changes in marine habitats have led to shifts in the distribution and phenology (timing of biological life cycles) of many organisms, with major implications for the productivity of marine ecosystems. Observations of key ocean indicators are thus critical to inform policy and support ocean governance and management.

The importance of ocean observation systems is highlighted by the United Nations Decade of Ocean Science for Sustainable Development (2021–2030), with one of the ten Ocean Decade Challenges being to expand the ocean observing system globally. The Global Ocean Observing System (GOOS) programme has identified a suite of priority physical, biogeochemical and biological ecosystem variables, known as essential ocean variables (EOVs), for routine and sustained observation to assess ocean changes globally. Updated and newly established time series of EOVs and related variables for South African waters, as well as the Southern Ocean, are summarised in this section of the Report.

Flowing poleward along the east and south coasts, the Agulhas Current transports warm, salty water from the Indian Ocean to the Atlantic Ocean, and directly influences regional weather and local fisheries. A monitoring tool that uses satellite altimetry data to track the location of the Current detected an early retroflection in May 2022 (Report Card 1), with the Current changing direction much further east than usual. The effects of this relatively rare and 22-day-long extreme event require further investigation, but include potential offshore advection and loss of marine biota from the Agulhas Bank ecosystem.

Time series of *in situ* temperatures spanning three decades from locations on the south and east coasts reflect considerable interannual variability in nearshore temperature, with strong cooling events at Mossel Bay and Tsitsikamma likely due to wind-driven upwelling (Report Card 2). Although not significant, a long-term cooling trend at Sodwana Bay may reflect increased variability in the movement of the Agulhas Current, but this also requires further investigation.

Moving to the Southern Ocean, two moorings deployed on the inter-island shelf at the Prince Edward Islands (PEIs) have been providing continuous measurements of bottom temperature and water column current speed and direction since April 2014. Flow patterns suggest persistent nutrient retention and hence elevated productivity on the shelf (Report Card 3), although this may be enhanced or interrupted for short periods by the passage of fronts or mesoscale eddies, influencing the feeding conditions for seabirds and marine mammals breeding at the PEIs. Several intense cooling events during 2021–2022 were linked to eddies or frontal migrations (Report Card 4), but overall elevated temperatures continued to reflect the warming tendency observed since 2018, indicating a more southerly location of the southern branch of the sub-Antarctic Front.

Off the west coast of South Africa, an area prone to episodic low oxygen events, a mooring was deployed off Hondeklip Bay in 2019 to monitor subsurface temperature and dissolved oxygen concentration (Report Card 5). Unexpectedly, a contrasting seasonal cycle for oxygen was observed compared to St Helena Bay further south, and additional observations along the entire west coast are recommended to determine where the transition occurs. Off St Helena Bay, long-term (20-year) records show that ocean acidity continues to strengthen across the entire shelf (Report Card 6), reflecting ongoing uptake of anthropogenic carbon dioxide (CO_2) emissions by the ocean. Currently, the nearshore and mid-shelf regions are both sources of CO_2, while the outer shelf is a CO_2 sink, but the trends suggest that the offshore region will also become a CO_2 source in future, and no longer have the capacity to absorb excess CO_2 from the atmosphere.

Long-term values of satellite-derived chlorophyll *a*, a proxy for phytoplankton biomass, reflect both seasonal and interannual variability off St Helena Bay, with relatively elevated productivity in 2019, 2020 and 2022, and lower productivity in 2018 and 2021 (Report Card 7). Regional differences in satellite-derived chlorophyll *a* (chl *a*) are evident when considering the entire Benguela upwelling ecosystem and the Agulhas Bank, (Report Card 8). Highest chl *a* index values are usually found off Namibia, although reduced off Lüderitz due to persistent upwelling and offshore transport, and lowest values are found off the south coast of South Africa. Despite considerable interannual variability in all areas, the long-term regional trends in productivity appear to be persisting. These include a small but significant long-term increase in chl *a* off Namibia, and a decrease off the South African west and south coasts.

Seasonal and interannual patterns in mesozooplankton biomass, an indicator of fisheries potential and ecosystem health, were investigated over a period of eight years within three Marine Protected Areas (MPAs) off the west coast of South Africa (Report Card 9). Patterns diverged between the single inshore MPA (Namaqua National Park) and the two offshore MPAs (Childs Bank and Orange Shelf Edge): mean annual biomass was 4-5 times lower in the offshore MPAs and was gradually declining over time, while there was an increasing trend at the inshore MPA. Sampling will continue in the MPAs to update the trends and investigate underlying causes.

The global breeding population of Cape cormorants, which is restricted to the Benguela upwelling ecosystem, has shown a dramatic recovery in recent years (Report Card 10). This follows a long and steady decline in South Africa and Namibia over the past 3-4 decades, which has been attributed largely to food scarcity. The recent recovery is mainly due to a substantial increase in abundance in southern Angola. The associated northward shift in distribution coincides with that of Cape fur seals into northern Namibia and southern Angola. This is thought to be linked to greater prey availability in these areas, evidenced by increasing catch rates of the horse mackerel fishery. If the increasing trend in Cape cormorant abundance continues, their current global Endangered status could be improved.

The future is bleaker for the African penguin (shown on the front cover of the Report), which has declined by 75% over the last few decades and was allocated Endangered status in 2010 (Report Card 11). In South Africa, the greatest decline has been observed for the Algoa Bay population, with only 2,800 breeding pairs remaining in 2022. Despite the implementation of a Biodiversity Management Plan (BMP) in 2013, the population has continued to decline, albeit at a slower rate. Food scarcity is considered to be a key driver of this decline, while the recently revised BMP also aims to address emerging stressors such as marine traffic, ship-to-ship bunkering and petroleum exploration.

Research Highlights

Satellite altimetry allows us to map ocean surface variations across the globe with good accuracy. An eddy-tracking algorithm applied to satellite altimetry data in the southeast Atlantic Ocean showed that eddies in the Angola Basin tend to be shorter-lived, often dissipating within 30 days, compared to eddies further south off Namibia, where they may persist for more than 120 days. As ocean eddies play a key role in transporting and redistributing heat, salt, nutrients and even plankton across long distances, their impacts on biological processes and marine productivity in the two regions may vary due to their differing lifespans (Report Card 12).

Off the east coast of South Africa, model simulations have revealed the presence of a northeastward counter current associated with the KwaZulu-Natal Bight, which is thought to increase nutrient and larval retention within the Bight, as well as connectivity between nearby MPAs (Report Card 13). It is important to bear in mind, however, that models do not necessarily reflect reality, as demonstrated by comparing various models of bottom depth at the remote Prince Edward Islands (PEIs; Report Card 14). Despite the high spatial resolution of the bathymetric models, inaccuracies were detected when compared with the relatively sparse *in situ* data, emphasising the need for systematic bathymetry surveys of the area.

Staying at the PEIs, decadal variations in satellite-derived measurements of wind speed and geostrophic current speed were explored in relation to those of Sea Surface Temperature (SST). Stronger current speeds at the surface are associated with lower SST and vice versa, but the relationship between SST and wind speed is weaker (Report Card 15). Vertical profiles of fluorescence at the PEIs show elevated chl *a* in the upper 100 m during both autumn and summer surveys, but the lack of data during spring and winter prevents a full seasonal comparison (Report Card 16).

Next, we highlight findings from a range of studies designed to improve our knowledge of plankton communities within South Africa's exclusive economic zone (EEZ) and beyond. A description of phytoplankton composition from the coastal waters near Plettenberg Bay is provided in Report Card 17, and a recently established Continuous Plankton Recorder (CPR) sampling route across the South Atlantic provides information on zooplankton diversity and microplastic pollution at the basin scale (Report Card 18). The latter is in support of the international AtlantECO programme which aims to protect the provision of ecosystem services within the Atlantic system. On the Agulhas Bank, a 24-year study of zooplankton composition has revealed distribution patterns of the dominant copepod taxa, which provide an important food resource for pelagic fish (Report Card 19). Copepod biomass declined significantly over the study period, likely due to increased predation by pelagic fish, while long-term warming from climate change is expected to further reduce ecosystem productivity on the Agulhas Bank.

Microplankton, small (20–200 µm) planktonic plants and animals, play a key role in marine ecosystems, contributing to nutrient recycling, carbon export and food web dynamics. New information on microplankton abundance and composition is provided for several areas off the east coast of South Africa, revealing the strong dominance of diatoms in this size class (Report Card 20). Dinoflagellates and tintinnids were more abundant at the northern stations, suggesting an affinity for warmer temperatures. Mixotrophic dinoflagellates (using both photosynthesis and heterotrophy to meet their energy requirements) dominated the microzooplankton community on the southern Madagascan shelf and within an eddy that had entrained water from the shelf during its genesis (Report Card 21).

Benthic camera systems were used to assess invertebrate communities and their associated habitats in several priority areas of the southern Benguela ecosystem: the newly declared Robben Island MPA, the Table Mountain National Park MPA, and the newly proposed Seas of Good Hope Ecologically or Biologically Significant Marine Area (EBSA), which extends eastward to Cape Agulhas (Report Card 22). Information from these non-destructive surveys will provide a baseline for future monitoring to support conservation efforts and more effective management within these important areas.

This section concludes with the initial findings from two recently established projects to monitor pollution at several sites across the Western Cape. Black mussels were tested for trace and heavy metal concentrations (Report Card 23), and mussels and sediment samples were tested for microplastics (Report Card 24) at locations within False Bay, Table Bay and Saldanha Bay.

Science to Policy

This section features report cards on two issues where scientific input is required to inform policy decisions. The first relates to ocean noise, or 'sonic pollution', from anthropogenic sources, which is emerging as a key threat to marine life. One such source is seismic surveys, which use air gun arrays towed behind vessels to map the ocean floor to locate subsea deposits of oil and gas. The potential impact of these surveys on marine life and fishers' livelihoods has been subject to considerable controversy and debate in South Africa, and there is a clear need for foundational science to investigate the potential effects of seismic surveys. This will require the development of local capacity in research on underwater noise to inform policies and develop standards and guidelines, including appropriate mitigation and monitoring measures (Report Card 25).

Report Card 26 evaluates how governance and management of South Africa's MPAs have kept pace with the expansion of the MPA network since 1964 when the first MPA (Tsitsikamma) was declared. A number of critical needs were identified for continued progress in this sphere, such as having detailed objectives for each MPA, and improved cooperation between government authorities responsible for MPAs and fisheries. Current challenges relate to managing new offshore MPAs that were declared in 2019.

Platforms, Technology and Innovation

The importance of maximizing both spatial and temporal sampling resolution to gain the best possible understanding from *in situ* data, using bottom temperature data measured at the PEIs as an example, is demonstrated in Report Card 27. Switching to modelled data, Report Card 28 evaluates the effectiveness of input data of varying resolution for using an "enhanced Bathtub Model" to simulate potential water pathways in the context of episodic coastal inundation in an urban setting, such as due to storm surges.

On a larger spatial scale, LACCE (Location of the Agulhas Current's Core and Edges) is an OCIMS decision support tool that uses satellite data to monitor the Agulhas Current. LACCE was validated during a voyage to Marion Island in 2022, with *in situ* measurements of surface temperature and current speed shown to correspond well to LACCE-identified features, including the core and edges, of the Agulhas Current and Agulhas Return Current (Report Card 29).

A new protocol for the digital image analysis of preserved mesozooplankton was developed and tested (Report Card 30). Larger organisms (>0.5 mm) are analysed using the ZooScan, while smaller organisms (<0.5 mm) are analysed using the FlowCam. This method produced better-quality images for organisms in both size ranges and was more representative of all taxa present in the water column. This in-house protocol has been instated as the standard operating procedure to provide a digital archive of zooplankton taxonomic identification for the west coast of South Africa.

The final article in this section provides an analysis of the impacts of COVID-19 on vessel operations for the RS *Algoa* during 2020 and 2021. Negative impacts included substantial reductions in the number of annual voyages as well as sea days, fewer participants permitted per voyage, and an increase in operational costs to meet COVID-19 compliance regulations. These unplanned expenses, of over R1 million for 2020 and 2021 combined, decreased the operational budget available for voyages, while the reduction in sea time hampered monitoring and research objectives, and severely limited capacity building opportunities (Report Card 31).

Training and Outreach

The Physical Oceanography group, together with CPUT Marine Science lecturers, hosted an outreach and training event for CPUT Marine Sciences National Diploma learners in the second year of their studies. A wide range of instruments commonly used by physical oceanographers was demonstrated to the learners, exposing them to some of the practical aspects of the technical work and scientific research conducted at DFFE, and hopefully stimulating their interest in the marine environment and technologies used in this field (Report Card 32).

Younger learners were targeted during the 'Adopt-a-float' initiative, which aims to inspire and educate students of all ages about global ocean biogeochemistry and climate change. The OCR Physical Oceanography team deployed five profiling biogeochemical floats in the Southern Ocean, each of which was 'adopted', named, and tracked online by a school in the USA (Report Card 33).

AtlantECO is a collaborative, international project that aims to map new and existing knowledge about microscopic organisms and plastic pollution in the Atlantic Ocean. As part of this initiative, the French research schooner *Tara* stopped in Cape Town during their 'Mission Microbiome' expedition to run a one-day training course on standard sampling protocols and analysis of marine microorganisms (Report Card 34). This approach is now being implemented during Integrated Ecosystem Programme (IEP) cruises off the west coast.

Another initiative of AtlantECO was the establishment of regular sampling across the entire South Atlantic using the CPR.The CPR is a robust instrument designed to be towed by merchant vessels, allowing the underway collection of phytoplankton and zooplankton at the basin scale. A 6-day training course was held in Cape Town to familiarise DFFE officials with various operational aspects of the CPR, facilitated by the Marine Biological Association of the UK (Report Card 35).

1. AN EXTREME DETOUR OF THE AGULHAS CURRENT DURING MAY/JUNE 2022

The Agulhas Current (AC) is the strongest Western Boundary Current in the Southern Hemisphere. It flows southwestward along South Africa's east and south coasts from the Southwest Indian Ocean towards the South Atlantic Ocean (Fig. 1a). South of Cape Town, the flow is redirected eastward, back into the Indian Ocean, as the Agulhas Return Current (ARC). This region of direction change is known as the Agulhas Retroflection, and is typically located between 16 and 22˚E.

On occasion, however, the AC detours and retroflects east of 22˚E. Such events are referred to as early retroflections. They have considerable implications on the inter-ocean exchange of heat and salt, i.e. Agulhas leakage, with studies having found that this is reduced during an early retroflection. In addition, these events can substantially influence the adjacent shelf ecosystem along South Africa's south coast, with potentially detrimental impacts (including offshore advection and loss) on marine biota, and on the local fishing industry.

The LACCE (Location of the Agulhas Current's Core and Edges) monitoring tool (see Report Card number 29) is continuously applied to daily near real-time satellite altimetry maps of sea surface height to monitor the state of the AC, and to identify the occurrence of extreme events, such as early retroflections. Figure 1 shows the occurrence of an early retroflection, with inception on 17 May 2022, when warm AC water began diverting from its usual path along the south coast to flow directly south into the ARC (Fig. 1b).

By 24 May 2022, the early retroflection was fully established, with most of the AC flow redirected into the Indian Ocean at ca. 25°E (Fig. 1c). On 15 June 2022, the typical flow pattern of the AC was re-established, marking an end to the 22-day extreme event (Fig. 1d). In total, six early retroflections have occurred between 1993 and 2022, with the most recent event being the third longest (Fig. 1). The direct impacts of the 2022 event on the south coast shelf ecosystem are unknown, but potential responses of biological communities may include reductions in coastal biomass and/or abundance due to offshore advection. Further research is required to determine such effects with certainty.

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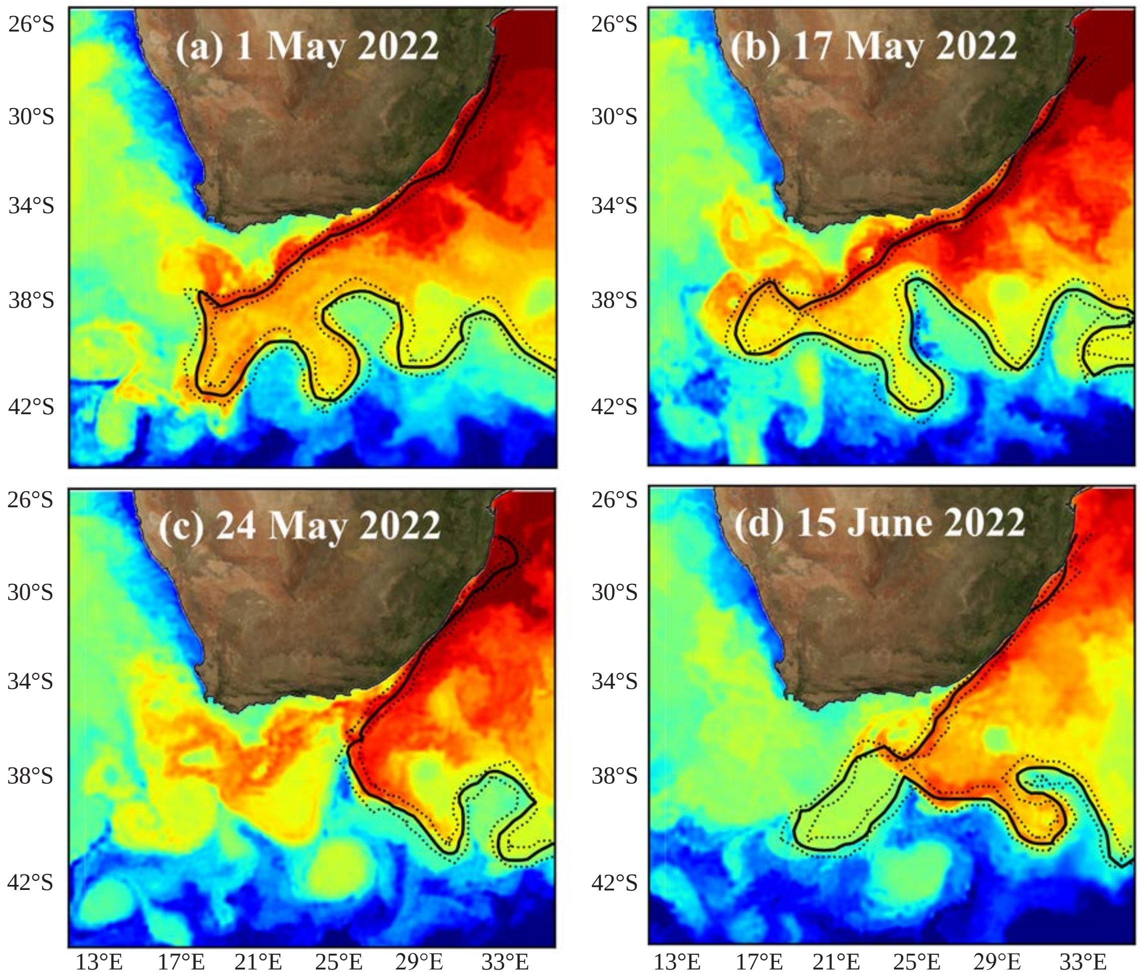

Figure 1. Location of the Agulhas Current (AC) system, including the core (solid black line) and edges (dotted black lines) of the AC, the Agulhas Retroflection, and the Agulhas Return Current, identified using the LACCE monitoring tool and overlaid onto maps of daily near-real time Sea Surface Temperature. a) A typical formation of the AC system, b) the inception of an early retroflection, c) a fully established early retroflection, and d) the end of the early retroflection.

2. SUB-SURFACE NEARSHORE TEMPERATURE VARIABILITY ALONG THE SOUTH AND EAST COASTS OF SOUTH AFRICA

Temperature is one of the primary factors driving distribution, ecology and evolution of marine biota, over a variety of spatial and temporal scales. As such, long-term temperature records are crucial to better understand the environmental drivers of biological variability in the world's oceans. Satellite observations have revolutionised our capability of studying temperature variations across marine environments over much larger spatial and temporal scales than *in situ* measurements allow. However, the limited capability of satellite sensors to accurately observe very shallow, nearshore coastal regions is well known. In contrast, Underwater Temperature Recorders (UTRs) provide a simple, yet effective means of measuring *in situ* nearshore temperature fluctuations.

In situ nearshore temperatures have been recorded at selected locations along the South African coast over the past few decades (Fig. 1). Here, we present long-term (1991–2022) observations from Mossel Bay (8 m depth) and Tsitsikamma (10 m depth) on the south coast, and from Sodwana Bay (18 m depth) on the east coast of South Africa.

Considerable intra-annual variability was evident for each site, with temperature maxima occurring during summer and minima occuring in winter (Fig. 2). Sodwana Bay exhibited overall higher temperatures (Fig. 2), since it is under the direct influence of the Agulhas Current that transports warmer tropical waters from the Indian Ocean (Fig. 1). In contrast, lower temperatures were observed at Mossel Bay and Tsitsikamma, which are located on the Agulhas Bank, further away from the inshore edge of the Agulhas Current and are therefore less impacted by it. Upwelling events are known to also result in cooler conditions over the Bank (Fig. 1).

While positive temperature anomalies at Mossel Bay indicated maximum monthly warming events of 2.6°C, negative anomalies indicated more substantial cooling up to -4.4°C (Fig. 3). Both the warming and cooling events at Tsitsikamma were large (± 3.3°C). The substantial cooling events at these locations were likely due to wind-driven upwelling. In contrast to the south coast sites, anomalies at Sodwana Bay were much smaller (± 1.9°C).

Although all long-term linear trends were statistically non significant, it is interesting that larger cooling trends occurred at Tsitsikamma and Sodwana Bay (Fig. 3). Cooling at Tsitsikamma may be associated with increased upwelling-favourable winds, while cooling at Sodwana Bay may be due to increased variability in the movement of the Agulhas Current. However, further research is required to determine this with certainty.

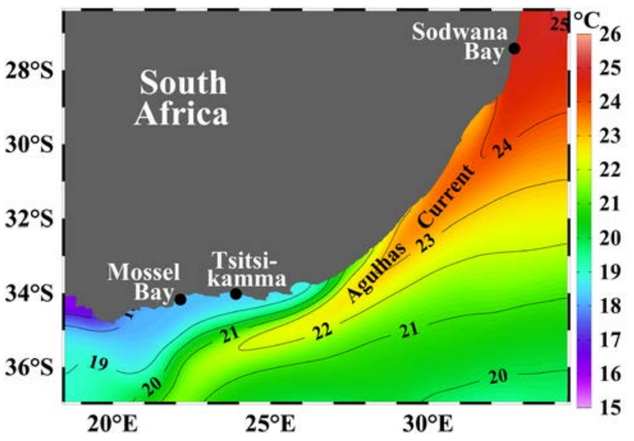

Figure 1. Long-term mean (1991–2022) satellite-derived Sea Surface Temperature (°C) map illustrating conditions around South Africa. Deployment locations of the UTRs at Mossel Bay, Tsitsikamma and Sodwana Bay are shown as black dots.

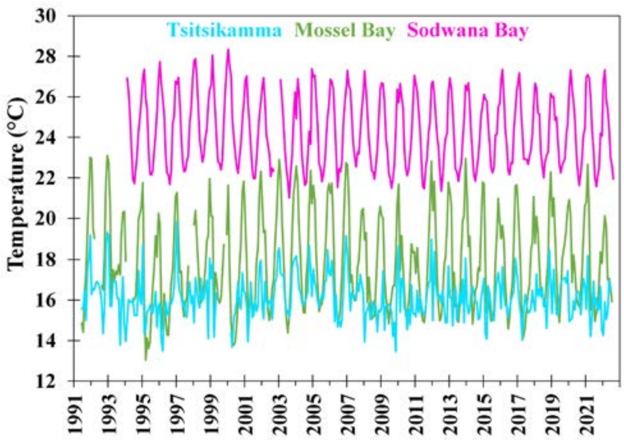

Figure 2. Monthly time series of nearshore sub-surface temperature for Mossel Bay, Tsitsikamma, and Sodwana Bay.

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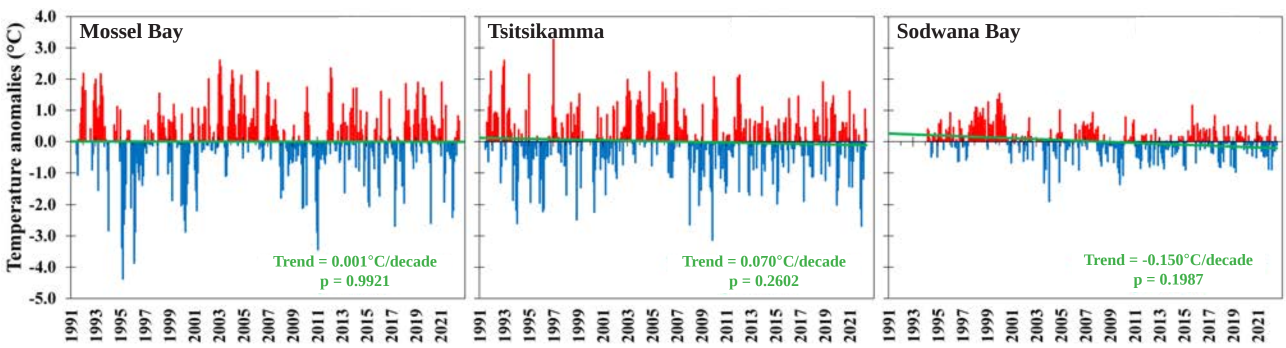

Figure 3. Monthly time series of sub-surface temperature anomalies for Mossel Bay, Tsitsikamma, and Sodwana Bay.

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

The Prince Edward Islands (PEIs) are a remote island archipelago in the sub-Antarctic zone of the Southern Ocean. They 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 in April–May. To contribute to long-term oceanographic observations, two moorings deployed on the inter-island shelf (Fig. 1) have been providing continuous measurements of water column current speed and direction since April 2014. Here we describe circulation patterns from these measurements, highlighting five cooling events that occurred in 2021.

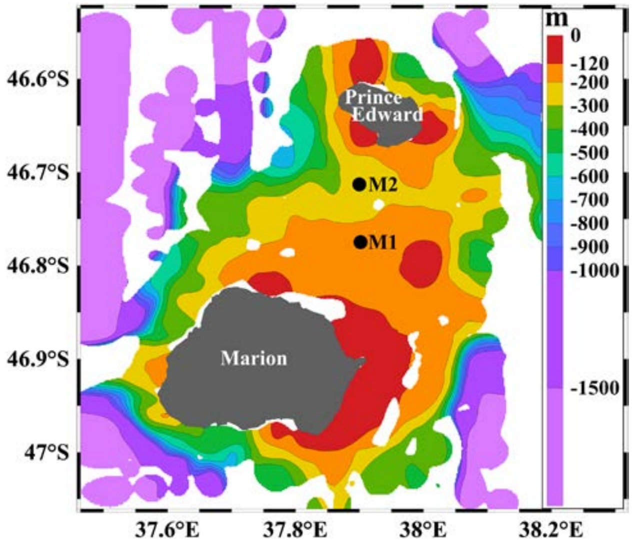

Figure 1. Bathymetry on the PEI shelf. Mooring positions M1 and M2 are shown as black dots.

During 2014–2022, daily mean current speeds at mooring M1 ranged between 0.01 and 50.90 cm s^{-1}, while those at M2 varied from 0.03 to 67.32 cm s^{-1}. The eastward-flowing Antarctic Circumpolar Current results in much stronger zonal (east/west) than meridional (north/south) flow at the PEIs. A Taylor column (stationary anticyclonic circulation) over the shelf is indicated by westerly flow in the bottom waters at M2 (Fig. 2). This westerly flow is persistent throughout the time series but can be enhanced or interrupted for short periods when fronts or mesoscale eddies interact with the PEI shelf. Retention of nutrients and biota by the Taylor column maintains enhanced productivity on the shelf, accounting for the high concentrations of marine biota at the PEIs.

In January 2021, current speeds at both moorings increased as the southern branch of the sub-Antarctic Front (S-SAF) moved from south to north of the PEIs. The strongest eastward flow was observed at M1 on 10 January (Fig. 2a), and one day later at M2 (Fig. 2b), as expected from northward migration of the S-SAF. Zonal flow changed to westerly at M1 on 18 January, and on 22 January at M2, as a cyclonic eddy further enhanced the cooling on the shelf.

Westward flow indicative of a Taylor column was observed throughout the water column during the May and June 2021 events (Fig. 2). Interestingly, this flow was stronger in May than in June, but only the June event was associated with a clear localised decrease in sea surface height (see Report Card number 4). The July–August 2021 and October 2021–January 2022 events were similar to January–February 2021, with northward migration of the S-SAF resulting in increased current speeds and mesoscale eddies causing stronger westward flow.

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

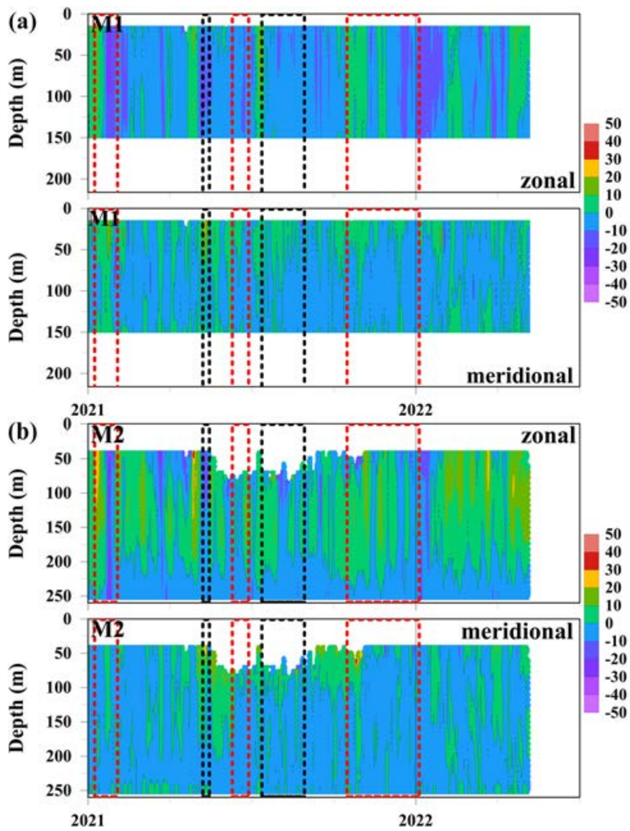

Figure 2. Daily mean zonal and meridional current components (cm s^{-1}) at (a) M1, and (b) M2 from April 2021 to April 2022. Positive values denote eastward (zonal) and northward (meridional) flow; negative values denote westward (zonal) and southward (meridional) flow. Dashed red boxes highlight cooling events during January–February 2021, June 2021, and October 2021–January 2022, while dashed black lines indicate cooling events during May 2021 and July–August 2021.

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Contributors: Jacobs L, Louw GS (OC Research)

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

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

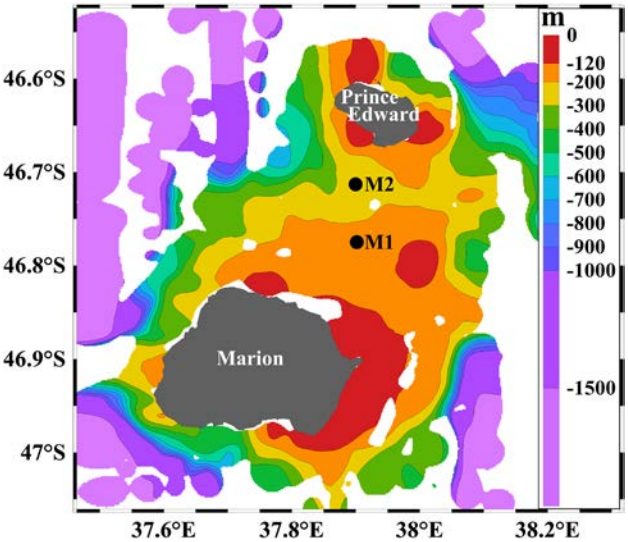

Figure 1. Bathymetry on the PEI shelf. Mooring positions M1 and M2 are shown as black dots.

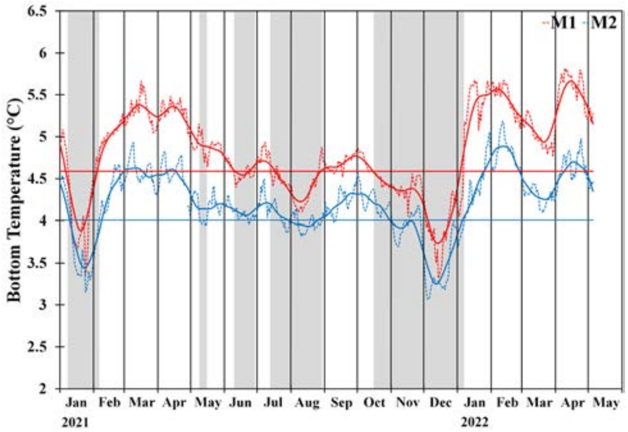

Figure 2. Daily mean bottom temperature (°C) at moorings M1 (red) and M2 (blue). Dashed lines indicate measurements while solid lines show low-pass filtered values. Horizontal lines show mean temperatures for each time series (2014–2022). Grey shading highlights cooling events during 2021.

During 2021–2022, temperature variability continued to show the tendency observed since 2018, with generally elevated values (exceeding the 2014–2022 mean) reflecting a more southerly location of the southern branch of the sub-Antarctic Front (S-SAF). For ease of interpretation, only the 2021–2022 data are shown (Fig. 2). Five cooling events were identified in 2021, when daily temperatures decreased below the 2014–2022 mean for longer than 2 days at a time (Fig. 2). Cooling began on 3 January 2021 as the S-SAF started migrating north of the PEIs and reached a maximum on 24 January 2021, with subsequent warming as the S-SAF migrated south of the PEIs. The second (9–15 May 2021) and third (10–28 June 2021) events were shorter. Both events occurred when the S-SAF was south of the PEIs, contradicting the expectation of warmer conditions on the shelf. The May event could not be clearly linked to mesoscale eddies, but the June event coincided with clear cyclonic circulation around Prince Edward Island (Fig. 3), suggesting a Taylor column (stationary anticyclonic circulation) over the shelf between the islands. Cooling during the 13 July–29 August 2021 and October 2021–January 2022 events resulted from the combined influence of eddies and northward migrations of the S-SAF.

Temperature variations are likely to affect the distances that seabirds and marine mammals have to travel from the islands to find food. This has consequences for time and energy spent foraging, for the survival of young that are dependent on foraging adults, and ultimately for the reproductive success and abundance trends of these populations. The events during 2021–2022 suggested that the cooling resulting from frontal movement and eddies is more intense than cooling resulting from the Taylor column.

Authors: van den Berg MA, Lamont T (OC Research)
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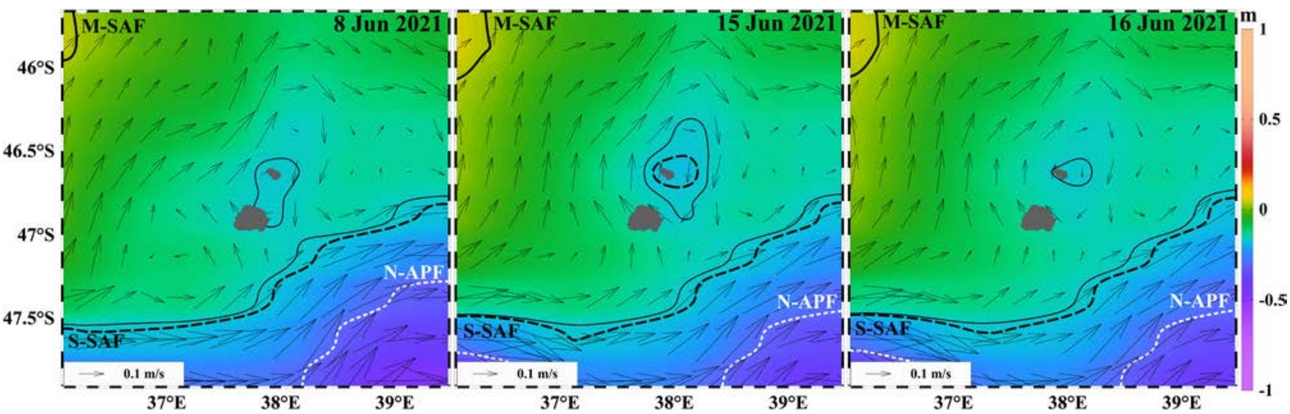

Figure 3. Selected daily maps of Sea Surface Height (SSH) around the PEIs. The middle (M-SAF) and southern (S-SAF) branches of the sub-Antarctic Front, and the northern (N-APF) branch of the Antarctic Polar Front, are labelled. The thin black contour highlights the cyclonic circulation and localised SSH decrease around Prince Edward Island. Arrows indicate current speed and direction (m s^{-1}).

5. DISSOLVED OXYGEN AND TEMPERATURE VARIABILITY OFF HONDEKLIP BAY

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

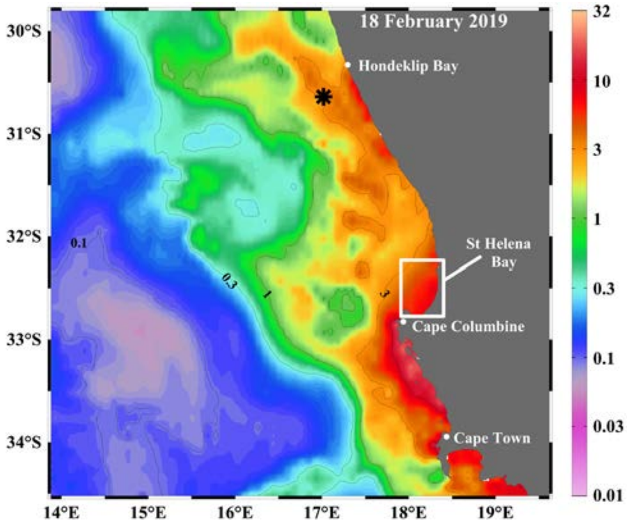

Figure 1. Satellite chlorophyll *a* (mg m^{-3}) for 18 February 2019, illustrating the mooring site (black star).

In February 2019, a mooring equipped with a miniDOT sensor (MDO) was deployed at 30.64°S and 17.02°E, southwest of Hondeklip Bay (Fig. 1). It measured temperature and DO at 96 m depth (ca. 74 m above the sea floor) over 10-minute intervals, from February 2019 to September 2021. Subsequently, the MDO was deployed at 75 m depth (ca. 95 m above the sea floor) following inclusion of additional sensors on the mooring. This depth change has not impacted the observed temporal patterns since there was no change in the water mass sampled. Temperature and DO showed rapid event-scale fluctuations over periods of a few days at a time (Fig 2). Thus far, there have been only seven anoxic days, when DO levels decreased below 2ml L^{-1} (Fig. 2b). Seasonal temperature changes were minimal (Fig 3a), while for DO, seasonality near Hondeklip Bay during 2019–2020 was marked by minima during winter and maxima in summer (Fig. 3b). This contrasted with DO seasonality further south in St Helena Bay, where minima usually occur at the end of the upwelling season, with maxima in winter. Initially, the DO seasonal cycle off Hondeklip Bay was interpreted with caution due to the short time series length. However, as the same cycle was observed in subsequent years, the opposing DO seasonality off Hondeklip Bay is now confirmed. Continuous, long-term, high temporal resolution observations along the entire SBUS coast are recommended, in order to determine where the change in DO seasonality occurs.

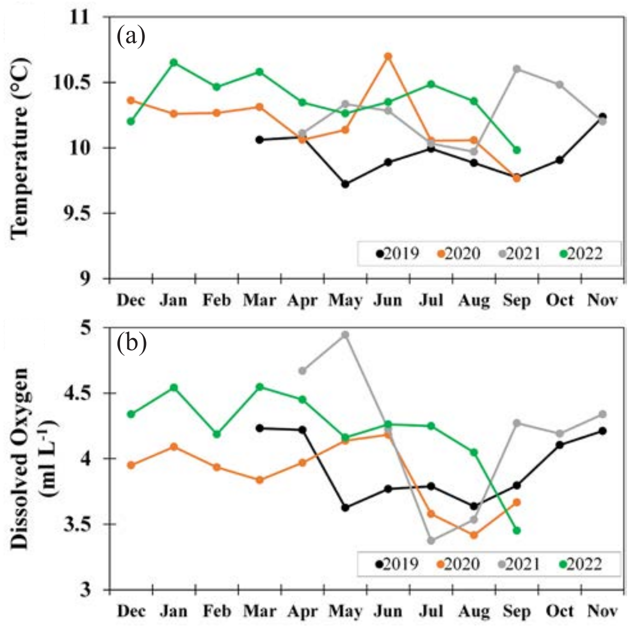

Figure 3. Daily-averaged (a) temperature and (b) DO at the mooring near Hondeklip Bay.

Authors: Lamont T, van den Berg MA (OC Research); Lahajnar N (UHH); Rixen T (ZMT)

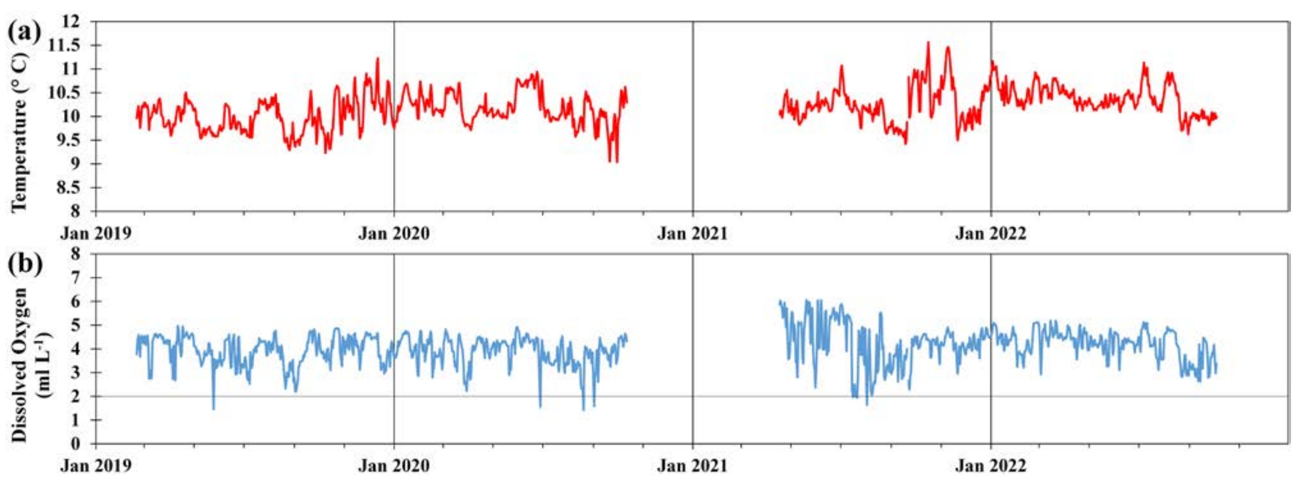

Figure 2. Daily-averaged (a) temperature and (b) DO at the mooring near Hondeklip Bay.

6. LONG-TERM AIR-SEA CARBON DIOXIDE FLUX TRENDS IN ST HELENA BAY

Coastal upwelling regimes inshore of Eastern Boundary Currents, such as the southern Benguela, are the most biologically productive ecosystems in the global ocean. However, changes resulting from human activities have already begun to emerge in these regions. Air-sea carbon dioxide (CO_2) fluxes in coastal areas play an important role in global carbon fluxes. However, locally, little has been done to understand such long-term changes. Here, we present long-term changes in the partial pressure of carbon dioxide (pCO_2) and carbon dioxide flux (FCO_2) along the St Helena Bay Monitoring Line (SHBML), in the southern Benguela ecosystem on the west coast of South Africa.

A 20-year record (2000–2019) of surface pCO_2 and FCO_2 was reconstructed by applying extended multilinear regression (eMLR) to *in situ* measurements of dissolved inorganic carbon and total alkalinity, and monthly averages of reanalysis (blended datasets of observations and model output) surface temperature, salinity, chlorophyll *a* and atmospheric CO_2 at Stations 3, 7, and 12 along the SHBML (Fig. 1). Positive FCO_2 values represent a CO_2 source (CO_2 is transferred from the ocean to the atmosphere), while negative FCO_2 values indicate a CO_2 sink (CO_2 is transferred from the atmosphere to the ocean).

The observed and reconstructed pCO_2 are in good agreement at Station 12 offshore but poorly related in the inner shelf. During 2000–2019, surface waters in the inner shelf region (Station 3) were saturated with CO_2, with values above the annual atmospheric CO_2 concentration (Fig. 2). At Station 7 (Fig. 3), surface pCO_2 began to rise above the atmospheric pCO_2 in 2000. In the outer shelf region (Station 12), surface waters were undersaturated with respect to atmospheric CO_2. Positive pCO_2 and FCO_2 trends were observed at each of the three stations (Figs. 2–4). Whereas the rate of pCO_2 increase was strongest at Station 3, the rate of FCO_2 increase was strongest at Station 12. The nearshore (Station 3) and mid-shelf (Station 7) regions are both sources of CO_2, and while the outer shelf (Station 12) is a CO_2 sink at present, the trend suggests that this region will also become a CO_2 source to the atmosphere in future. These trends should be monitored to better understand future responses of the southern Benguela ecosystem to continued increases in anthropogenic (human-induced) CO_2.

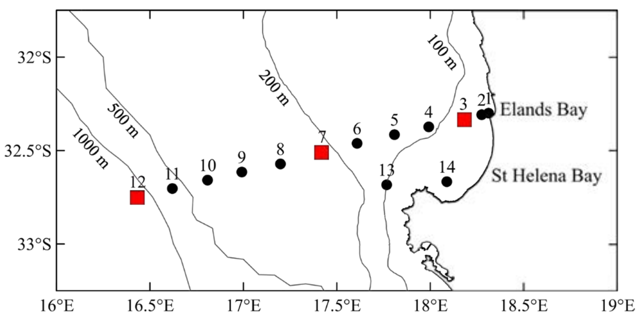

Figure 1. Map showing the St Helena Bay Monitoring Line (SHBML). Stations 3, 7, and 12, where sampling took place, are highlighted as red squares.

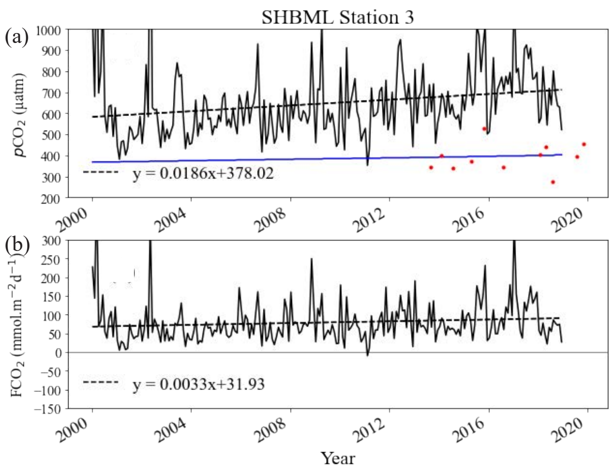

Figure 2. Time series of surface (a) reconstructed monthly pCO_2 (black), with *in situ* observations (red dots) and the annual atmospheric CO_2 (blue line), and (b) reconstructed FCO_2 from 2000 to 2019 at Station 3 of the SHBML.

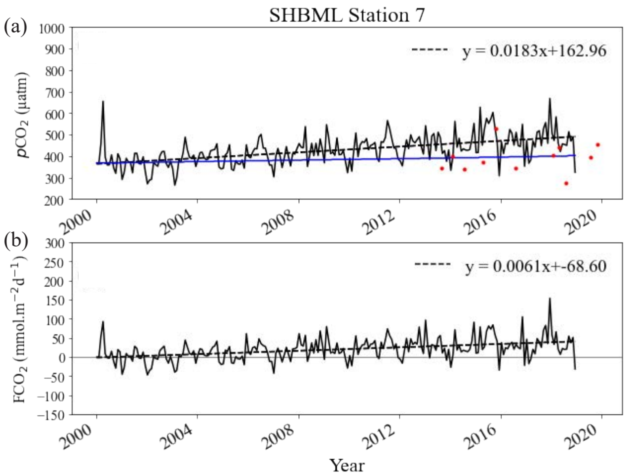

Figure 3. Time series of surface (a) reconstructed monthly pCO_2 (black), with *in situ* observations (red dots) and the annual atmospheric CO_2 (blue line), and (b) reconstructed FCO_2 from 2000 to 2019 at Station 7 of the SHBML.

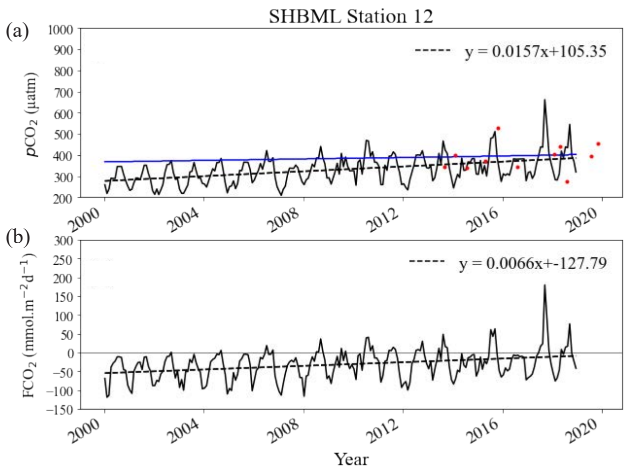

Figure 4. Time series of surface (a) reconstructed monthly pCO_2 (black), with *in situ* observations (red dots) and the annual atmospheric CO_2 (blue line), and (b) reconstructed FCO_2 from 2000 to 2019 at Station 12 of the SHBML.

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

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

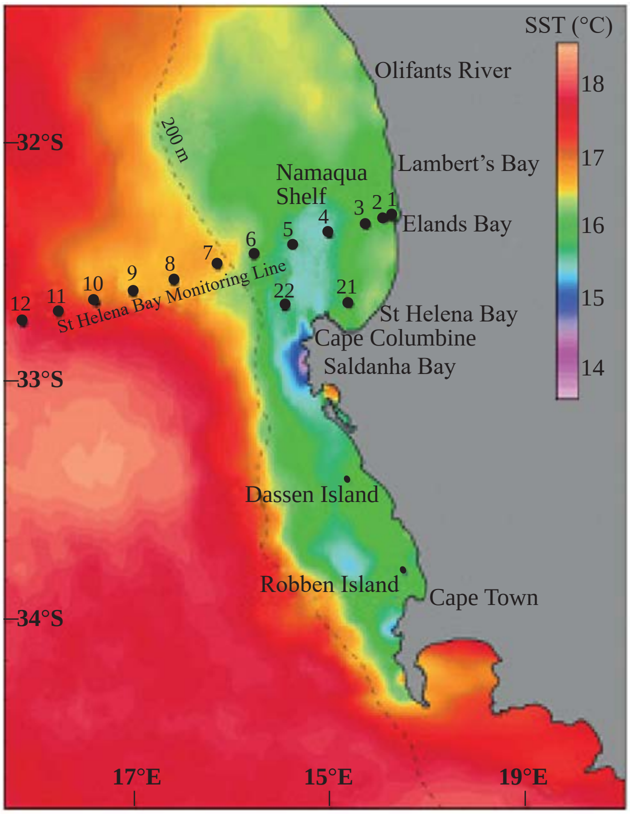

Figure 1. Map of satellite-derived sea surface temperature, illustrating cooler waters typically found inshore and warmer waters offshore. The location of the St Helena Bay Monitoring Line is shown.

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

Higher chlorophyll *a* is usually associated with greater phytoplankton biomass and a more productive ecosystem, which largely results from the higher availability of nutrients in the upper ocean during upwelling. In contrast, lower chlorophyll *a* indicates lower phytoplankton biomass and a less productive ecosystem, usually associated with less upwelling and nutrient availability in the upper ocean during late autumn to early spring (April–September) each year. Generally, higher chlorophyll *a* occurs close to the coast and decreases with distance offshore (Fig. 2). During 2015, high values (>20 mg m^{-3}) extended ca. 20 km offshore in autumn (March) and late spring/early summer (September–November). In contrast, values >20 mg m^{-3} were observed much closer to the coast during 2016–2019 and in 2021. Such high values extended about 10 km offshore in February–March 2020 and October 2022. Elevated chlorophyll *a* (>5 mg m^{-3}) extended ca. 110 km offshore in March 2015 – the farthest offshore extent for such elevated values since March 2010. Since then, the farthest offshore extent (ca. 80 km) of values above 5 mg m^{-3} was observed in February and March 2016 and in April 2022. In contrast, such values did not extend beyond 70 km offshore during 2017–2021.

Chlorophyll *a* in 2017 was lower overall than in 2016 but remained elevated throughout the year. Generally lower values in 2018 and 2021 suggested a less productive ecosystem during these years. In contrast, higher values during 2019, 2020, and 2022 suggested increased productivity. Peak values in 2019 occurred during April–August, suggesting a more productive autumn/winter than usual. In contrast, peak values during 2020–2022 occurred during March and October, in agreement with the usual seasonal maxima.

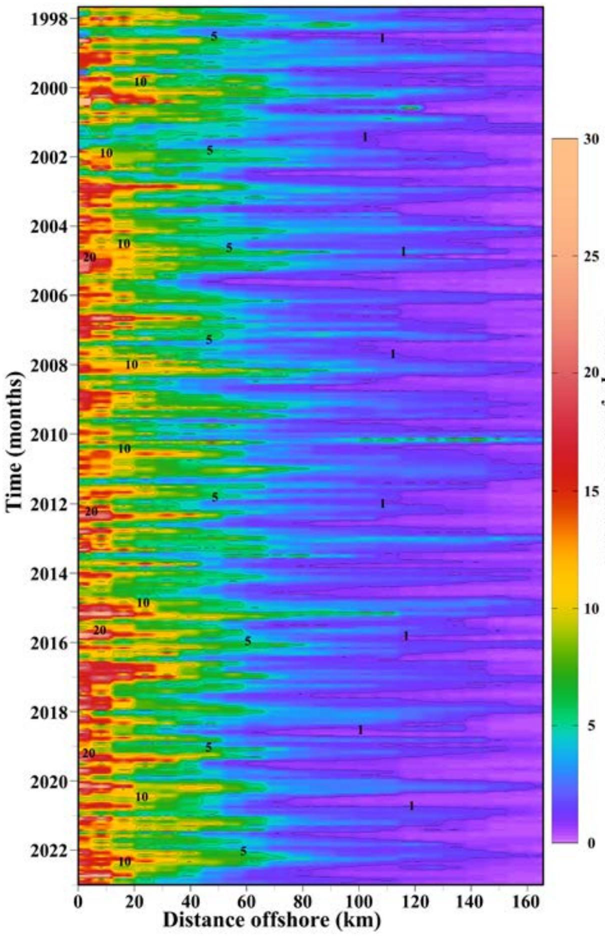

Figure 2. Time series of satellite-derived monthly chlorophyll *a* (mg m^{-3}) along the St Helena Bay Monitoring Line between September 1997 and 2022.

Author: Lamont T (OC Research)

8. CHLOROPHYLL VARIABILITY ON THE WEST AND SOUTH COASTS

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

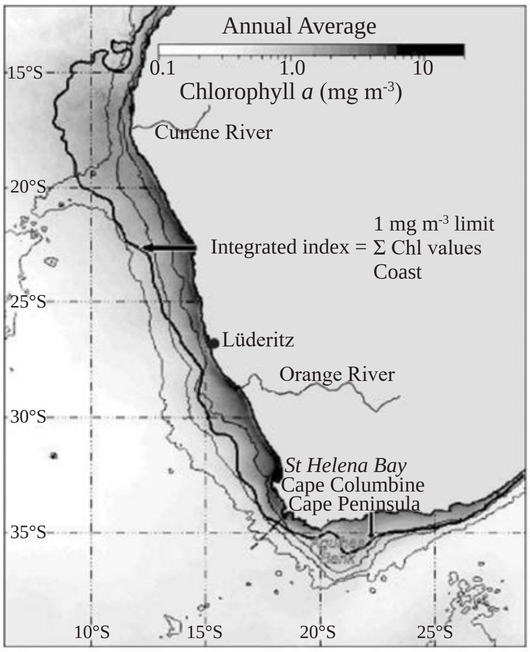

Figure 1. Annual average chlorophyll *a* concentration and location of the 1 mg m^{-3} contour (thick line).

Higher values are associated with greater phytoplankton biomass and a more productive ecosystem, while lower values indicate lower biomass and a less productive ecosystem. Highest index values are usually found off Namibia (16–26°S; Fig. 2). Biomass here in 2018 was the lowest since 2013. While biomass was elevated during 2019 and 2020, the 2021 and 2022 values were somewhat lower again. Persistent upwelling and offshore transport at Lüderitz (ca. 27°S) are typically associated with very low index values. Elevated values here during the summers of 2020 and 2021 suggested decreased upwelling, but lower 2022 indices implied stronger upwelling.

Along South Africa's west coast (SAWC, 28–34°S), index values are elevated around the Namaqualand, Cape Columbine and Cape Peninsula upwelling cells. Off Namaqualand (28.5–30°S), values in 2018 were the highest since 2013. Lower values during 2021 reflected less productive conditions, while elevated values in 2022 suggested improved productivity. Along South Africa's south coast (SASC, 18.5–29°E), index values are generally lower than on the WC. During 2013–2022, the highest values occurred at 22°E in January–February 2014, with reduced peak biomass levels in subsequent years. Low values in 2016 suggested this was the least productive year for the SASC during 2013–2022. Lower values during the second half of 2022 also suggested lower productivity. The varying trends in productivity observed across the region, i.e. a small but significant long-term increase in chlorophyll *a* off Namibia, and a decrease off the SAWC and SASC, appear to have continued over the past year.

Author: Lamont T (OC Research)

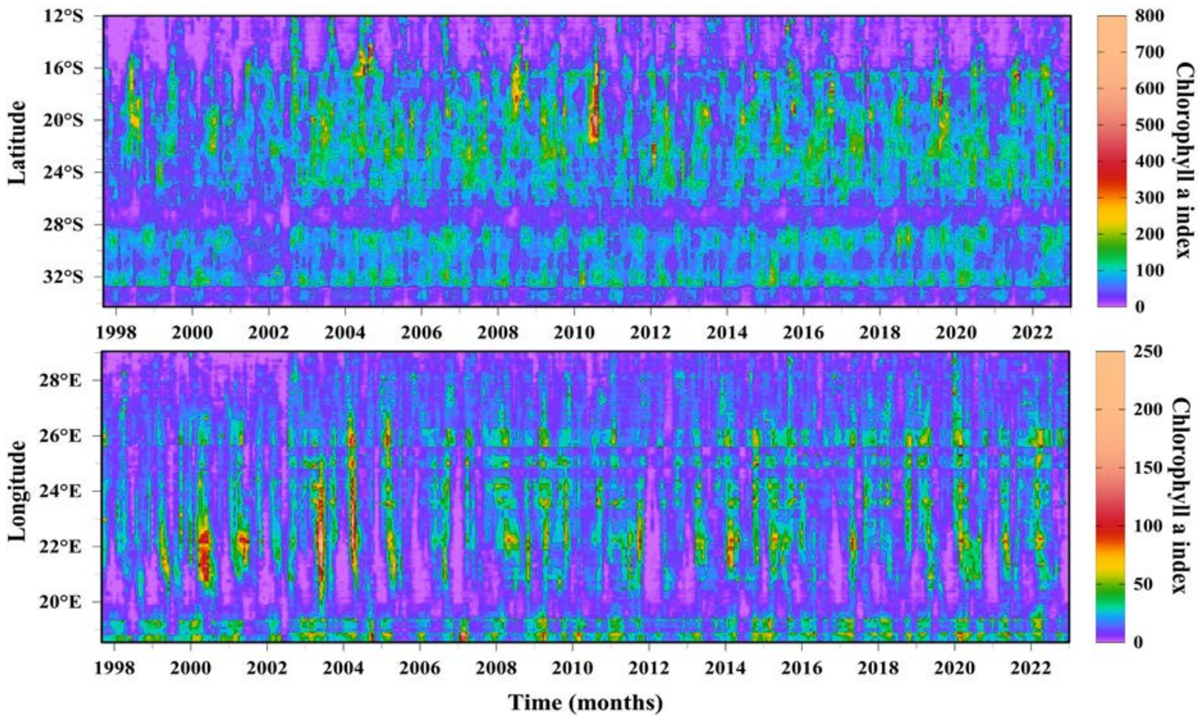

Figure 2. Monthly chlorophyll indices (1997–2022) for the west coasts of Namibia and South Africa (top panel) and for South Africa's south coast (bottom panel).

9. MESOZOOPLANKTON BIOMASS IN THREE WEST COAST MARINE PROTECTED AREAS

Mesozooplankton are small (<2 mm), free-floating marine animals that fuel the ecosystem as food for fish, juvenile rock lobsters and birds. Seasonal and annual variability in mesozooplankton biomass was investigated for three Marine Protected Areas (MPAs) off the west coast of South Africa, namely (from coastal to offshore) the Namaqua National Park (Namaqua) MPA, Childs Bank MPA, and Orange Shelf Edge MPA (Fig. 1). Namaqua MPA is important for the recovery of west coast rock lobster, and both Namaqua and Childs Bank MPAs are nursery areas for juvenile fish. Orange Shelf Edge MPA is an important feeding area for seabirds including threatened albatrosses and it protects the only untrawled continental shelf edge region which provides a reference point for research in an offshore ecosystem in a pristine state.

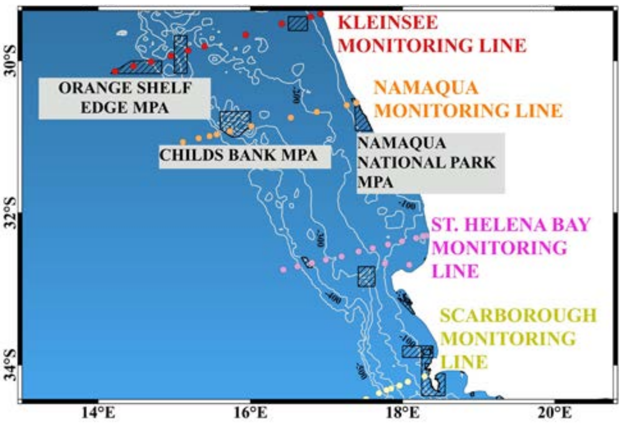

Figure 1. The Integrated Ecosystem Programme: southern Benguela monitoring lines (coloured circles = stations) and associated MPAs. Stations inside MPAs are sampled quarterly for mesozooplankton using a Bongo net.

Mesozooplankton biomass was highest in summer and lowest in autumn–winter in the inshore Namaqua MPA, while the opposite seasonal pattern was observed offshore for Childs Bank and the Orange Shelf MPAs (Fig. 2). Mean annual biomass differed significantly between MPAs, being highest for Namaqua MPA (2.26 ml m^{-3}), followed by Childs Bank (0.59 ml m^{-3}) and Orange Shelf Edge (0.43 ml m^{-3}) MPAs. Offshore, a decreasing trend in annual mesozooplankton biomass was observed, compared to an increasing trend inshore (Fig. 3). However, the strength of the trends was only moderate (Orange Shelf Edge MPA) to weak (the other two MPAs). This may have been affected by the relatively short duration of the time series (eight years), and sampling will continue in the MPAs to update the trends and investigate underlying causes.

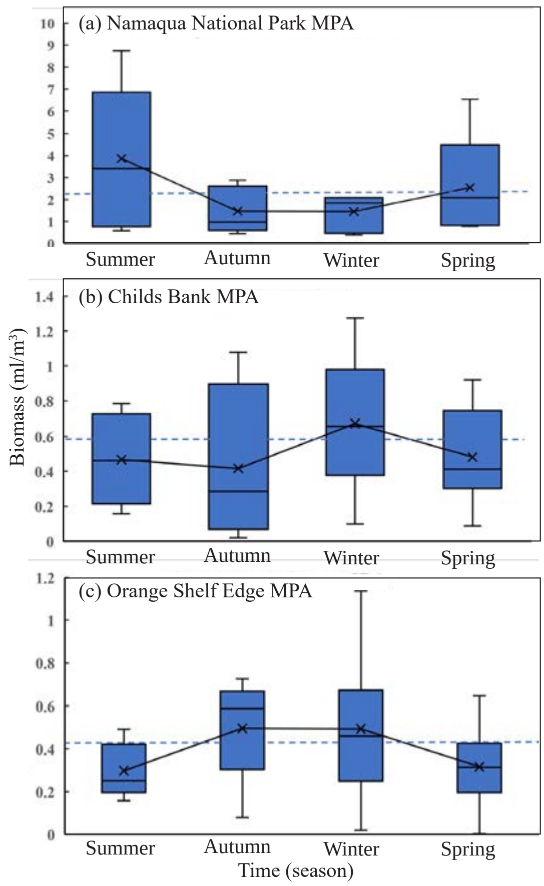

Figure 2. The distribution of mesozooplankton biomass by season for each of the three MPAs. The crosses represent seasonal means and the dashed lines the annual means.

Authors: Pillay K, Worship M, van der Poel J, Setati S (OC Research)

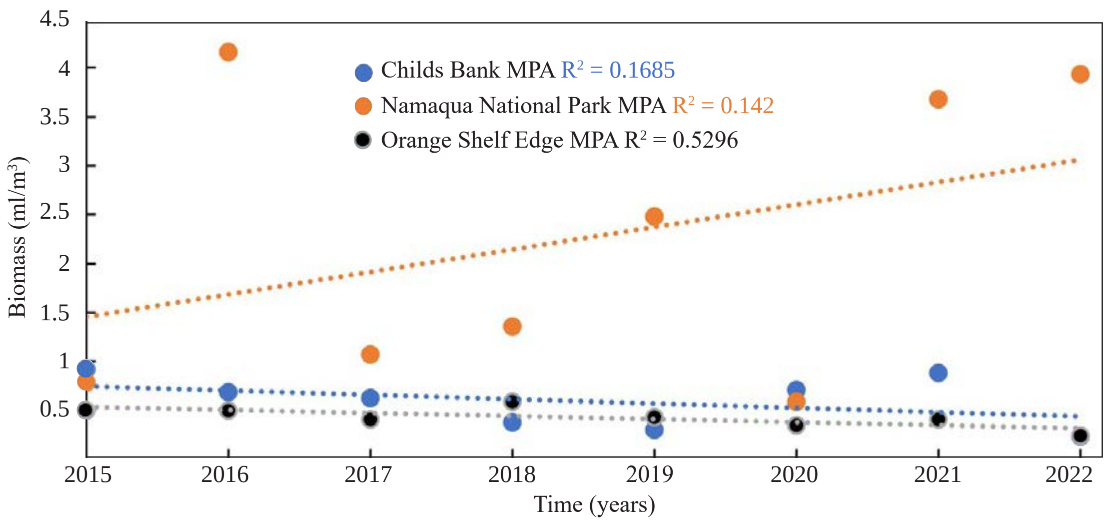

Figure 3. Linear trends in mean annual mesozooplankton biomass at the three MPAs in 2015–2022. Higher coefficient of determination (R^2) values indicate stronger trends.

10. SPATIO-TEMPORAL SHIFTS OF THE CAPE CORMORANT BREEDING POPULATION

Cape cormorants *Phalacrocorax capensis* are endemic to the Benguela ecosystem, where they breed at numerous localities between Ilha dos Tigres in southern Angola, and Algoa Bay on South Africa's south coast (Fig. 1). Historically, the breeding population was limited to South Africa and Namibia. Here we describe recent numerical trends and distributional shifts in breeding numbers.

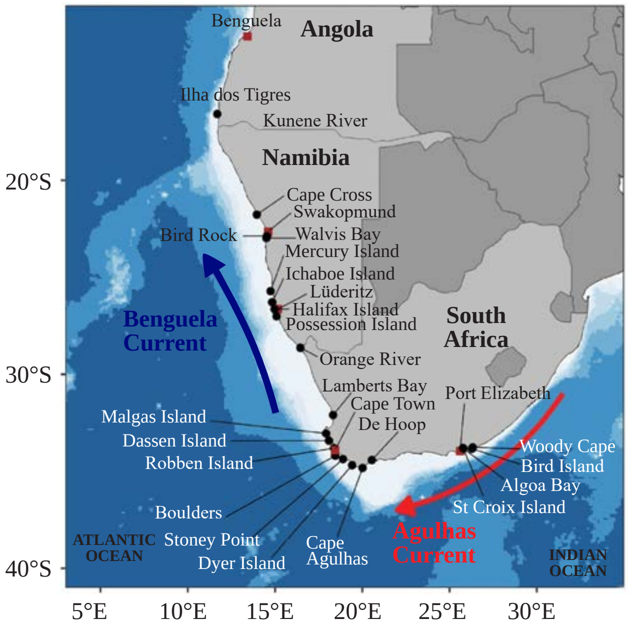

Figure 1. Map showing the major breeding localities of Cape cormorants on the coast of Southern Africa.

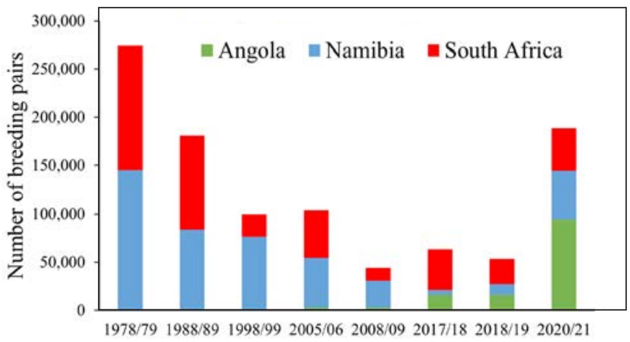

Figure 2. Numbers of Cape cormorants breeding in Angola, Namibia and South Africa, between 1978 and 2020.

The global breeding population of Cape cormorants decreased from ca. 275,000 pairs in 1978/79 to ca. 100,000 pairs in 2005/06, before recovering to ca. 190,000 pairs in 2020/21 (Fig. 2). In this period, numbers of breeding pairs in Namibia decreased by approximately 65% from ca. 143,000 pairs in 1978/79 to ca. 50,000 pairs in 2020/21 (Fig. 2). Similarly, the numbers in South Africa decreased by approximately 83%, from ca. 104,000 pairs to ca. 18,000 pairs.

In both Namibia and South Africa, there were recent increases in the numbers of breeding pairs, with numbers in South Africa having reached a nadir in 2008/09, and Namibia in 2017/18. However, the recovery of the global population was mainly attributable to a substantial numerical increase at Ilha dos Tigres in southern Angola, which was first colonised in the 1990s. At Ilha dos Tigres, the population increased from ca. 2,600 pairs in 2005/06 to 95,000 pairs in 2020/21, showing a 92% increase in the annual growth rate. Whereas Cape cormorants were historically most abundant in Namibia with 62% of the breeding population, and the rest of the population occurred in South Africa, these countries now account for only 26% and 23% of the global population, respectively. Currently, >50% of the population breed in Angola, meaning that there has been a substantial northwards shift in the distribution of the breeding population.

The declines in South Africa and Namibia have been attributed largely to food scarcity. In South Africa, this is related to an eastward shift in the distributions of forage fish (anchovy *Engraulis capensis* and sardine *Sardinops sagax*), with reduced prey on the west coast where the majority of Cape cormorants occur in the country. Fishing pressure and environmental changes have resulted in low prey availability in the Northern Benguela, which largely coincides with Namibia. Besides food scarcity, other stressors such as disease (avian flu has caused mortality of over 25,000 individuals), predation (e.g. by Cape fur seals *Arctocephalus pusillus pusillus*, and kelp gulls *Larus dominicus*), human disturbance, and oil spills have also affected the populations.

The increase of Cape cormorants in southern Angola and their associated northward distributional shift coincided with the shift of Cape fur seals into northern Namibia and southern Angola. Apart from the abundant breeding space afforded by Ilha dos Tigres, the attraction for these important top predator species is almost certainly prey availability in this region. In particular, the horse mackerel *Trachurus capensis* stock in the region has shown recovery, with good fisheries catches reported for Northern Namibia and Angola, thus providing an abundant prey resource for these predators. If the recent incline of the Cape cormorant population endures, its Endangered status may be down-listed, globally. Currently, Endangered or Vulnerable status is applicable at national levels for South Africa and Namibia, respectively.

Authors: Makhado AB, Dyer BM, Masotla MJ, Upfold L, (OC Research); Crawford RJM (ex-OC Research, retired)

11. AFRICAN PENGUINS IMPERILLED: A MANAGEMENT CHALLENGE

The population of the African penguin *Spheniscus demersus*, which is endemic to South Africa and Namibia, has declined substantially in the past 100 years, with the decline reaching precipitous proportions in the present century. Since 2010, the International Union for Conservation of Nature (IUCN) has classified the species as Endangered. Population trends for the past three generations are presented here, focusing on South Africa.

The global population of the African penguin was at its lowest known level of ca. 14,000 breeding pairs in 2022 (Fig. 1a). This is 2% of the ca. 570,000 pairs estimated to have bred only at Dassen Island on the west coast of South Africa in 1910. In the past 30 years (approximately three generations) the global population is estimated to have declined by about 75%. The decline of the population in South Africa closely resembles the global population trend, in that there was a 74% decrease from ca. 42,000 pairs in 1992 to ca.10,000 pairs in 2022 (Fig. 1b). This is equivalent to an annual decrease of ca. 5.5%.

Relative to trends in other regions of South Africa (Fig. 1b–c), Algoa Bay (the easternmost extent of the African penguin's breeding range) has shown the greatest decline in numbers over the past three generations. There, the population declined from ca. 23,000 breeding pairs in 1991 to ca. 3,500 in 2021, and then to ca. 2,800 pairs in 2022 (Fig. 1d). The median annual rate of decrease in the most recent generation rose to ca. 10.5%, from 6% in the previous generation. This rate of decline is even more severe than the unsustainable annual decline of 9.7% previously recorded for west coast colonies from 1999–2019. If the IUCN Red List A2 criterion (population reduction where the causes of reduction may not have ceased, may not be understood, may not be reversible) were applied specifically to Algoa Bay, this regional population would meet the threshold for listing as Critically Endangered, with 95% probability of extinction over the last three generations. Food scarcity is considered to be the main driver of the African penguin's decline, but other stress factors have been identified, including predation, disease outbreak, pollution and climate change-related factors.

Of concern is that despite the implementation of several actions in terms of South Africa's Biodiversity Management Plan for the African Penguin (BMP-AP; gazetted in 2013), the population has continued to decline, albeit at a slower rate. The BMP-AP had a five-year time frame, aiming to halt the population decline in South Africa within two years of its implementation, and after that to achieve a population growth that would result in a down-listing of the species in terms of its IUCN Red List status. Although it failed in these objectives, the BMP-AP achieved a number of its subsidiary goals and several management actions were implemented, including: (i) improved cooperative management and research; (ii) population reinforcement; (iii) improved breeding-habitat management; (iv) improved management of the captive population; and (v) experimentally closed purse-seine fishing around some key island breeding colonies on a short-term, rotational basis. The BMP-AP was reviewed recently, and the new BMP-AP will aim to: strengthen previously implemented actions; address emerging stressors such as marine traffic, ship-to-ship bunkering and petroleum exploration; enhance socio-economic benefits; and improve education and awareness.

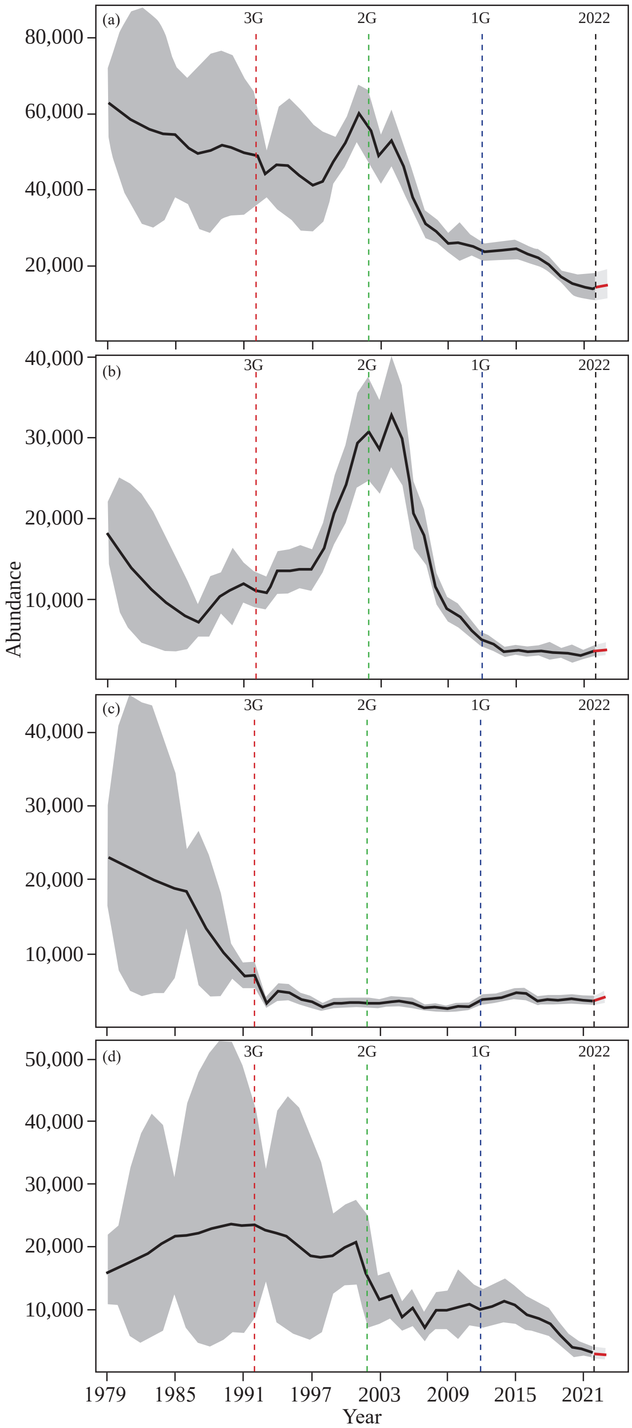

Figure 1. Changes in the African penguin breeding population over the past three generations for (a) the global population, and for three regions of South Africa: (b) the west coast, (c) the southwest coast, and (d) Algoa Bay. The solid line is the number of breeding pairs based on nest counts, the grey shading represents the 95% confidence interval, and dashed lines indicate the 10-year generation lengths up to 2022, where 1G, 2G and 3G represent 1, 2 and 3 generations back from 2022.

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

12. MESOSCALE EDDY VARIABILITY IN THE TROPICAL SOUTHEAST ATLANTIC OCEAN

Mesoscale oceanic variability plays an important role in regulating the weather and climate, as well as the ecology of the marine environment. Eddies are the most energetic physical feature within the mesoscale regime (Fig. 1), with typical length scales of 10–300 km, and time scales of days to months. Eddies trap organic and inorganic materials in their core and redistribute them through the water column, transporting them across long distances. An understanding of how eddies emerge, their spatial and temporal distribution, growth, and their evolution and decay, is essential for us to accurately predict variability in the marine environment. Using statistical measures and an automatic eddy identification algorithm applied to satellite altimetry data from 1993 to 2017, we conducted a census of eddies in the tropical southeast Atlantic Ocean, tracking them from their genesis to dissipation (Fig. 1).

The eddy demography reveals a north-to-south increase of their population in the region (Fig. 1). In the Angola Basin, eddies are short-lived, with 73.5% of them dissipating within 30 days (Fig. 1a), whereas in the Cape Basin off Namibia, long-lived eddies dominate (Fig. 1c). This pattern of an equatorward decrease of the eddy population has been attributed to a regime transition within the mesoscale range, characterised by a sharp shift in the prevailing physical processes, which change from eddy domination in the south to planetary Rossby wave domination in the north. Oceanic Rossby waves are slow-moving, large-scale undulations of the ocean that differ from waves that break along the shore in that they are undetectable to the human eye.

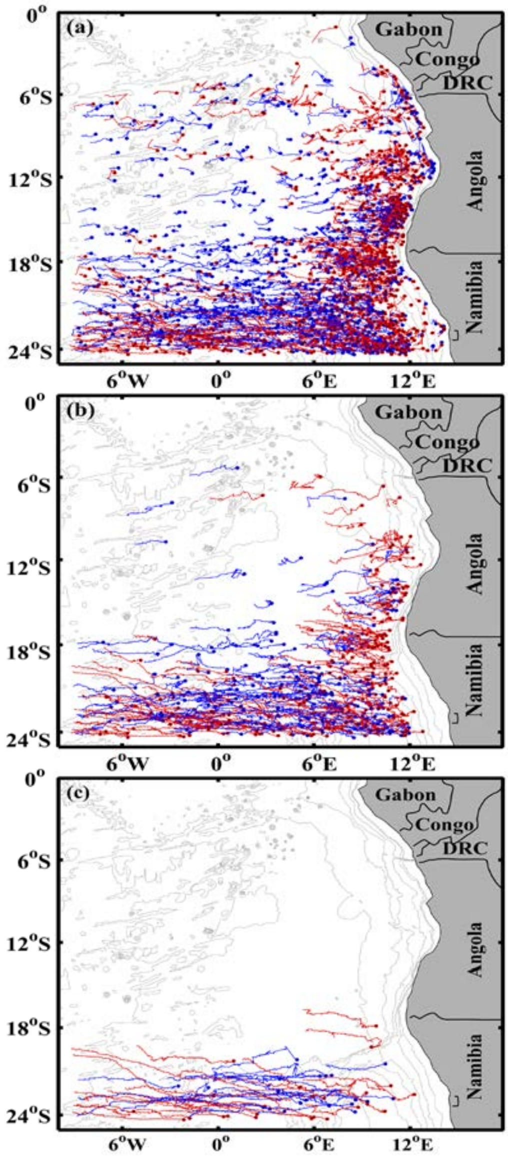

Figure 1. Satellite-derived eddy distributions from 1 January 1993 to 31 December 2017. Blue tracks are cyclonic eddies (clockwise rotating) and red tracks are anticyclonic (anticlockwise rotating). The panels show eddies that lived (a) more than 7 days, (b) more than 30 days, and (c) more than 120 days.

The mesoscale variability (Fig. 2) is more strongly impacted by seasonality in the Angola Basin than in the Cape Basin off Namibia, indicating that seasonality is an important forcing mechanism to be considered when investigating eddy variability. Eddies in the south travel longer distances offshore (Fig. 1). Also, their strong nonlinearity (i.e. rotational speed exceeds translation speed) indicates that they have relatively higher capacity to trap and advect water masses and biota. This suggests that the mesoscale eddies may have different impacts on the biological processes and marine productivity between the Angola Basin and the Cape Basin. Indeed, chlorophyll *a* concentrations retained within these mesoscale features (not shown here) supports this. Similar investigations of the interactions of mesoscale eddies with marine ecosystems should be expanded to the southern Benguela region and the Agulhas Current system, to determine whether similar latitudinal variations occur in these areas.

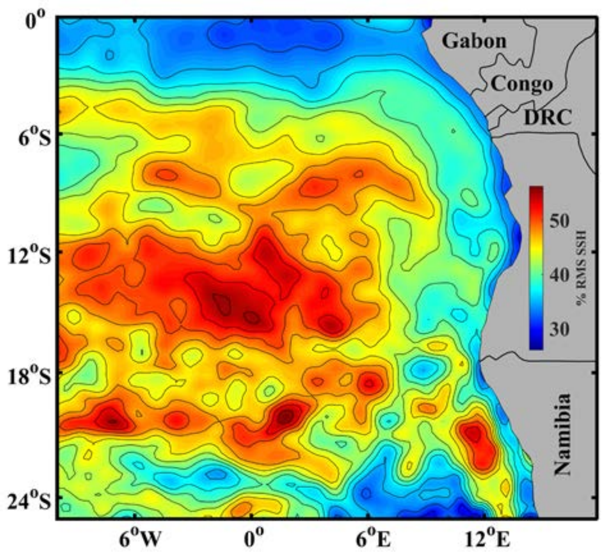

Figure 2. Mesoscale variability of Sea Surface Height (SSH), from 1 January 1993 to 31 December 2017, estimated from the difference between SSH with and without seasonality included in the data, expressed in percentage.

Authors: Halo I (OC Research); Raj R, Korosov A (NERSC); Penven P (IRD); Johannessen J (NERSC); Rouault M ✝ (NTC)
Contributor: Tutt GCO (OC Research)

13. THE KWAZULU-NATAL BIGHT COASTAL COUNTER CURRENT: A MODELLING STUDY

The KwaZulu-Natal (KZN) Bight is an embayment off South Africa's east coast, covering roughly 140 km of coastline between 29°S and 30°S (Fig. 1). Its offshore edge is influenced by the strong southwestward-flowing Agulhas Current, while the shelf is dominated by weak and variable currents. As a result, the KZN shelf forms a suitable spawning ground for a wide range of species. Previous studies of the circulation in the Bight used spatially and temporally limited data that primarily provided information about the surface circulation. In this study, we used output from a realistic high-resolution (2.5 km) hydrodynamic model, together with a wind reanalysis product, and a particle tracking tool, to improve our understanding of the shelf circulation across the KZN Bight.

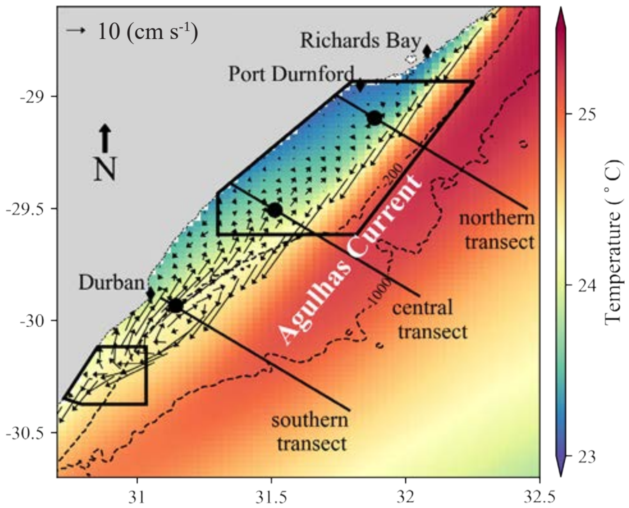

Figure 1. A map of the modelled mean surface circulation and surface temperature of the KZN Bight, from January 2005 to December 2014. The three black lines indicate the transects displayed in Figure 2 and the black dots mark the points with the most frequent northeastward flow along each transect. Current vectors (arrows) are only shown on the shelf for speeds less than 30 cm s^{-1}. The dotted contour black lines indicate the 200 m and 1,000 m isobaths, and the two black polygons represent the uThukela Banks (north of Durban) and Aliwal Shoal (south of Durban) Marine Protected Areas.

On the shelf, model simulations indicated the presence of a mean northeastward flow (Fig. 1), which we named the Natal Bight Coastal Counter Current (NBC3). This current flows parallel to the coast and extends from the southern to the northern section of the Bight, becoming progressively narrower and weaker toward the north. The NBC3 extends throughout the water column, and at its origin off Durban (Fig. 1) it almost connects with the Agulhas Undercurrent (Fig. 2). In this region, the NBC3 is about 20 km wide and has an average speed of 20 cm s^{-1} at its core, which may occasionally exceed 100 cm s^{-1}.

The passage of southward-propagating anticyclonic eddies offshore of the Agulhas Current is associated with a southward flow on the southern part of the shelf, interrupting the otherwise northeastward currents. While the circulation across the shelf is primarily driven by perturbations at the inshore edge of the Agulhas Current, there is also some indication that coastal waters, particularly north of 29.5°S, are directly influenced by the wind.

Virtual particle tracking experiments show that the NBC3 increases the water retention within the KZN Bight. As a result, the residence times within the uThukela Banks Marine Protected Area (MPA) are also increased (Fig. 1). However, the NBC3 may also increase the connectivity between MPAs in this region. This may trap nutrients from coastal origins on the shelf, together with any suspended particles, such as larvae. Therefore, the NBC3 has the potential to increase the suitability of this habitat for larval settlement.

Authors: Heye S (UCT); Krug M (OC Research)

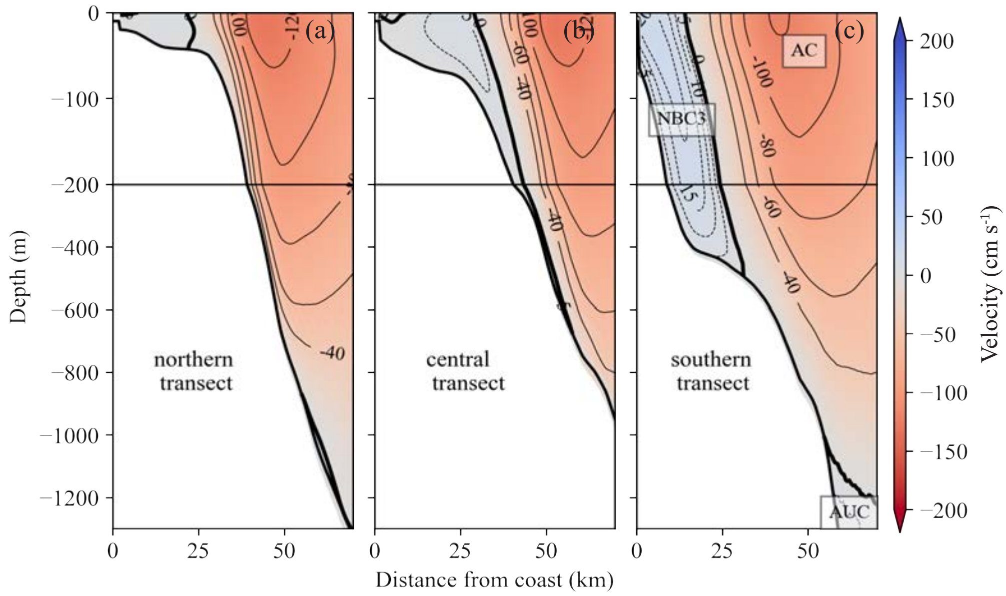

Figure 2. Modelled vertical sections of the 10-year mean current velocities across the (a) northern, (b) central, and (c) southern transects illustrated in Figure 1. The bold black contours show the transition between northeastward (positive) velocities shown in blue and southwestward (negative) velocities shown in red. The thinner solid black contours indicate southwestward velocities, while the thinner dotted black contours indicate northeastward velocities. The Agulhas Current (AC), the Agulhas Undercurrent (AUC), and the Natal Bight Coastal Counter Current (NBC3) are labelled.

14. BATHYMETRY OBSERVATIONS AT THE PRINCE EDWARD ISLANDS

Bathymetry refers to "seabed topography," depicting the terrain of the sea floor. Bathymetric data are most commonly used to produce nautical charts for safe maritime navigation, but scientists use such data for various other applications. These include: mapping of ocean currents; creating ocean models for researching, monitoring and forecasting the properties of the ocean; determining oceanographic mooring deployment locations; mapping habitats of benthic biota; mapping of sediment and glacial deposits; and monitoring climate change/variability impacts, including beach erosion, sea level rise and subsidence.

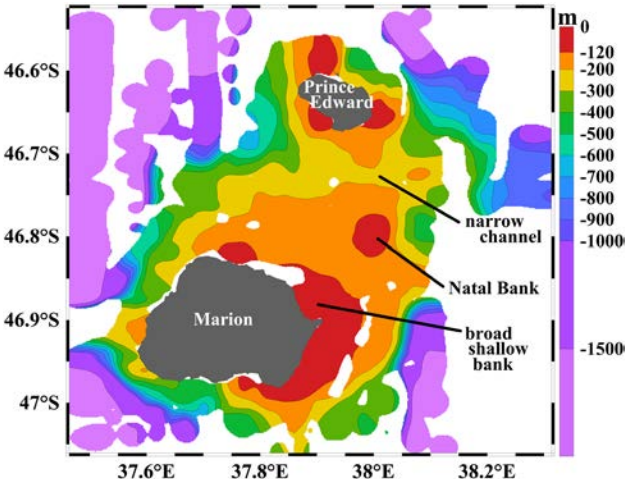

Figure 1. *In situ* bathymetry around the PEIs, consisting of Prince Edward Island and Marion Island. White shading indicates areas of no data.

Bathymetric data are typically obtained from measurements made using multibeam echo sounders, mounted either below or over the side of vessels. Such data are not widely available in remote ocean regions such as the Southern Ocean, thus many studies rely on satellite- and/or model-derived bathymetry products to illustrate and examine variations in bottom depth. However, as we demonstrate here, such products are not always accurate or suitable.

Since 2013, DFFE has been conducting *in situ* sampling at the Prince Edward Islands (PEIs; Fig. 1) in the Southern Ocean, during annual re-supply cruises of the SA *Agulhas* II research vessel. During these cruises, CTD and Ship-mounted Acoustic Doppler Current Profiler (S-ADCP) data are collected to monitor vertical variations in water column structure. The CTD is equipped with an altimeter able to detect the bottom of the ocean when in close range. When used together with CTD pressure sensor data, the altimeter observations can be used to accurately determine the ocean floor depth. The S-ADCP can detect the bottom when set to sample additional bottom tracking pings in shelf regions shallower than ± 700 m. The SA *Agulhas* II is also equipped with scientific transducers operating at 38, 120, and 200 kHz, which can detect the ocean floor when within range. We used existing CTD, S-ADCP and scientific transducer data to develop a map of the sea floor around the PEIs (Fig. 1), providing a useful high spatial resolution *in situ* data source against which satellite/model bathymetry (Fig. 2) can be compared.

The outputs from four bathymetric models were examined (Fig. 2). We expected the higher spatial resolution of such data to yield more accurate spatial variations in the bathymetry (see Report Card number 27), but this was not observed. The ETOPO1 model shows a small island east of Prince Edward Island, while GEBCO2021 shows a "hole" just north of Marion Island, deeper than 1,500 m. These features are confirmed as errors when compared with *in situ* data and from field experience in this region. The Natal Bank (Fig. 1) is not captured by ETOPO1 but is observed in the three GEBCO products. *In situ* data displays a narrow channel, >200 m deep, incising the shelf from west to east, which satellite products fail to capture accurately. The satellite products show a channel, >500 m deep, along the northeastern edge of Marion Island, but *in situ* data shows a broad, shallow bank <120 m in depth.

Satellite/model product inaccuracies arise due to erroneous interpolation of minimal data with overall poor quality and coarse spatial resolution. Given the importance of bathymetry as a key input for defining locations for moored deployments of oceanographic instruments and many other applications, it is vital to have accurate bathymetric data. Systematic bathymetry surveys of the area are thus recommended as urgent, to improve *in situ* data coverage.

Authors: Soares BK (UCT); Lamont T, van den Berg MA, Tutt GCO, Halo I (OC Research); Hedding D (UNISA); Nel W (UFH)

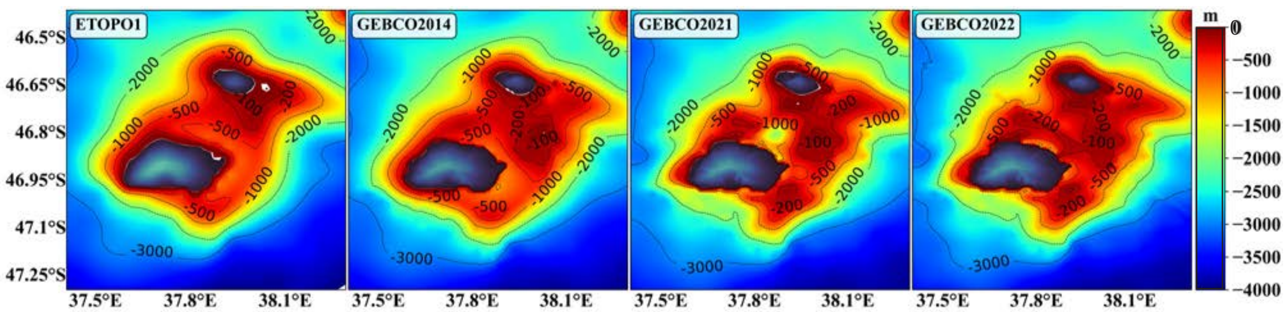

Figure 2. Satellite/model-derived bathymetry around the PEIs. ETOPO1 (1 Arc-minute; ca. 2 km resolution Global Relief Model) was produced in 2009, while the General Bathymetric Chart of the Oceans (GEBCO) datasets were produced in 2014 (GEBCO2014; ca. 1 km resolution), 2021 (GEBCO2021; ca. 0.5 km resolution) and 2022 (GEBCO2022; ca. 0.5 km resolution), respectively.

15. DECADAL VARIABILITY IN SURFACE HYDROGRAPHY AT THE PRINCE EDWARD ISLANDS

In the Southern Ocean, the sub-Antarctic Prince Edward Islands (PEIs) (Fig. 1) play a significant ecological role by hosting large populations of seasonally breeding marine mammals and seabirds. Individuals of these populations are sensitive to changes in the surrounding ocean environment. For example, the spatial distribution of the prey on which these mammals and seabirds feed may be affected by changes in water temperature, which in turn can be simultaneously driven by a number of oceanic and atmospheric factors. To better comprehend the links between these biotic and abiotic factors, a good understanding of the oceanic environment at the PEIs is needed. We examined satellite data to highlight decadal changes in Sea Surface Temperature (SST), wind speed, and geostrophic current speed at the islands

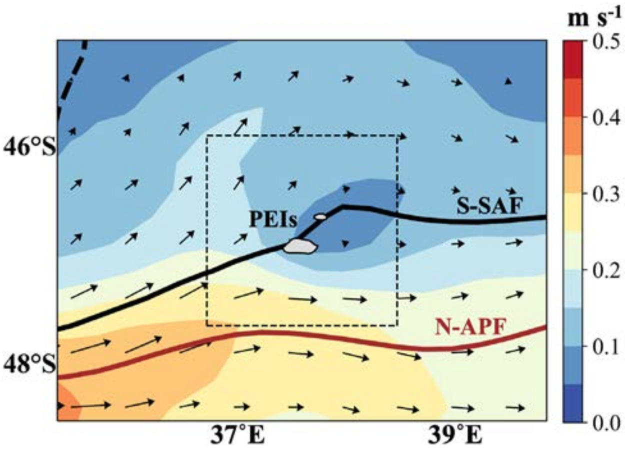

Figure 1. Geostrophic current speed (colour and vectors) around the PEIs. Solid black and brown lines represent the long-term mean positions of the southern branch of the sub-Antarctic Front (S-SAF) and the northern branch of the Antarctic Polar Front (N-APF), respectively. The dashed black box highlights the 2° x 2° area over which the satellite data in Figure 2 were averaged.

To accentuate decadal-scale variability, we computed 5-year running means of each parameter (Fig. 2), averaged over a 2° x 2° area centred over the islands (Fig. 1). Current speeds displayed an inverse relationship with SST, whereby stronger speeds were associated with lower SST, while weaker speeds were linked to higher SST (Fig. 2a). A strong negative correlation ($r = -0.89$, $p < 0.001$) was clear between SST and current speed from 1996 to 2020.

For the same period, the correlation between wind speed and SST was weak ($r = -0.08$, ns). When considering the full time series (1984–2020), there was a general inverse relationship between the parameters (Fig. 2b). This relationship appeared to break down during 1991–2001 when a positive correlation ($r = 0.378$, $p < 0.01$) was observed. During the post-2001 period, the inverse relationship was substantially stronger ($r = -0.64$, $p < 0.001$), although still weaker than that between current speed and SST. This suggests that decadal variations in SST at the PEIs were more strongly associated with changes in surface currents, while wind speed variability was of secondary importance.

Since 2015, the oceanic environment at the PEIs seems to be in a state of lower temperatures, associated with elevated geostrophic current and wind speeds. While the lower temperatures likely promote a more productive ecosystem with increased prey availability, the stronger current and wind speeds can be expected to result in stronger advection of water, and hence prey, away from the islands. This suggests that mammals and seabirds breeding at the PEIs may need to travel further to be able to exploit the elevated productivity. Additional research is required to determine the relationships between environmental variability, ecosystem productivity, and the foraging patterns of mammals and seabirds breeding at the PEIs.

Authors: Toolsee T (UCT); Lamont T (OC Research)

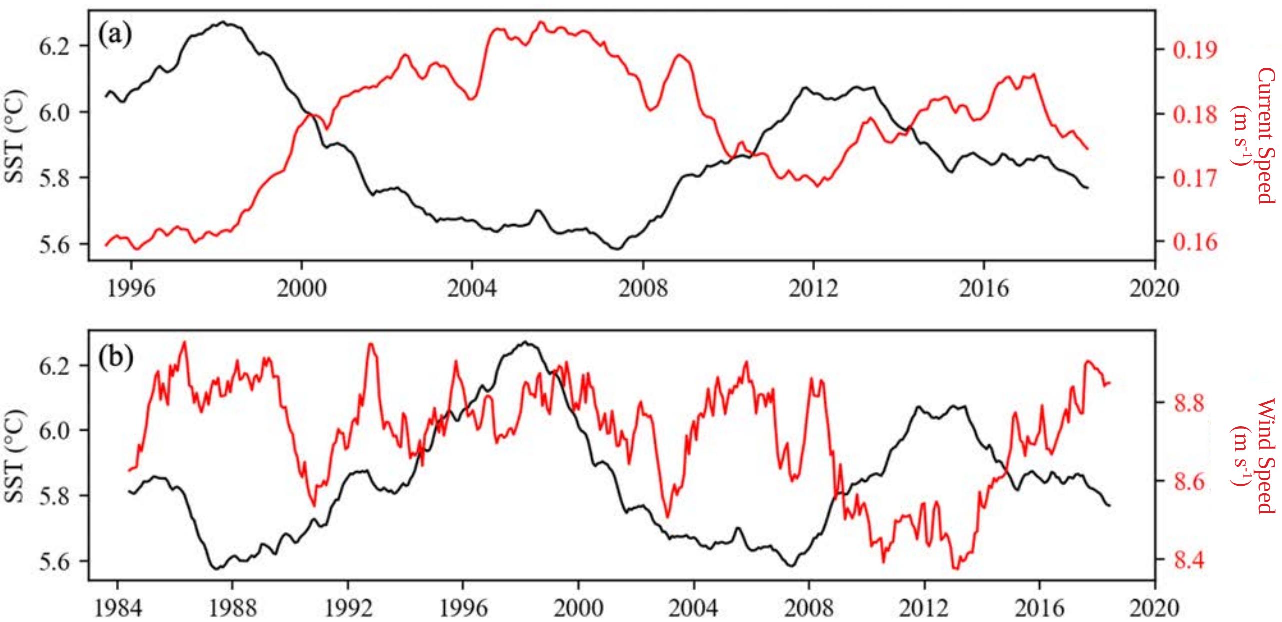

Figure 2. Time series of the 5-year running means of (a) SST (°C; black) and geostrophic current speed (m s^{-1}; red), and (b) SST (°C; black) and wind speed (m s^{-1}; red). Note the different x-axes, reflecting the different lengths of available time series data.

16. VERTICAL CHLOROPHYLL *A* PATTERNS AT THE PRINCE EDWARD ISLANDS

Most of the Southern Ocean is characterised by persistent high nutrient, low chlorophyll *a* (chl *a*) concentrations. An exception to this is the Prince Edward Islands (PEIs) ecosystem where elevated plankton biomass supports productive biological communities. Despite a long history of oceanographic research at the PEIs, sampling has been mainly restricted to April–May each year for logistical reasons, resulting in poor knowledge of the seasonal variations in local plankton variability. Here, we illustrate vertical chl *a* profiles derived from fluorescence sensors on Conductivity-Temperature-Depth (CTD) systems. We contrast profiles collected during autumn (April–May) from 2013–2022 on the SA *Agulhas* II with historical observations from the FRS *Africana* in summer (December) 2008, to describe vertical chl *a* patterns in the region (Fig. 1).

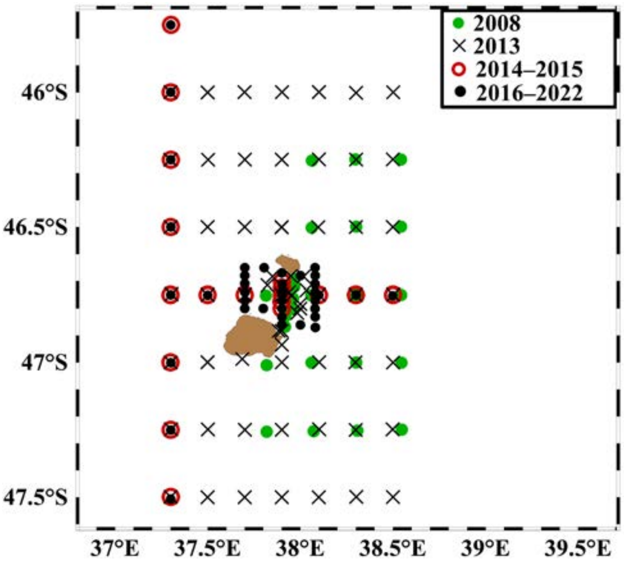

Figure 1. Map of sampled CTD stations at the PEIs, between 2008 and 2022.

During summer, the mean upper mixed layer depth was 61 m, while it varied between 9 and 15 m during autumn 2013–2022. In contrast, elevated chl *a* was evident throughout the upper 100 m during both seasons, and sometimes extended to depths of 200 m. Mostly, chl *a* concentrations were <1.4 mg m^{-3} (Fig. 2), except in 2018 when values as high as 3 mg m^{-3} were measured in the surface layers. Whereas the CTD was deployed over the side during most surveys, in 2013 and 2014, it was lowered through the vessel's moonpool, resulting in fluorescence data loss in the upper 10 m.

During all cruises, numerous daytime profiles were affected by non-photochemical quenching (orange profiles; Fig. 2). This is a process that occurs when phytoplankton are exposed to high light conditions, leading to severe underestimation of chl *a* in the surface layers. It often results in the appearance of subsurface chl *a* maxima, even when none actually exist. Notably, many daytime profiles did not exhibit surface quenching (green profiles; Fig. 2). While quenching is generally greatest around local noon, our data indicated no clear distinctions for the time of day for profiles showing quenching compared to those that did not. It is also important to note that many profiles, unaffected by quenching, showed clear subsurface maxima during both day and night.

To date, there are no observations of vertical chl *a* patterns at the PEIs during winter or spring, thus we are unable to describe the seasonal cycle of chl *a* through the water column. Since phytoplankton form the base of the food-web at the PEIs, it is vital to improve our understanding of the vertical distribution, as well as the seasonal and inter-annual variations, in this component of the ecosystem. Substantial investment in moored technologies and other autonomous platforms will be required to realise this.

Authors: Lamont T, Tutt GCO, van den Berg MA (OC Research)

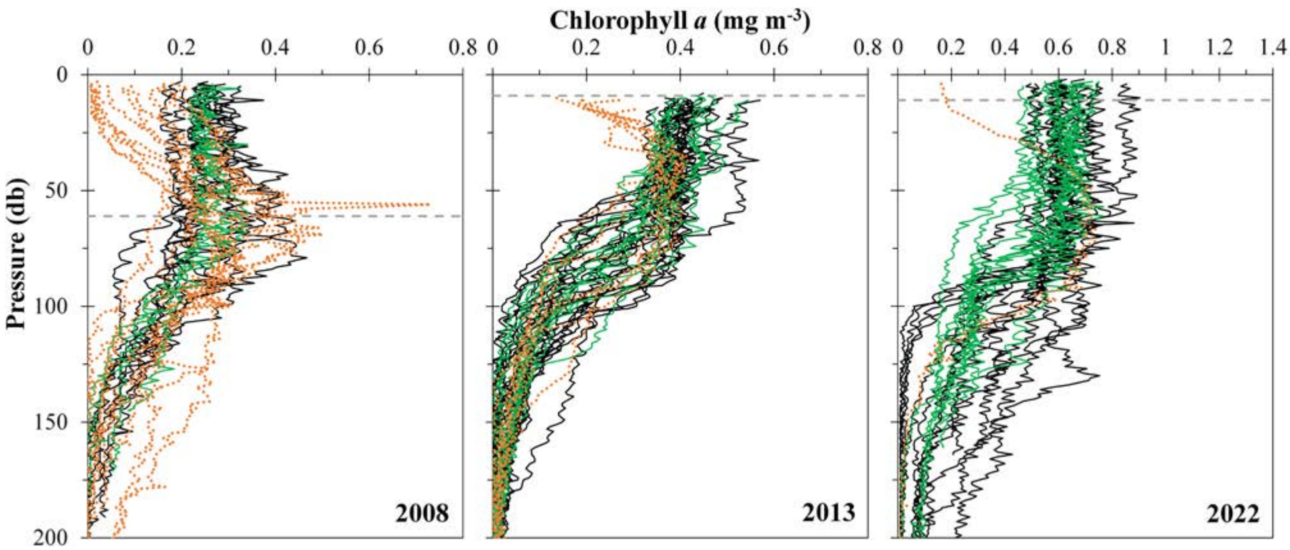

Figure 2. Vertical profiles of chlorophyll *a* for selected cruises during December 2008, April–May 2013 and April–May 2022. Daytime profiles not affected by non-photochemical quenching are shown in green, while those affected by quenching are shown as dotted orange lines. Night-time profiles are indicated in black. The grey dashed horizontal lines show the mean upper mixed layer depths during the respective cruises. Note the different x-axis scales for the various cruises.

17. PHYTOPLANKTON ABUNDANCE AND COMMUNITY COMPOSITION INSHORE AND OFFSHORE OF PLETTENBERG BAY

The functional role of marine phytoplankton in coastal bay productivity is a relatively under-explored area of study in South Africa. Although remote-sensing techniques are convenient for identifying biomass blooms in coastal areas, the datasets they produce often do not accurately indicate the taxonomic groups that make up coastal bay communities. Whereas boat-based studies are often expensive and limited by weather conditions and time constraints, they are necessary to obtain *in situ* biological samples for species identification. In this study, phytoplankton samples were collected and analysed to describe the abundance and community composition of marine phytoplankton in Plettenberg Bay, and to compare inshore and offshore populations.

In October 2021, water samples were collected on board a small motorboat in the coastal area of Plettenberg Bay. Four sites (two inshore and two offshore) were sampled on six different days (18th, 19th, 22nd, 24th, 25th and 31st October; Fig. 1). Surface temperature and salinity measurements were made using a CTD. The water samples were preserved with 2% Lugol's iodine after collection and placed into dark storage. An inverted light microscope was used to count the cells present and to identify them to their lowest taxonomic level possible.

The inshore region was dominated by centric diatoms (77%); mostly *Coscindodiscus* spp. and *Chaetoceros* spp. (Fig. 2a). The offshore region was dominated by small chlorophyte flagellates (52%) and pennate diatoms (42%), mainly *Pseudo-nitzschia* spp. (Fig. 2a). Phytoplankton abundance was significantly higher offshore compared to inshore (Fig. 2b). Surface salinity showed a small but significant difference between the sites, with a lower salinity inshore. This suggests a small influence of freshwater input at the inshore stations, possibly from the Keurbooms estuary (Fig. 1).

Centric diatoms are generally larger in size compared to pennate diatoms and chlorophytes, and have a small surface area-to-volume (SA:V) ratio. In this study, large cells (with a small SA:V ratio) dominated the inshore region, an area of high nutrient availability from land-based sources. The lower salinity inshore suggests a possible freshwater source of nutrients into the coastal system. Small cells (with a large SA:V ratio) appeared to occupy the offshore region where nutrient concentrations are somewhat lower. This study supports observations made from previous literature highlighting successions in phytoplankton communities in response to nutrient availability. Also, it provides a baseline from which further research can be carried out in the Plettenberg Bay area. A better understanding of phytoplankton dynamics in coastal bays will help to improve the scientific understanding of the role these bays play toward ecosystem functioning along the South African coastline.

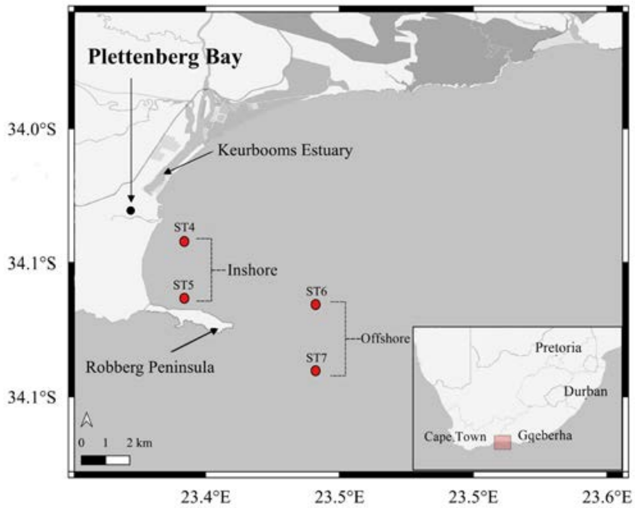

Figure 1. Study area with inshore and offshore stations.

Authors: Kupczyk A (OC Research and CPUT); Walker DR (CPUT)
Contributors: Findlay K, Kieswetter N, Buthelezi A, Mabalabala O (CPUT)

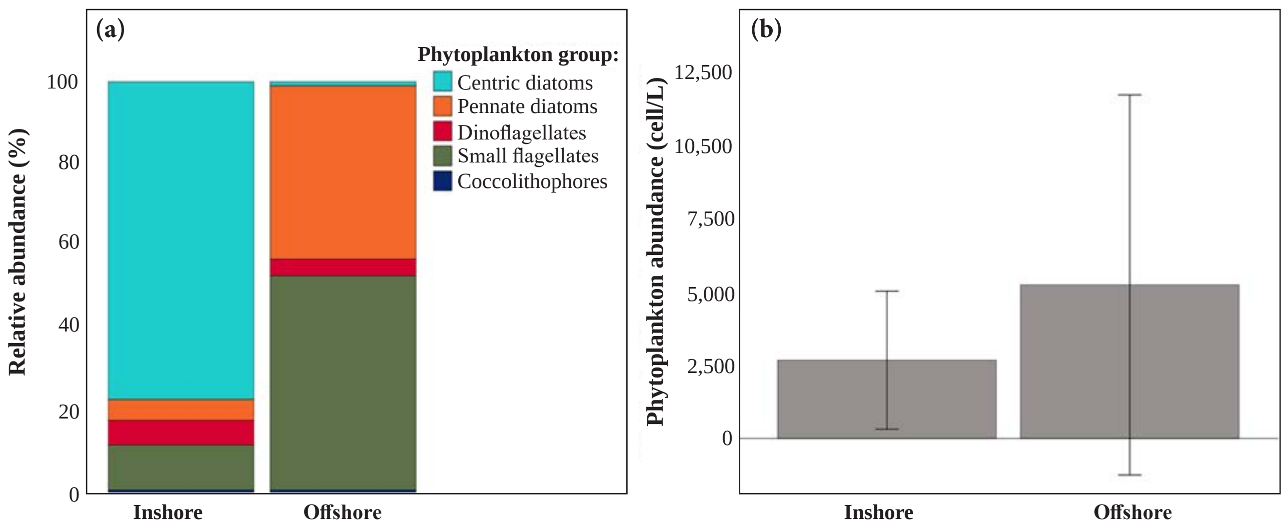

Figure 2. (a) Relative cell abundance (%), and (b) phytoplankton abundance (cells/Litre) at the inshore and offshore sites. Error bars represent 95% confidence intervals.

18. THE ESTABLISHMENT OF A CONTINUOUS PLANKTON RECORDER TRANSECT BETWEEN BRAZIL AND SOUTH AFRICA

The AtlantECO Project is a European Union Horizon 2020 research and innovation programme# focused on studying the Atlantic Ocean from pole to pole. The project aims to examine the structure and function of marine microbiomes in the context of ocean circulation, and to document the presence of microplastics and the plastisphere (microbial communities that grow on plastic debris). A key objective was to establish a sustainable Continuous Plankton Recorder (CPR) route between Brazil and South Africa. The CPR is a well-known subsurface (ca. 10 m depth) plankton sampler, ideal for towing over large distances from merchant ships on their normal trading routes. Four CPR transects were conducted between Brazil (25°S) and South Africa (35°S) during 2021–2022, a distance of 3,500 nautical miles (NM) per transect (Fig. 1). The first was in October 2021, followed by transects in January, July and December 2022. Samples from the first set of tows have now been analysed in Brazil.

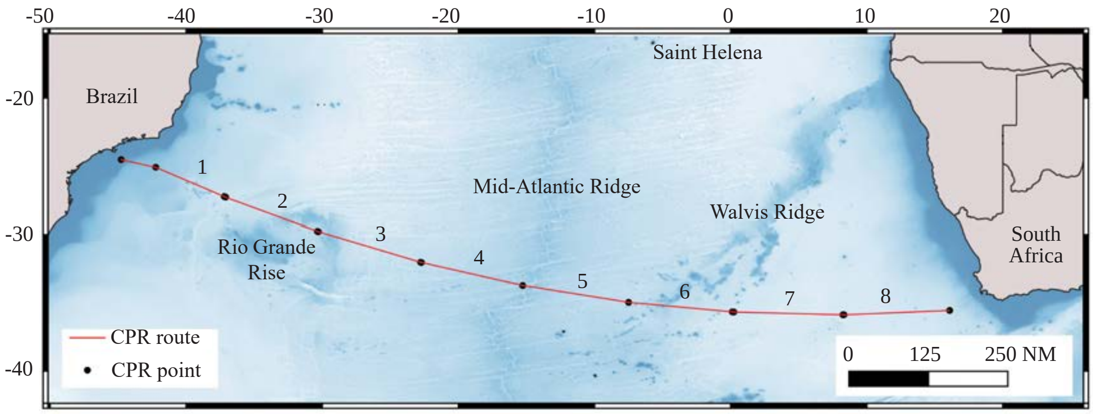

Figure 1. First CPR transect across the south Atlantic between Brazil and South Africa during October 2021. The transect comprised eight separate tows, numbered 1 to 8. CPR points are the locations where the CPR was deployed or retrieved, including to exchange the silk-bearing cassettes.

Total zooplankton abundance varied across the basin, being lowest in the Rio Grande Rise (RGR) and Mid-Atlantic (MA) regions ca. 5 ind. m^{-3}), and highest in the Walvis Ridge (WR) region, reaching 35 ind. m^{-3} (Fig. 2a). Copepods were most abundant, followed by chaetognaths, euphausiids and foraminiferans (Fig.2b). Samples collected between the Brazilian coast and the RGR were most diverse (six major zooplankton groups found; Fig. 2b). The MA region comprised mostly copepods and chaetognaths. Five major groups were found in the WR region, which also had the highest number of species, with copepods *Neocalanus tonsus* and *Pleuromamma piseki* being most abundant.

Microplastic fibers (blue and red) were most abundant in the RGR region off the Brazilian coast (Fig. 2c). Data collected during this project will help to identify biodiversity and plastic pollution hotspots at the basin-scale, and improve understanding of ecosystem structure, function, health and services of the Atlantic Ocean as a whole. The long-term vision of AtlantECO is to design policies, support decision-making, and encourage responsible behaviour to manage the Atlantic system and protect its provision of ecosystem services.

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Grant agreement No. 862923

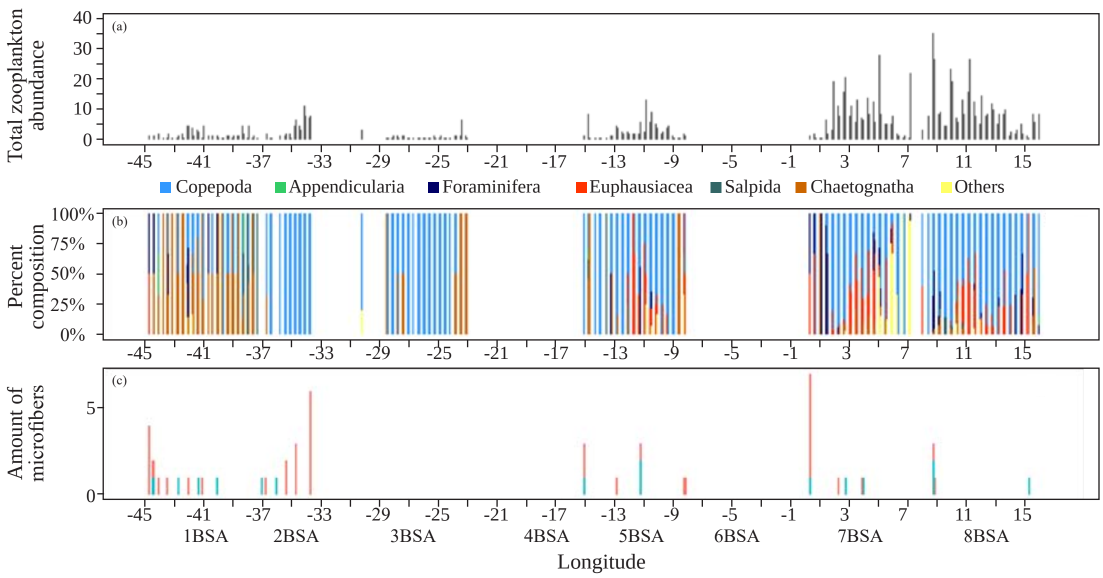

Figure 2. (a) Total zooplankton abundance (ind. m^{-3}); (b) percentage (%) of major zooplankton groups; and (c) amount of plastic microfibers (no.) recorded across the South Atlantic during the first CPR tow in October 2021. Gaps in the data reflect faulty tows. Labels 1BSA to 8BSA denote the tow number along the Brazil-South Africa (BSA) route (see Fig. 1).

19. COPEPOD BIOMASS AND SPECIES COMPOSITION ON THE AGULHAS BANK

Copepods dominate the zooplankton community on the Agulhas Bank (AB) off South Africa, where they provide an important food resource for pelagic fish and other biota. Studies have shown that the copepod *Calanus agulhensis* is strongly associated with the productive cold ridge of upwelled water on the central and eastern AB (Fig. 1), comprising up to 80% of copepod biomass. However, little is known about other copepod taxa and community composition fluctuations over time in response to environmental variability or other ecosystem changes. To address this question, zooplankton samples collected annually in late spring were analysed to explore spatiotemporal variability in copepod biomass and species composition over a 24-year period (1988–2011) on the AB.

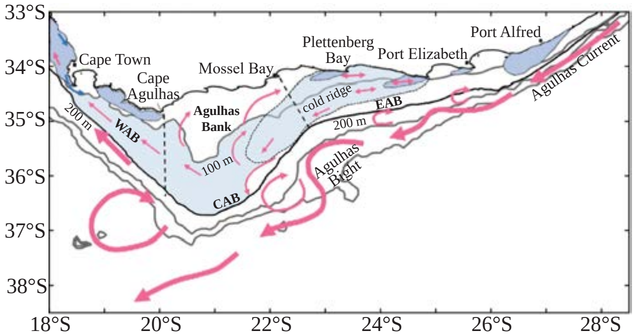

Figure 1. Schematic of circulation features influencing the Agulhas Bank. Darker blue areas indicate main upwelling areas, and light blue area indicates approximate location of the cold ridge. Dashed lines separate the western (WAB), central (CAB) and eastern Agulhas Bank (EAB).

Total copepod biomass was concentrated on the outer central and eastern shelf (>100 m), coincident with a region of elevated chlorophyll *a* (chl *a*) at 30 m, largely downstream from the cooler subsurface water of the cold ridge and coastal upwelling (Fig. 2a). Eight taxa, along with large calanoid nauplii larvae), collectively comprised 94% of the total copepod biomass. The predominantly herbivorous *C. agulhensis* (Fig. 2b) and small calanoids (Paracalanidae and Clausocalanidae; Fig. 2c) comprised 73%, driving the observed pattern for total biomass. The upwelling specialist *Calanoides natalis* was associated with shelf-edge upwelling, particularly near the Agulhas Bight (Fig. 2d), but was low in biomass compared to the Benguela upwelling system on the west coast of South Africa. The detritivores *Metridia lucens* (Fig. 2e) and *Oncaea* spp. (Fig. 2f) were concentrated in the western sector but showed different niche preferences. *Metridia lucens* inhabited the chl-rich outer bank of the WAB, a continuation of the Benguela community, while *Oncaea* spp. were associated with deep thermoclines where swarms of their gelatinous prey (e.g. salps) often occur. Omnivorous ambush feeders, *Centropages* spp. (Fig. 2g) and *Oithona* spp. (Fig. 2h), were mostly inshore of the main influence of the Agulhas Current. *Centropages* spp. on the inner WAB were also likely an extension of the Benguela community (*C. brachiatus*). Deep vertical migrators *Pleuromamma* spp. (Fig. 2i) were concentrated beyond the WAB shelf edge.

Total copepod biomass declined significantly over the time series, mainly due to declining biomass of *C. agulhensis* and the small calanoids. This decline was likely due to increased predation by pelagic fish. No trends were observed for the other taxa, but long-term warming from climate change is expected to reduce the overall size and biomass of the copepod community, and hence ecosystem productivity on the AB.

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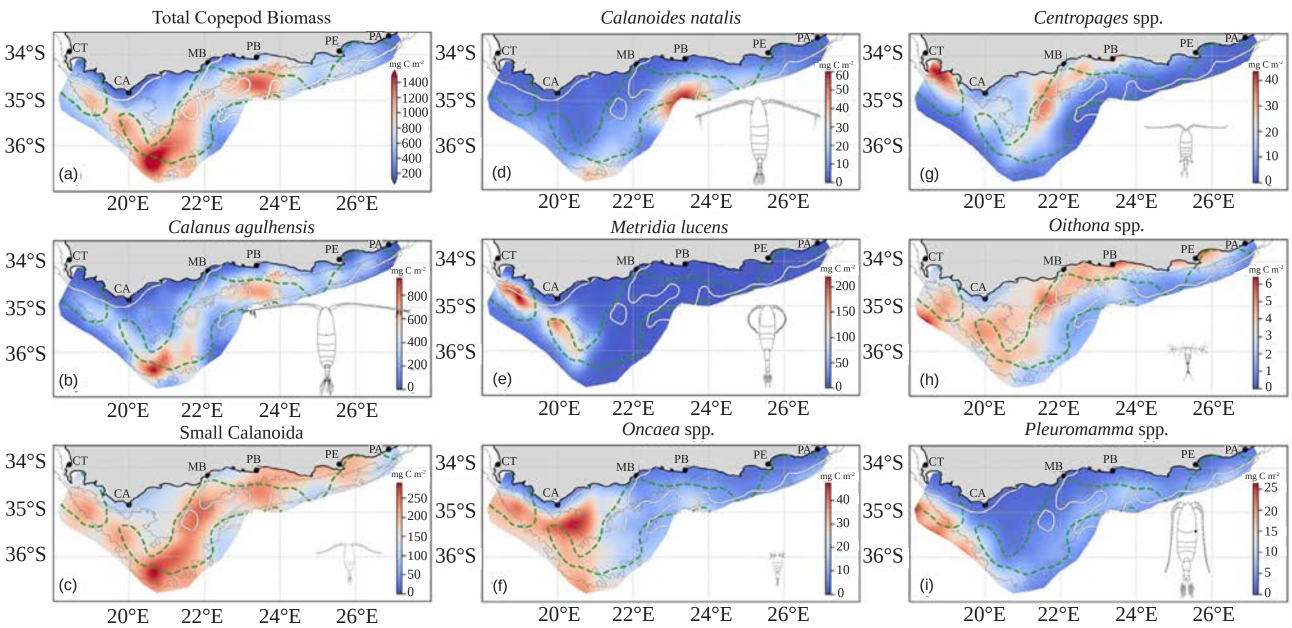

Figure 2. Long-term mean biomass (mg C m^{-2}) and, (b–i) dominant copepod taxa on the Agulhas Bank. Line drawings of female copepods indicate relative sizes. The solid white line represents the mean 17°C isotherm at a depth of 30 m, and the dashed green line indicates the mean 0.9 mg m^{-3} chlorophyll *a* isoline at 30 m depth. CT = Cape Town, MB = Mossel Bay, PB = Plettenberg Bay, PE = Port Elizabeth (now Gqeberha).

20. MICROPLANKTON ABUNDANCE AND DIVERSITY ALONG THE EAST COAST OF SOUTH AFRICA

Microplankton are a diverse group of phyto- and zooplankton in the size range of 20–200 µm. They occupy key roles in ecosystems, notably in regulating ocean productivity, carbon export and food web dynamics. The east coast of South Africa is characterised by a shelf that is narrow in the north and broadens southward (Fig. 1). The shelf environment is influenced by the Agulhas Current, which not only plays an important role in global heat circulation and climate variability, but also greatly influences local biological communities. Microplankton are highly sensitive to environmental variations, and therefore characterising their abundance and diversity can provide key insights into the effects of a changing climate.

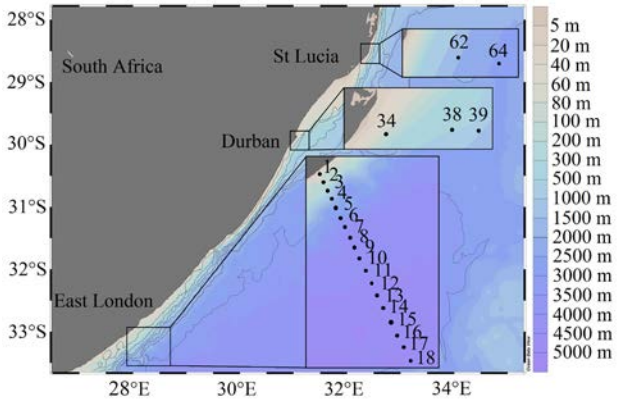

Figure 1. Bathymetry map indicating the locations of sampling stations off St. Lucia, Durban and East London. Station numbers are indicated above each station.

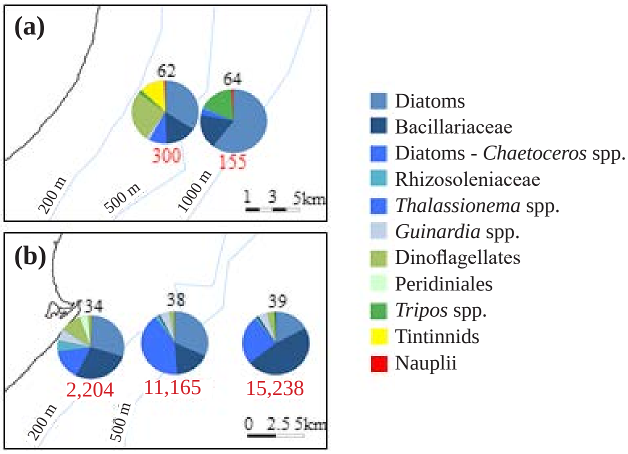

Figure 2. Microplankton diversity off (a) St. Lucia, and (b) Durban. Station numbers are indicated in black and total abundance (no. L^{-1}) is indicated in red.

In January 2018 (summer), microplankton sampling took place aboard the RV *Dr Fridtjof Nansen* off East London, Durban and St. Lucia (Fig. 1). During July 2018 (winter), the SA *Agulhas* II was used to collect samples off East London. Microplankton were identified either to group or species level, and their abundance was quantified as the number of organisms per litre of seawater.

Total microplankton abundance (no. L^{-1}) in January 2018 was higher off Durban than St. Lucia and increased from inshore to offshore, where Bacillariaceae (a group of diatoms consisting of *Pseudo-nitzschia* spp.) accounted for ca. 50 % of the total abundance (Fig. 2). At St. Lucia, total abundance decreased from inshore to offshore, with tintinnids occurring only inshore (Fig. 2).

In July 2018, abundance increased from inshore to offshore at East London (Fig. 3), with the lowest abundance observed along the 2,000 m isobath (ca. Station 7). Nauplii were most prevalent inshore during both January and July (Fig. 3). Diatoms were dominant in all areas during both January and July, although their species composition differed among the sites (Figs. 2 and 3). *Chaetoceros* spp. were generally the most abundant diatoms, except at St. Lucia (Figs. 2 and 3).

Despite their importance, microplankton have traditionally not been well studied. This study provides a snapshot of their presence at key locations on the east coast. A changing climate can lead to changes in microplankton community structure and diversity, in response to varying levels of nutrients and light. Some species (e.g. *Pseudo-nitzschia*) release toxins that are harmful to humans and other marine life. Further monitoring is advised to understand the longer-term variability of microplankton and their impacts on ecosystem productivity in this region.

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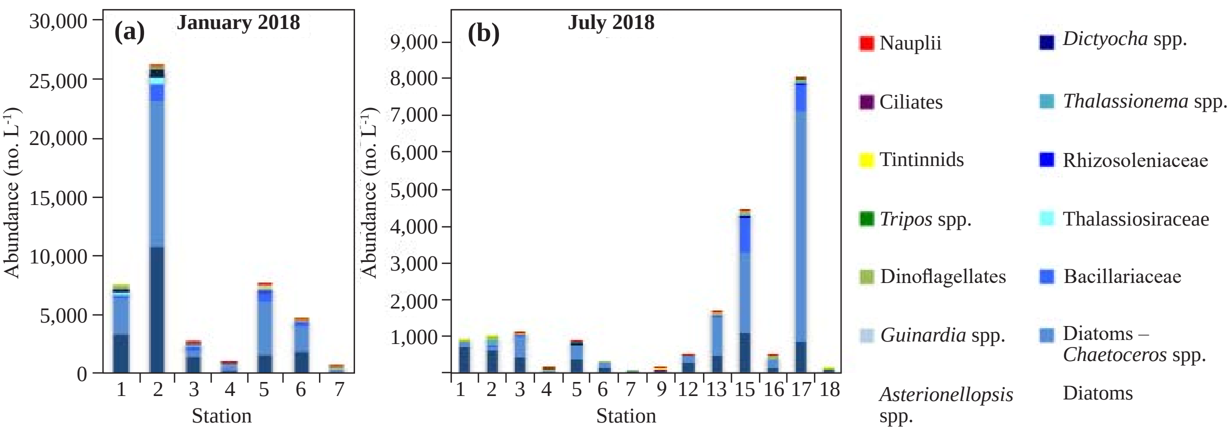

Figure 3. Microplankton abundance (no. L^{-1}) and diversity off East London in (a) January 2018 (summer), and (b) July 2018 (winter).

21. MICROZOOPLANKTON ON THE SHELF AND IN AN EDDY OFF SOUTHERN MADAGASCAR

Microzooplankton are small (20–200 µm) planktonic animals such as ciliates, dinoflagellates, foraminiferans, radiozoans and larval crustaceans. These organisms play a key but largely understudied role in marine ecosystems as primary consumers of phytoplankton, food for mesozooplankton, and nutrient recyclers. Mesoscale eddies have a strong structuring effect on biological production by injecting nutrients into the euphotic zone (the ocean layer receiving enough sunlight for photosynthesis to occur). They can also entrain and transport entire plankton communities from shelf environments into the open ocean. We used image analysis (Fig. 1) to compare the abundance and composition of microzooplankton in a month-old cyclonic eddy that had originated off southern Madagascar, with the plankton community over the Madagascan shelf (Fig. 2). At each station, water samples were collected from the surface and depth of maximum fluorescence (fmax), i.e. the depth of greatest chlorophyll concentration.

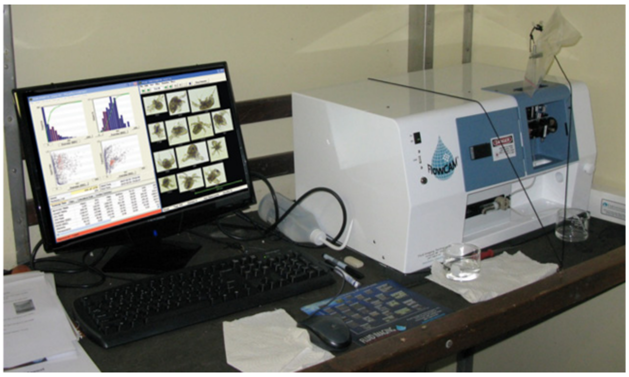

Figure 1. A FlowCam used to count microzooplankton in water samples collected off southern Madagascar.

The microzooplankton community was consistently dominated by mixotrophic dinoflagellates (using both photosynthesis and heterotrophy to meet their energy requirements), followed by ciliates, radiozoans and copepod nauplii (Fig. 2). Mean (± SD) total abundance in surface samples (number of individuals (ind.) per litre (L) of seawater) was significantly greater on the Madagascan shelf (265±171 ind. L^{-1}) compared to the eddy (155±113 ind. L^{-1}). Neither community composition nor abundance at the shelf fmax (223±85 ind. L^{-1}) differed significantly from the surface, suggesting that the shelf waters were well-mixed. In contrast, abundance at the eddy fmax (263±134 ind. L^{-1}) was significantly greater than at the surface (155±113 ind. L^{-1}), mainly due to the higher abundance of dinoflagellates. This may be a result of nutrient enrichment at the fmax due to upwelling of deeper waters in the eddy core. Radiozoans were also more numerous in the eddy than on the shelf, suggesting enhanced growth and feeding conditions. Related studies have shown that the eddy had entrained shelf water during its genesis. However, the variability observed in abundance and composition within the eddy compared to the shelf, suggests that microzooplankton assemblages are strongly and rapidly influenced by local conditions. These include vertical nutrient enrichment and water column structure of the eddy, as well as horizontal mixing processes. Further analyses will provide more insight into physical-biological coupling linked to mesoscale eddy activity in this dynamic region.

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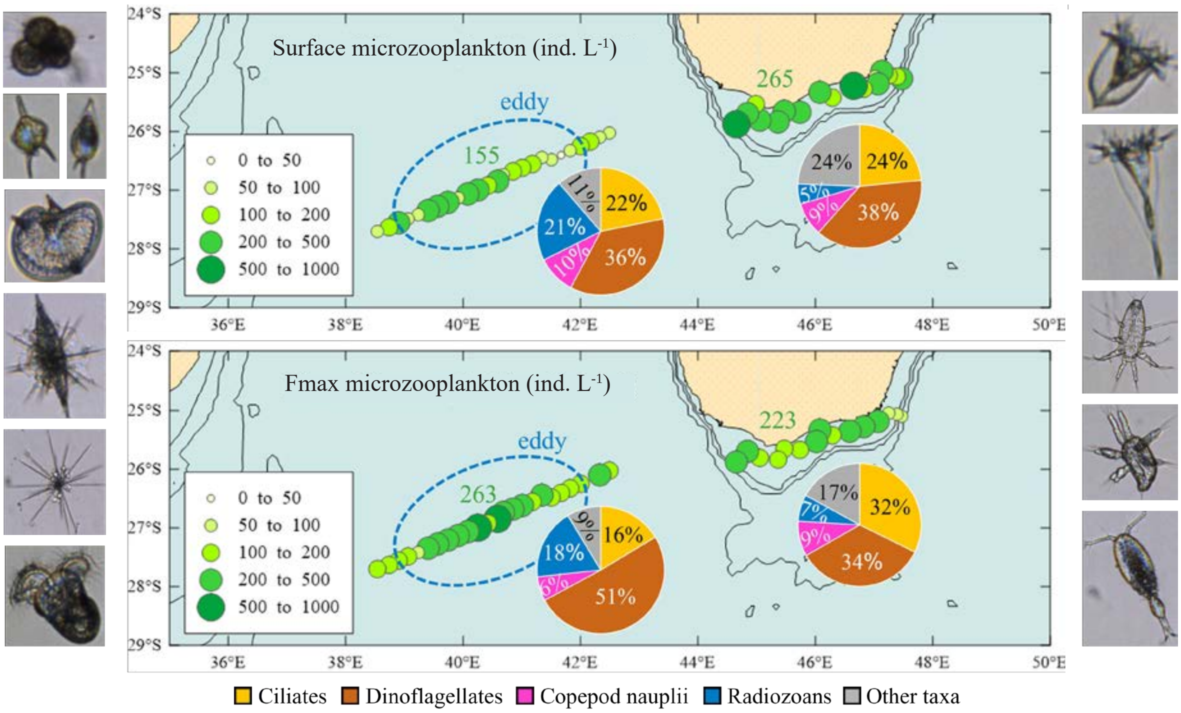

Figure 2. Composite figure showing mean surface and fmax abundance (ind. L^{-1}; green text) of microzooplankton in the eddy and on the shelf off southern Madagascar. Pie charts indicate proportion (% abundance) of ciliates, dinoflagellates, copepod nauplii, radiozoans, and other taxa at each location. Side panels (not to scale) illustrate representative FlowCam images of microzooplankton taxa found during the study.

22. BENTHIC INVERTEBRATE FAUNA OF THE SOUTHERN BENGUELA ECOREGION

Despite many years of research in the southern Benguela ecosystem, detailed knowledge of the distribution and diversity of benthic invertebrate fauna is still relatively poor. Recently, several priority areas within the southern Benguela have been identified for urgent improvement of the knowledge of benthic invertebrate communities and associated habitats. These priority areas include the newly declared Robben Island Marine Protected Area (MPA), the Table Mountain National Park (TMNP) MPA, and the newly proposed Seas of Good Hope Ecologically or Biologically Significant Marine Area (EBSA; Fig. 1). We sampled within these three areas in order to: (i) contribute to the first baseline assessment for continuous long-term monitoring in these regions; (ii) determine the species diversity of benthic invertebrate communities, and which geological (i.e. habitat type) and physical factors (i.e. location, depth) may be responsible for driving their distribution and abundance; and (iii) provide a legitimate conservation rationale for the establishment, or expansion, of these priority areas.

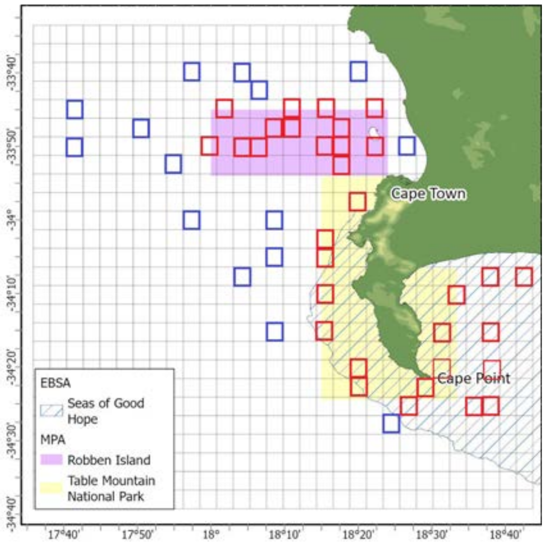

Figure 1. Sampling areas within the southern Benguela ecosystem, showing Robben Island and TMNP MPAs, and a section of the Seas of Good Hope EBSA, which extends eastward to Cape Agulhas. Squares represent randomly selected stations within a grid at depths between 16–250 m. Stations sampled within and outside of priority areas are indicated as red and blue squares, respectively.

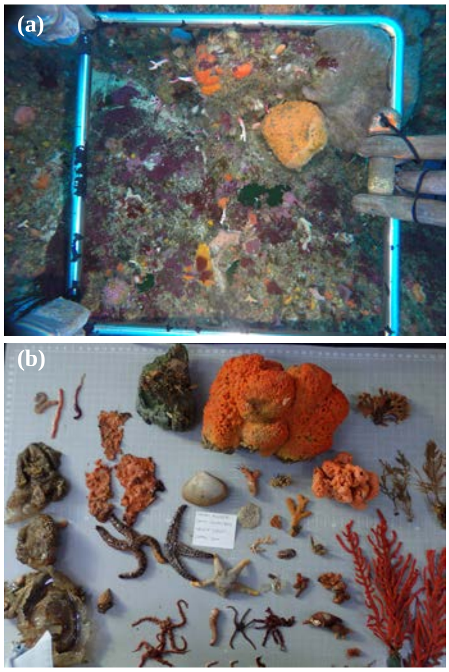

Figure 2. (a) An example of an image from a benthic camera system, and (b) physical specimens collected using a dredge.

The survey was conducted from the RS *Algoa* during August 2019, and included visual assessments using various benthic camera systems. Outside of priority areas, dredge and grab samples were collected to corroborate camera images and footage (Fig. 2). Visual assessments showed a total of 72 species across the study area. In the TMNP MPA, cnidarians (30%) (e.g. corals, sea anemones, sea pens, and sea fans) and poriferans (sponges; 21%) were the most abundant and diverse taxonomic groups.

Echinoderms (50%) (e.g. sea stars and urchins) and cnidarians (19%) were predominant in the Robben Island MPA, while molluscs (35%) (e.g. clams, chitons, sea slugs, assorted shells/snails) and poriferans (30%) were most prevalent in the Seas of Good Hope EBSA (Fig. 3). Although benthic community structure was similar among the three regions, changes in depth and habitat/substrate type resulted in significant differences in distribution. Abundance and diversity declined in deeper waters, possibly due to decreases in food availability and temperature.

The study revealed that the southern Benguela ecosystem is heterogeneous, and the distribution of macro-epibenthic organisms (i.e. large organisms attached to, or on a surface) varies spatially according to substrate type, position and depth. Rocky/reef habitat types were important drivers of species diversity, and expanding MPA boundaries to include these high-profile areas may improve conservation efforts. The establishment of the Robben Island MPA ensures that connectivity between coastal, inshore and offshore zones in this area is maintained. In the long-term, the non-destructive benthic camera monitoring will enable more effective management. This should not be limited to macro-epibenthic surveys, but should be extended to include the full suite of benthic ecosystem types (e.g. sediments) as part of multidisciplinary research and monitoring efforts.

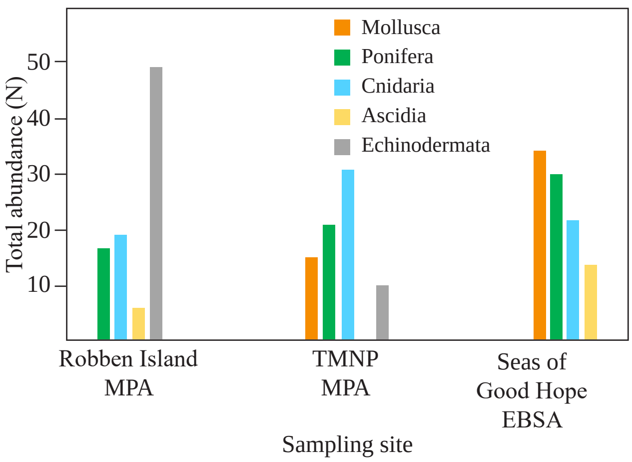

Figure 3. Total abundance (N) of taxonomic groups per priority area observed in images from a benthic camera.

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23. SPATIAL AND SEASONAL DISTRIBUTIONS OF METALS IN MUSSELS IN THE WESTERN CAPE

The discharge of metal pollutants (heavy and trace metals) into the marine environments, where they accumulate and result in toxicity, is a global concern. Metals such as iron (Fe), zinc (Zn) and manganese (Mn) are essential elements but may be toxic to humans if consumed in excess (e.g. in seafood). Mercury (Hg), arsenic (As) and cadmium (Cd) are non-essential elements because of their toxicity, even in trace (small) amounts. Mussels are popular shellfish that are used widely as bio-indicators of trace and heavy metal pollution or toxicity in coastal marine environments. This is because they are abundant filter-feeders that accumulate different elements to a degree suitable for measuring. By collecting specimens of an invasive mussel species, we initiated a long-term monitoring study of metal pollution at selected hot-spot areas (e.g. bays and lagoons), to determine the spatial distributions and seasonal variability of trace and heavy metal concentrations in the Western Cape.

Samples of black mussel *Mytilus galloprovincialis* (n = 10) were collected at three sites in the Western Cape, namely Saldanha Bay (SB), Lagoon Beach at Milnerton (LB) and Strandfontein (St), during February (late summer), August (winter), and November (early summer) of 2021, and in February 2022 (Fig. 1). Trace and heavy metal concentrations were measured from the samples, and compared to certified reference materials for precision and accuracy.

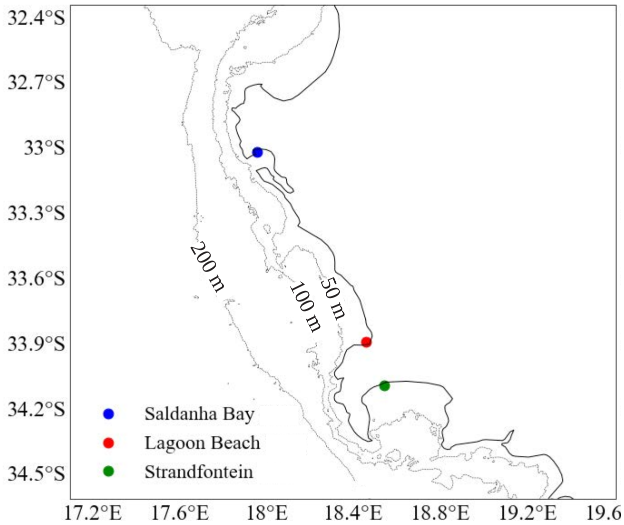

Figure 1. Map showing the three sampling sites.

Concentrations of essential elements, in particular Fe and Zn, were highest at SB and lowest at St, except for winter when there was a spike in Fe concentration at LB (Fig. 2). For the other essential element, Mn, the concentrations were generally higher at St, except during late summer of 2022, when it was highest at LB. In general, essential element concentrations were higher during winter and early summer (reflecting high rainfall and river outflow during these periods) than in late summer. In contrast, the highest concentrations of non-essential elements occurred in late summer of 2021, with Cd and Hg peaks observed in St and SB, respectively.

The metal concentrations were comparable with past recorded values reported for these sites. However, Zn concentrations recorded at SB in early summer and Cd concentrations at all sites (Fig. 2) were slightly higher than the South African permissible legal limits for these elements in shellfish, (300 µg g^{-1} and 3 µg g^{-1}, respectively). The sources of such high levels of metal pollutants require further investigation. Monitoring will be continued and eventually extended to other hot-spot sites along the South African coastline, subject to sufficient funding and capacity. In addition to metals, other potential toxicants need to be considered, such as those resulting from Harmful Algal Blooms, which may also have a considerable impact on coastal marine ecosystems and human health.

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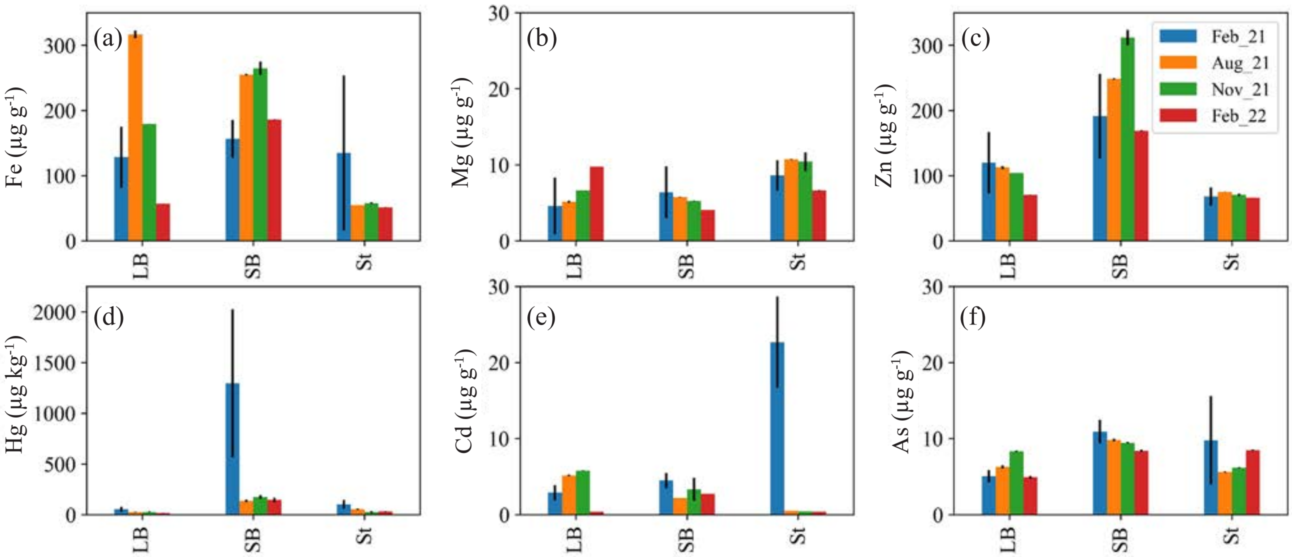

Figure 2. Spatial and seasonal distributions of the mean concentrations of essential (top panels) and non-essential elements (bottom panels) at the Lagoon Beach (LB), Saldanha Bay (SB) and Strandfontein (St) sampling sites. Concentration units are in microgram per gram and microgram per kilogram (µg g^{-1} or µg kg^{-1}). Error bars depict standard deviation.

24 MONITORING MICROPLASTICS IN THE WESTERN CAPE – A PILOT STUDY

Microplastics (<5 cm) are an emerging contaminant globally and pose considerable threats to coastal ecosystem structure and function. To monitor the extent of microplastic pollution along South Africa's coastline, a cost effective, technical, and scientifically acceptable method is required. Focusing on sediment and mussel collections, sampling and analysis trials were conducted at three different sites in the Western Cape. As filter-feeders that take up microplastics from sediment, mussels are useful indicators of microplastic concentrations, because the microplastics accumulate in their body tissue.

The three sites are Saldanha Bay, Lagoon Beach at Milnerton, and Strandfontein (Fig. 1). At Strandfontein, the beach and Pavilion areas were sampled separately. At each location, five replicate sediment samples, and at least 20 mussel *Mytilus galloprovincialis* samples were collected in summer (February) and winter (August) of 2021. Microplastics were extracted from the sediment and mussel samples, and characterised based on shape, colour and size.

While a greater percentage of sediment samples than mussel samples contained microplastics (88% vs 62%), the mean concentration of microplastics was higher in mussels, for all sites and for both seasons. Lagoon Beach had the highest microplastic concentration during winter, both for mussel and sediment samples. In summer, the highest concentrations in mussels occurred at Saldanha Bay, and in sediment at Strandfontein (Fig. 2).

Polyethylene blue-green fibres were the most common form of microplastic, varying in size between sediment (0.5–1 mm) and mussel samples (1–2 mm). Interestingly, higher concentrations of microplastics were found in smaller mussels (Fig. 3). This may be linked to the size of microplastics available for uptake by the mussels, indicating that smaller-sized microplastics were most prevalent in the sediment.

The methods applied in this study were cost effective, making use of inexpensive equipment and materials that were suitable for monitoring microplastic pollution along the coast of South Africa. However, training is recommended to ensure efficient data collection and results that are scientifically sound. If there is sufficient budget and capacity, monitoring microplastics at additional sites is recommended.

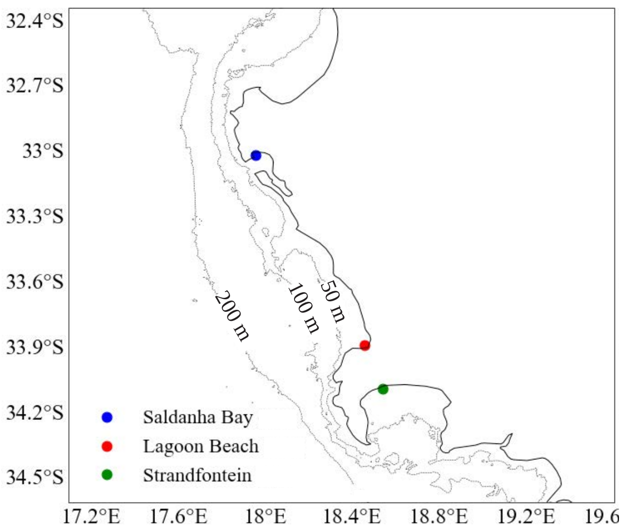

Figure 1. Map showing the three sampling sites.

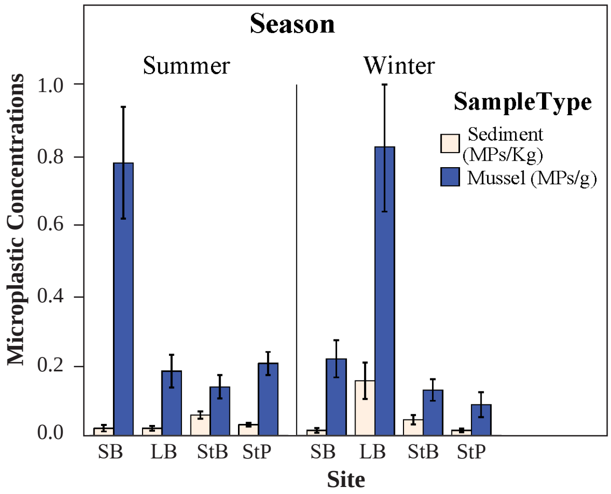

Figure 2. Mean summer and winter microplastic (MP) concentrations in sediment and mussel samples at Saldanha Bay (SB), Lagoon Beach (LB), Strandfontein Beach (StB) and Strandfontein Pavilion (StP). Error bars indicate standard error of the mean.

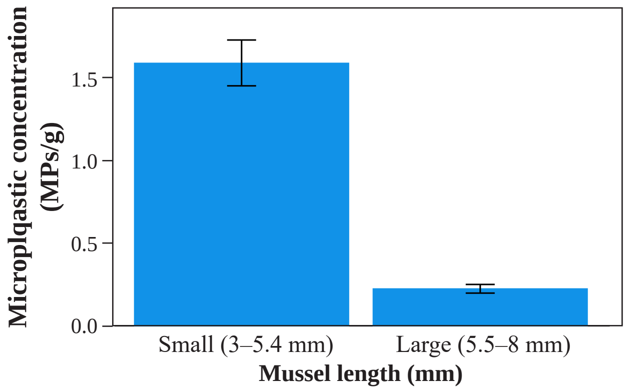

Figure 3. Mean microplastic concentrations per gram of soft tissue (MPs/g) in small and large mussels. Error bars indicate standard error of the mean.

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25. EFFECTS OF SEISMIC SURVEYS ON MARINE LIFE

Globally, there is emerging recognition of the threat posed by underwater anthropogenic noise to marine life, especially to organisms that utilise sound for biological and ecological processes. One of the noise sources is seismic surveys, which are used to map the structure, composition and dynamics of the ocean floor, primarily to locate subsea deposits of oil and gas. Seismic vessels tow airgun arrays and hydrophone streamers of varying lengths (up to 12 km) behind vessels (Fig. 1). Exposure to the high-intensity, low frequency sounds generated by the airguns can potentially affect marine life. Potential impacts include masking of natural signals and communication, behavioural responses such as avoidance of affected areas, physical or physiological effects that may result in mortality, and indirect effects (e.g. by affecting feeding or other functions necessary for survival). Organisms that may be affected range from large whales to plankton. In South Africa, the potential impact of seismic surveys on marine life and fishers' livelihoods has become a subject of considerable controversy and debate.

Currently, no international standard for mitigation and monitoring of seismic impacts exists, but guidelines for mitigation and monitoring that have been developed in other countries (e.g., the United Kingdom) have been amended and adopted for surveys in South Africa. Critical elements of a robust mitigation and monitoring plan include advance planning using baseline biological, ecological, physical, socio-economic and other relevant data, and appropriate communication and consultations with stakeholders and affected parties. Sensitive areas and seasons for species and their life history functions must be avoided, and Marine Protected Areas should have buffer zones of no activity, at least equivalent to the distance within which no acute negative impacts are to be expected. There should also be an exclusion zone surrounding the sound source that is visibly clear of animals both before and during operations, with slow ramping up of airgun operations to allow free-swimming animals to clear the area at the start of operations. Coordinated visual and acoustic monitoring is vital to determine the response of animals and the efficacy of mitigation measures, as well as to provide data on species distributions to inform further planning.

While international science has broadly determined the impact of seismic sounds on marine organisms and ecosystems, information for some faunal groups such as invertebrates (e.g. squid, lobsters, sessile benthic fauna) is lacking, and there are conflicting findings for some other groups, such as fish and plankton. Furthermore, local conditions such as geology and temperature will impact how sound is transmitted in South African marine ecosystems, which vary considerably in oceanographic conditions (e.g. between the east and west coasts). The cumulative effects of persistent seismic surveys on individuals, populations and ecosystems are also largely unknown, and cannot be addressed through mitigation. This issue is of great concern to people whose livelihoods are dependent on marine resources, and requires careful consideration. Furthermore, while it may seem logical that mitigation measures based on current scientific understanding should work, their efficacy at avoiding or reducing impacts on marine life remain largely unproven. There is a need to assess this, particularly in the South African context. A clear need for foundational science to investigate the effects of seismic surveys in South Africa has therefore been identified, in order to inform policies and develop standards and guidelines, including appropriate mitigation and monitoring measures. This will require development of local capacity in research on underwater noise.

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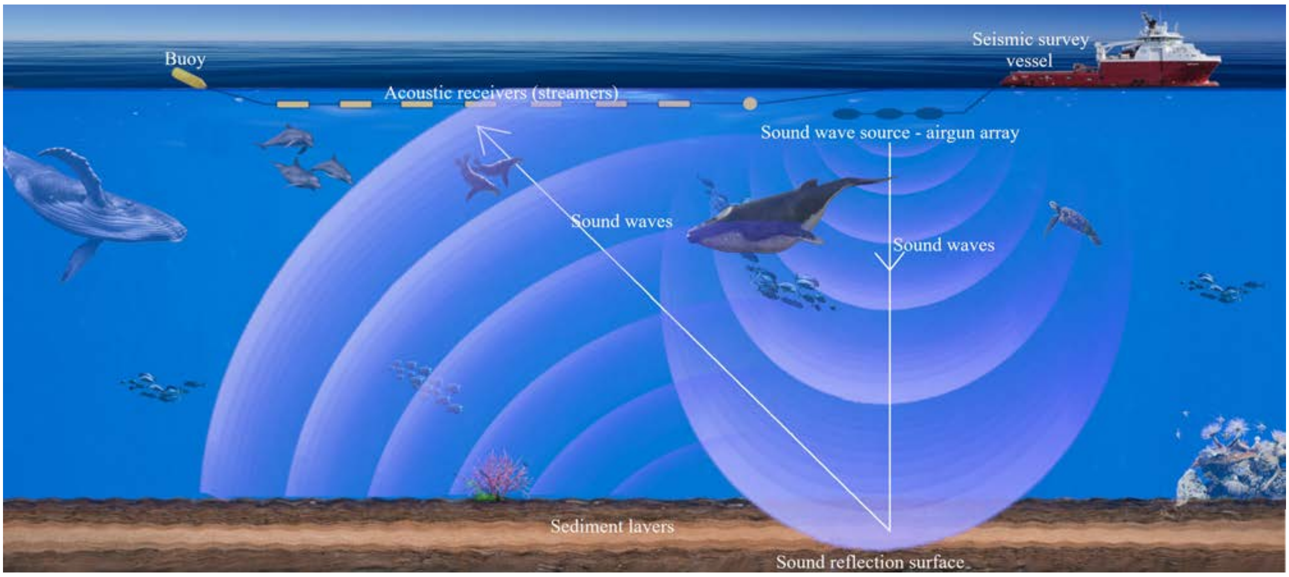

Figure 1. Schematic illustration of a seismic survey.

26. PROGRESS IN GOVERNANCE AND MANAGEMENT OF SOUTH AFRICA'S MARINE PROTECTED AREAS

In South Africa, Marine Protected Areas (MPAs) have been used as tools for marine area-based management since 1964 when the Tsitsikamma MPA was declared. The effectiveness of protection provided by MPAs, and related socio-economic benefits, are dependent on success of MPA governance and management. Governance relates to the interaction of policies, institutions, and processes that determine who participates in decisions, how decisions are made, and who is responsible for implementation, while management relates to the resources, plans, and actions for implementation. Management of South Africa's MPAs have kept pace with the expansion of the MPA network since 1964.

Four phases of MPA governance and management were identified for South Africa's MPAs (Table 1), based on a review of their history, including consultation of experts, scientific papers, books, reports, legislation, management effectiveness evaluations, and other sources. Progress was scored over these phases for 17 components of governance and management (Fig. 1), selected because they represent key issues for which changes could be readily identified throughout. Fifteen components indicated overall improvements – most obviously for legislation and policies, MPA establishment, planning and design, staff training and skills, and management effectiveness evaluation. However, progress for some of these components was weak, including the operational budget, adequacy of MPA objectives, management plans, stakeholder engagement and participation, co-management, and rights, access, equity and benefit sharing. Zero net gains were recorded for enforcement and compliance, and staff for complement.

Eight critical needs were identified for continued progress in governance and management of South Africa's MPAs: (1) detailed objectives for every MPA; (2) fast-tracking of management plans for new MPAs; (3) improved law enforcement; (4) strengthening of mechanisms and capacity to enhance participation of adjacent local communities and other stakeholders; (5) addressing the social impacts and injustices of MPAs and improving benefit sharing; (6) ensuring financial sustainability; (7) strengthening of management effectiveness evaluation (especially consistency of indicators between evaluations); and (8) improved cooperation between government authorities responsible for MPAs and fisheries.

Table 1. Broad temporal phases of MPA governance and management in South Africa, with summaries of key attributes.

Phase	Attributes
1. (1964–1994)	Initial protection based on exclusionary, preservationist policies; protection *ad hoc* in absence of a national plan; focus on shallow waters; social considerations neglected.
2. (1994–2010)	People-oriented policies introduced; focus shifted from species to ecosystems, with consideration of deeper water protection; efficacy enhanced by formation of a national coordinating body.
3. (2010–2019)	Improvements in design of MPAs, ecosystem representation, and stake holder engagement; however, fractured governance (between MPA and fisheries functions) hindered coordination and management.
4. (2019–ongoing)	Additional challenges of managing new offshore MPAs declared in 2019.

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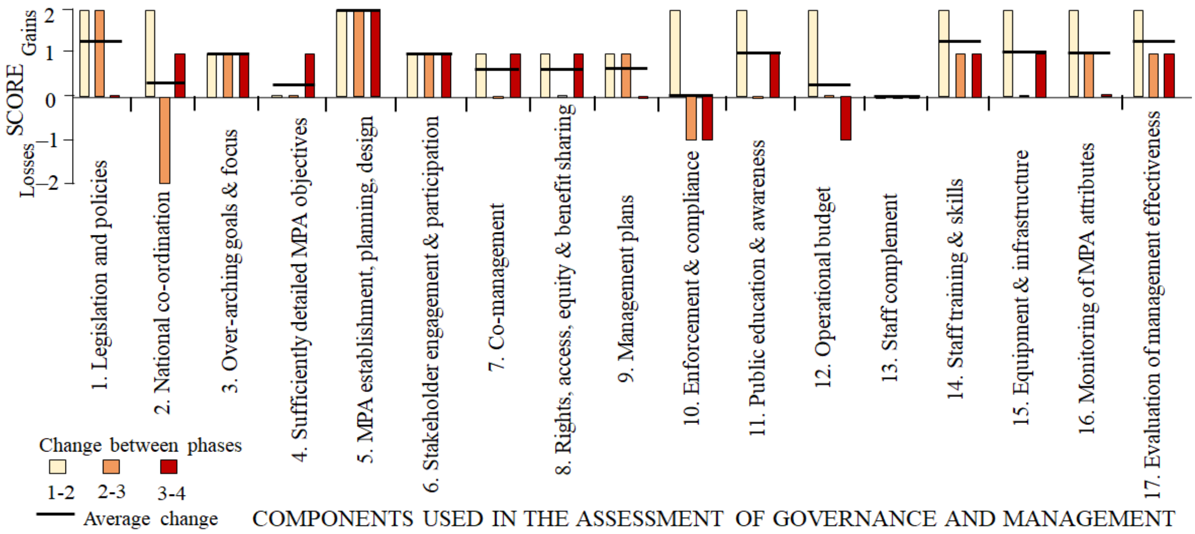

Figure 1. Summary of scores for changes between phases (see Table 1) in 17 components of governance and management of MPAs in South Africa. Scores of 2, 0 and -2 represent consensus between assessors that there was positive progress, no progress or a decline in the situation between phases, respectively, while 1 and -1 are intermediate scores indicating a lack of consensus between scores.

27. IMPACTS OF SPATIAL AND TEMPORAL RESOLUTION OF *IN SITU* SAMPLING ON KNOWLEDGE AND UNDERSTANDING

In the context of environmental sampling, spatial resolution refers to the linear spacing between data points that may be used to construct images illustrating environmental parameters. When fewer data points are used, the spacing between them tends to be larger, resulting in a coarser resolution image with less discernible detail. In contrast, when more data points are available, the spacing between them is generally smaller, and as a result, more features can be identified from the constructed images. Temporal resolution refers to how frequently observations are made at the same locations. Greater temporal resolution increases the ability to detect short-term changes. Here, we provide a synopsis of *in situ* CTD sampling at the Prince Edward Island (PEI) shelf (Fig. 1) in the Southern Ocean, between 2014 and 2022, to demonstrate the effect of spatial and temporal resolution on knowledge and understanding of oceanographic variations on the shelf.

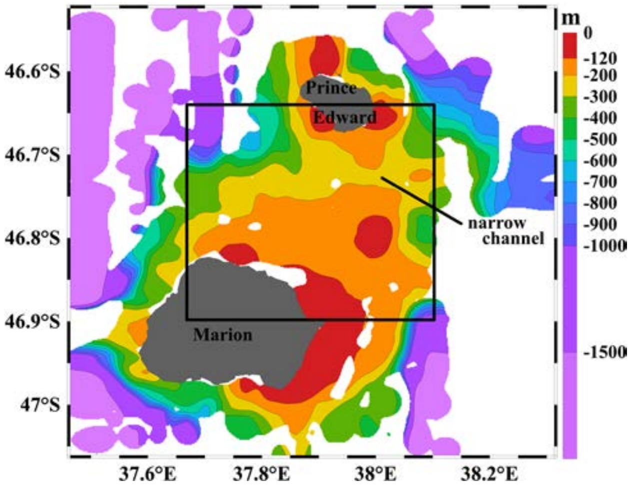

Figure 1. Satellite bathymetry of the Prince Edward Islands and surrounds, with the area of interest indicated by the black box.

In situ CTD sampling at the PEIs is restricted to April–May during annual cruises to re-supply the island's research base. Thus, there are no CTD observations across the shelf during the rest of the year, constraining our knowledge to conditions during autumn only. During 2014 and 2015, sampling was limited to a single transect and a few randomly spaced stations, making it impossible to visualise and interpret oceanographic conditions across the shelf (Fig. 2). Since then, DFFE has steadily increased CTD sampling at the islands. The ultimate result is better visualisation and interpretation of sea conditions across a bigger shelf area, with more spatial patterns and visible features. The improved data coverage also makes it easier to relate differences in the biomass and distribution of benthic communities and other biota to oceanographic variations.

In the Southern Ocean, surface temperature generally decreases from north to south, but on the bottom of the PEI shelf, the opposite pattern is evident. Cooler waters occur closer to Prince Edward Island, while the waters closer to Marion Island are warmer (Fig. 2). This is simply due to the narrow, deeper channel that incises the shelf closer to Prince Edward Island, resulting in data collection from deeper depths than those closer to Marion Island. Importantly, this pattern was not clearly visible during 2014, 2015, and 2022, when sampling was constrained by logistics and inclement weather.

Sampling resolution has the same impact on data visualisations and interpretations across the world's oceans and for all disciplines. The coarser the spatial and temporal resolution of sampling, the less the knowledge and understanding that can be gained from the collected data. Thus, in order to gain the best possible understanding, it is critically important to maximise the spatial and temporal resolution of sampling as much as possible.

Authors: Tutt GCO, van den Berg MA, Lamont T (OC Research)

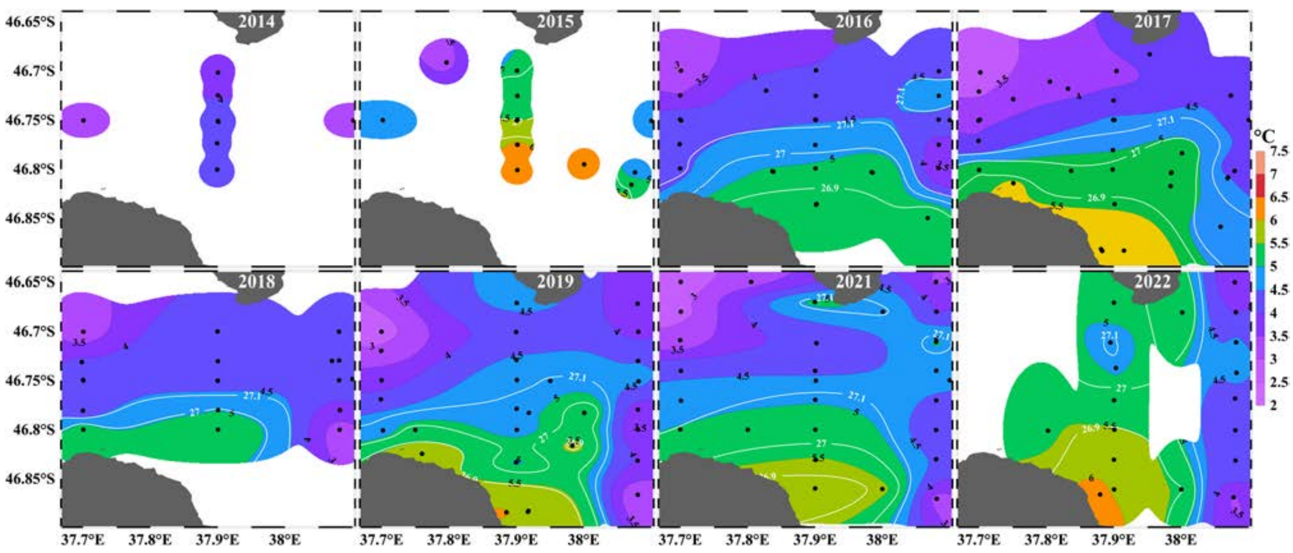

Figure 2. Maps of bottom Conservative Temperature (°C) on the PEI shelf during April–May 2014–2022. Note that sampling was not possible during 2020 due to COVID-19 pandemic restrictions. Black dots indicate CTD sampling stations; white lines indicate neutral density contours used to distinguish water masses; and white shading indicates areas where no data were collected.

28. GIS DATA CONSIDERATIONS FOR THE ENHANCED BATHTUB MODEL FOR COASTAL INUNDATION

Geographic Information Systems (GIS) provide an accessible means to model hazards such as coastal inundation primarily via a 'bathtub' approach (i.e. uniformly inundating areas below a given elevation threshold). This study determines the appropriateness of input data used to drive the GIS-based enhanced Bathtub Model (eBTM) for examining coastal inundation in an urban setting. The eBTM was designed to simulate potential water pathways in the context of episodic coastal inundation (e.g. storm surge).

Coastal GIS-based models rely on high-resolution data to generate adequate elevation models, such as Digital Surface Models (DSMs) which capture both natural and built features of the environment. These data, which are often obtained from light detection and ranging (LiDAR) sensors, provide a near-accurate surface for inundation modelling. However, the resolution of elevation models that can be achieved using LiDAR data are dependent on the point density (points per square unit area). In this study, various tests were conducted with DSMs, using a study site in False Bay, to determine: (a) the highest appropriate horizontal resolution (pixel size) achievable from available LiDAR data, (b) the optimal DSM horizontal resolution for coastal inundation modelling based on 'out-of-the-box' solutions (i.e. elevation models derived from LiDAR and disseminated as raster products); and (c) mechanisms to address the challenge of DSMs representing overhanging structures (e.g. bridges) as solid structures based on first return LiDAR points (i.e. the subset of LiDAR data associated with the highest features in the landscape).

LiDAR data, procured by the City of Cape Town (CoCT) in 2019, had an average point density of 2–3 points per square meter, with a vertical accuracy of 15–20 cm. The CoCT also provided a 1 m resolution DSM in raster format, which conformed to the minimum criteria of having at least two LiDAR points per raster cell. Two sub-meter DSMs of 0.75 m and 0.5 m resolution were derived from the LiDAR data.

The highest resolution DSM achievable from the LiDAR data was 0.75 m, whereby most raster cells had a minimum of two points, unlike the 0.5 m DSM where most raster cells had only one point. The high number of raster cells with no points in the 0.5 m DSM indicate a highly interpolated surface and may therefore misrepresent features and/or affect the observed inundation extent (Fig. 1).

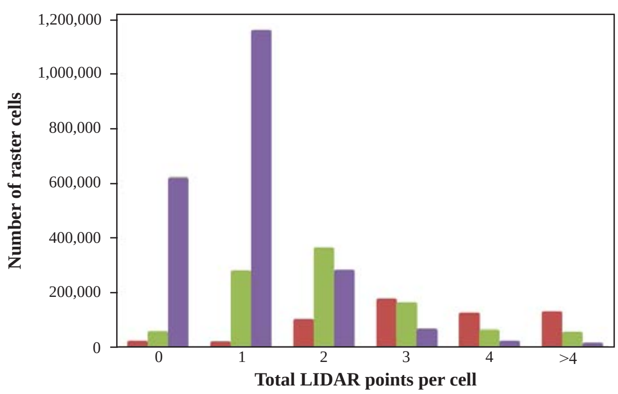

Figure 1. Frequency of raster cells per number of LiDAR points contained in a raster cell, for three different raster resolutions.

Out-of-the-box DSM products showed that 1 m resolution DSMs allowed water passage between buildings and narrow thoroughfares, and thus performed better than DSMs at 5 and 10 m resolution. This demonstrates that high horizontal resolution DSMs are required for inundation modelling in an urban setting (Fig. 2).

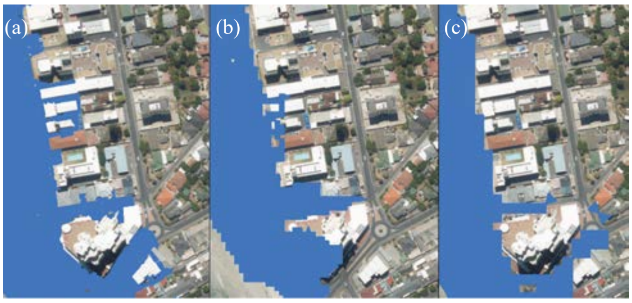

Figure 2. Results of the eBTM resolution test with (a) 1 m, (b) 5 m, and (c) 10 m resolution DSMs, for a study site in False Bay.

Challenges posed by first return LiDAR depicting bridges as solid structures (and thus not allowing rising water to pass under them) could be circumvented by modifying the input water source used for the eBTM processing by extending it further inland (Fig. 3).

Data appropriateness will influence the eBTM outputs, therefore users should be aware of data characteristics and limitations. Point density is important when generating DSMs from LiDAR data, and over-interpolation needs to be avoided. Out-of-the-box DSMs require a maximum resolution of 1 m to be effective in coastal inundation modelling and a modified eBTM input water source can help to address the LiDAR first return data deficiencies.

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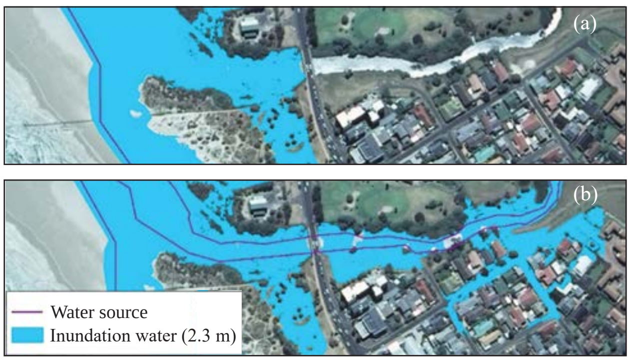

Figure 3. Comparing eBTM outputs and the effects of bridges using (a) a water source positioned along the coast and (b) a modified water source extending further inland beyond the bridge.

29. VALIDATION OF THE LACCE ALGORITHM TO DETECT THE AGULHAS CURRENT SYSTEM

The Agulhas Current (AC) transports large quantities of heat, salt, and water from the Indian Ocean into the South Atlantic Ocean (Fig. 1), thus playing a significant role in maintaining the global thermohaline circulation. The AC has a substantial influence on local weather and climate, including rainfall patterns over the adjacent South African continent. By interacting with the continental shelf and slope regions on the east and south coasts of South Africa, the AC also influences the distribution of water masses and biota in these regions.

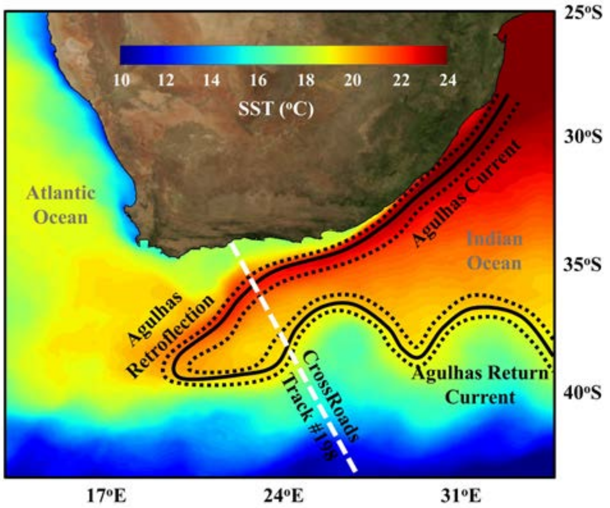

Figure 1. Long-term mean Sea Surface Temperature (SST, °C) map illustrating the Agulhas Current System including the Agulhas Current, the Agulhas Retroflection and the Agulhas Return Current. The white dashed line indicates the CrossRoads transect, which is located below satellite altimetry track 198.

The Location of the Agulhas Current's Core and Edges (LACCE) is an algorithm developed in 2019 to apply to satellite altimetry data for routine identification and monitoring of the AC (Fig. 1). In order to assist in the effective governance of South Africa's oceans, LACCE runs operationally in near-real time on the National Oceans and Coastal Information Management System (OCIMS) as a decision support tool.

To ensure that LACCE is performing optimally, the output is routinely validated, using *in situ* observations collected during the annual SA *Agulhas* II cruises to re-supply the research base at Marion Island. This validation is performed using Ship-mounted Acoustic Doppler Current Profiler (S-ADCP) data collected along the CrossRoads transect (Fig. 1). During the 2022 SA *Agulhas* II cruise to Marion Island, the AC was transected four times (Fig. 2), providing a unique opportunity to validate LACCE in various locations. Thermosalinograph (TSG) data were collected along all the transects, each of which showed good agreement between the *in situ* data and the LACCE-identified features of the AC and the Agulhas Return Current (Fig. 2a-d). The S-ADCP measurements were only collected along the CrossRoads transect. As expected, there was good correspondence between the S-ADCP data and LACCE-identified core and edges of the AC (Fig. 2d), given that this transect is located directly below the repeated satellite altimetry track 198 (Fig. 1).

There were some minor differences between LACCE and the *in situ* data (Fig. 2). These discrepancies were a result of small-scale oceanographic features that were captured only by the *in situ* data, because of its much higher spatial resolution in comparison to satellite altimetry. Nevertheless, Fig. 2 illustrates that LACCE continues to function optimally, providing a useful tool to monitor the entire AC system at daily timescales.

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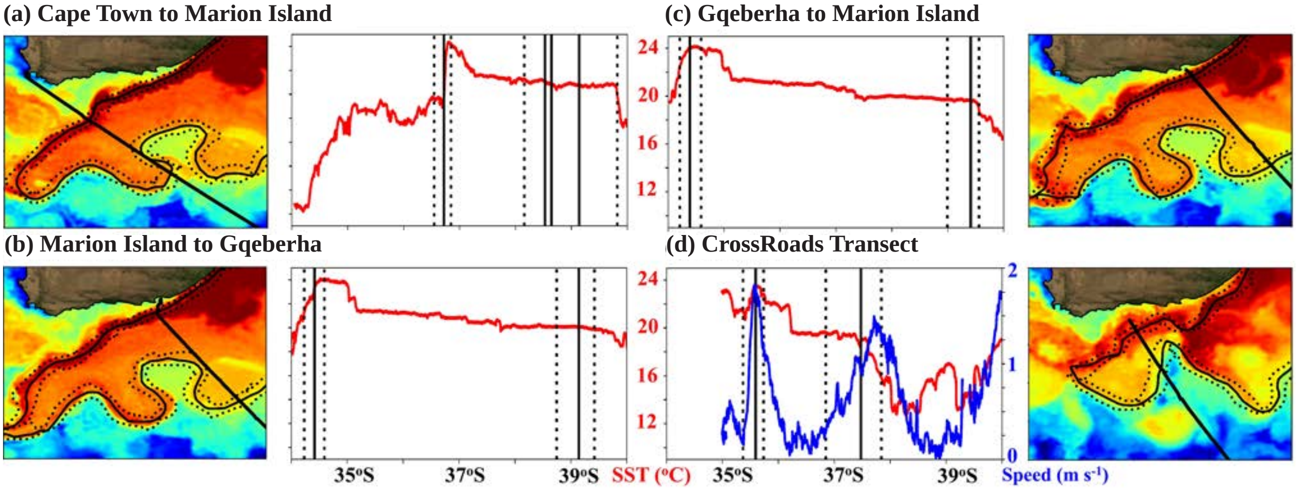

Figure 2. Maps of daily SST (°C) overlaid with the LACCE identified core (solid black contours) and edges (dotted black contours) of the components of the Agulhas Current System, and transect locations during the 2022 Marion Island re-supply cruise. Note that the colour scale for the SST maps is the same as that shown in Figure 1. (a) Shows the transect sampled en route between Cape Town and Marion Island, (b) illustrates the transect from Marion Island to Gqeberha, (c) indicates the transect from Gqeberha to Marion Island, and (d) shows the CrossRoads transect. The line graphs illustrate *in situ* surface temperature (°C) from the TSG (in red) and surface current speed (m s^{-1}) from the S-ADCP (in blue) measured along the respective transects.On the line graphs, vertical black solid and dashed lines indicate the core and edges of the Agulhas Current System, respectively.

30. PICTURE PERFECT: CREATING A WEST COAST MESOZOOPLANKTON DIGITAL ARCHIVE

Oceans and Coastal Research has been measuring multiple variables off the west coast of South Africa for decades. One example is mesozooplankton, which has been sampled since 1950. These are small (200–2000 µm), free-floating marine animals that fuel the ecosystem as food, maintain ecosystem balance and play a key role in the recycling of nutrients and carbon from the surface to the deep ocean through excretion and migration. Over the years, mesozooplankton have been analysed using two methods: (i) settled volume (Fig. 1) – a simple, cost-effective and easy method yielding the amount of zooplankton in the water; and (ii) species identification and counting using a light microscope (Fig. 2a) – a time-consuming (therefore costly) and labour-intensive approach yielding detailed information on individual species present. This method requires the user to have an in-depth knowledge of mesozooplankton species identification.

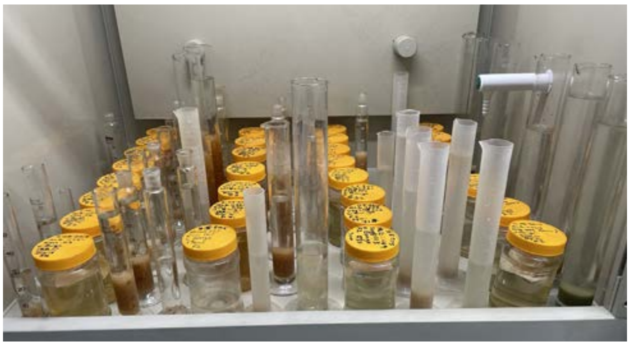

Figure 1. Settled volume analysis in the laboratory.

In this new digital age, government departments are required to digitise and archive information, as cost-effectively as possible. In line with this, OC Research has been using a ZooScan in recent years, for identifying and counting the types of mesozooplankton with automated image analysis (Fig. 2b). Settled volume remains the method of choice for determining amounts of mesozooplankton in the water.

A laboratory protocol written by the developers of ZooScan was tested against the count method used in OC Research laboratories. Automation generated results 16 times faster than the older microscope method. The resolution of taxonomic identification was lower, achieving only group-level and not species-level identification. However, the lower taxonomic resolution is still useful for addressing trend-related monitoring questions.

In the process, it became apparent that the original count method used at OC Research underestimated the presence of many larger taxa, because the aliquot size and method of sub-sampling were not suited to be representative of all species present. Also, the automated method provided by the developer resulted in low-resolution images of the smaller organisms (200–500 µm; Fig 3a). Therefore, an in-house protocol was developed and tested. This produced better quality images for organisms sized between 500–2000 µm and was more representative of all the taxa present in the water column (Fig. 3b). Analysis of the

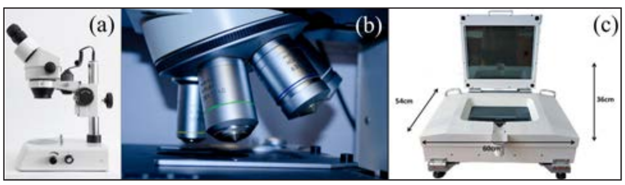

Figure 2. (a, b) Microscopes, traditional technology used to analyse plankton; and (c) the ZooScan, automated image analysis technology (for organisms >200 µm).

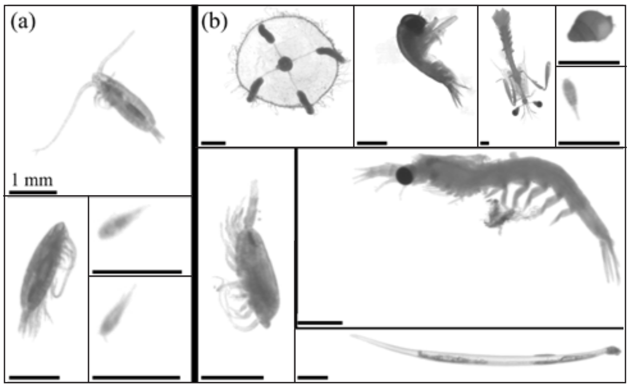

Figure 3. (a) Low-resolution images from the ZooScan using the original method – animals in the 200–500 µm size class (<1 mm) are indistinct; (b) higher resolution images and greater taxonomic representation from the west coast in-house ZooScan protocol – however, animals <1 mm remain indistinct. Black bars indicate 1 mm in length, relative to organism size.

200–500 µm sized-group was tested on a different automated instrument, the FlowCam, which generated better quality images for that specific size class (Fig. 4).

This in-house protocol has been instated as the standard operating procedure to digitally analyse mesozooplankton off the west coast of South Africa. Currently, the digital archive for settled volume extends from 1988–2022 and the digital taxonomic identification record through image analysis is from 2015–2022. Both archives are undergoing data validation and will be available on the Marine Information Management System (www.ocean.gov.za) under the historic archive, Integrated Ecosystem Programme: southern Benguela.

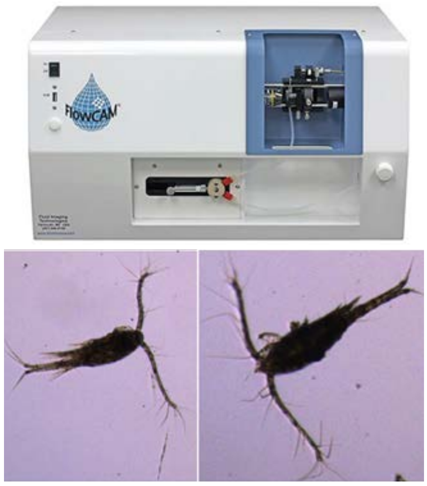

Figure 4. FlowCam: image technology used to analyse the 200–500 µm size class – animals <1 mm are now distinct.

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31. IMPACTS OF THE COVID-19 PANDEMIC ON THE OPERATIONS AND MANAGEMENT OF THE ENVIRONMENTAL RESEARCH SHIP *ALGOA*

The World Health Organisation (WHO) declared the Coronavirus disease (COVID-19) as a global pandemic in 2020. Throughout the pandemic, DFFE's Branch: Oceans and Coasts, in collaboration with ship-management company, African Marine Solutions (AMSOL) endeavoured to fulfil environmental monitoring, research, governmental and societal objectives through continuing to operate and manage the RS *Algoa* to undertake voyages (Fig. 1). To demonstrate the effects and impacts of COVID-19 on vessel operations, financial and operational data and information for the 2020 and 2021 calendar years were compared to the 2017–2019, pre-COVID-19 period (Table 1).

Table 1. Sea days and vessel operational costs of the RS *Algoa* during years impacted by COVID-19 (2020 and 2021 calendar years) in comparison with pre-COVID-19 years (average of 2017–2019). Costs are given in South African Rands (k=1,000).

Categories of costs and effort	2017-2019	2020	2021
Daily vessel costs	R200k	R200k	R200k
Number of cruises	12	3	5
Number of days at sea	180	50	74
Number of passengers per cruise	16	10	12
Costs of PCR tests[1] per cruise	0	R14k	R16,8k
Number of isolation days before each cruise	0	14	10
Total costs of isolation (board and lodging per cruise)[2]	0	R140k	R120k
Additional annual costs related to COVID-19	0	R462k	R684k
Percentage of cruise costs attributable to COVID-19	0	4.4	4.4

[1]Polymerase Chain Reaction (PCR) test for COVID-19. Two tests required, on arrival and prior to boarding the vessel, @ R700 per test for scientific personnel only
[2]Estimated @ R1k per person per day in a hotel

The COVID-19 global pandemic was a major setback for marine research, affecting institutions and individuals that rely on vessels to collect environmental and biological data for monitoring and research purposes. Financial, social, personal and professional impacts were observed. Negative impacts on the management and operations of RS *Algoa* included (but were not limited to):

- Substantial reductions in the number of voyages and sea days during 2020, thus reducing the quantity of data collected for research and environmental monitoring purposes;
- A decrease in numbers of participants on board per voyage, with only experienced people able to participate. This limited capacity development and skills transfer for young and early-career scientific and technical professionals;
- An unforeseen increase in vessel operational costs per voyage to meet with COVID-19 compliance regulations (costs of board and lodging for pre-cruise isolation periods, COVID-19 medical tests, and other costs). The unplanned expenses decreased the operational budget available for voyages and capacity building;
- Some Small, Medium and Micro Enterprises (SMMEs) supplying equipment, hospitality items and fuel, closed their operations due to a lack of business, thus increasing the logistical complexities of the voyages.

During 2021, there was some improvement in the vessel operations and management, as research institutions and individuals adopted the adjusted precautions required by the COVID-19 pandemic, thereby adapting to a gradual return to pre-COVID "normality". The psychological and personal effects on scientific, technical, maritime and support personnel are not addressed here, but further studies should be undertaken to better prepare for similar pandemics.

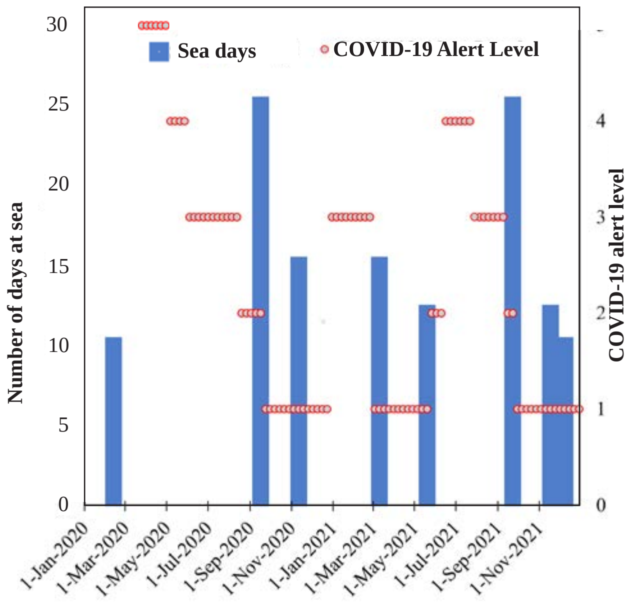

Figure 1. Research voyages undertaken by the RS *Algoa* between 2020 and 2021, juxtaposed against the COVID-19 alert levels (from Department of Health, 2022. https://sacoronavirus.co.za).

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32. OUTREACH AND TRAINING FOR MARINE SCIENCE LEARNERS

The Cape Peninsula University of Technology (CPUT) Marine Sciences National Diploma aims to empower students with theoretical knowledge, understanding, and practical proficiency to establish successful careers in the marine sector and related industries. As part of this education, on 26 August 2022, the Physical Oceanography group at the DFFE OCR, together with CPUT Marine Science lecturers, hosted an outreach and training event for a total of 25 CPUT Marine Sciences National Diploma learners in the second year of their studies (Fig. 1).

Figure 1. Selected photographs highlighting the technical training workshop.

The overall aim of the event was two-fold: (1) to provide first-hand experience to the learners on the practical aspects of the technical work and scientific research conducted at DFFE, and (2) to promote and stimulate the interest of the learners in the marine environment and the development of technologies in the marine field. The learners were exposed to a wide range of different instruments commonly used by physical oceanographers, and the underlying functioning principles for each instrument were discussed (Fig. 1). The instruments included a Conductivity-Temperature-Depth (CTD) system together with a Niskin rosette, a Thermosalinograph (TSG), Current- and Pressure-equipped Inverted Echo Sounders (C/PIES), ship-mounted and moored Acoustic Doppler Current Profiler (ADCP) systems, Argo float profilers, and moored CTDs (microCATs). The various aspects of designing moored hydrographic systems were also discussed.

The event provided an overview of technical knowledge required to consolidate the learners' theoretical background and expectations with real-life practicalities of the marine science field. It also promoted the existing collaboration between DFFE and CPUT and highlighted the need for further events of this nature.

The success of the event was gauged by the enthusiastic engagement from all learners on the day (Fig. 1), and through subsequent evaluation questionnaires completed by each learner (Fig. 2). Of the 88% of learners who responded, the majority (85.7%) rated their workshop experience and potential futures in marine science as excellent This outreach and training event was an overall positive experience for both learners and lecturers, and future events of this nature are highly recommended, including expansion of such hands-on exposure to include other fields of marine science.

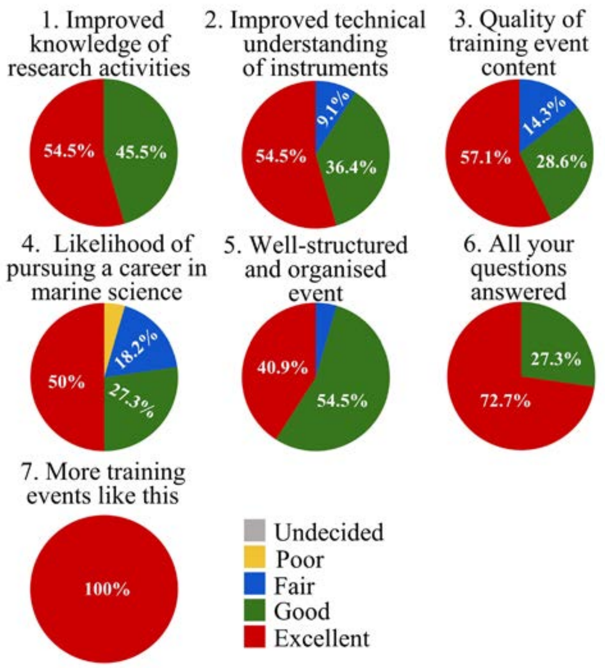

Figure 2. Pie charts illustrating feedback received from CPUT learners, as determined from completed evaluation questionnaires.

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33. DFFE PARTNERS WITH THE SOCCOM ADOPT-A-FLOAT INITIATIVE TO PROMOTE OUTREACH

The Southern Ocean Carbon and Climate Observations and Modeling project (SOCCOM) Adopt-a-float initiative (Fig. 1), aims to inspire and educate students of all ages about global ocean biogeochemistry and climate change. This is achieved by encouraging them to 'adopt-a-float', which they can name, decorate, and track, creating a personal link between themselves and the data collected by the float.

Figure 1. Selected photographs highlighting various aspects of the Adopt-a-float initiative (https://www.go-bgc.org/outreach/adopt-a-float).

The programme uses profiling biogeochemical floats fitted with a suite of sensors that gather ocean data such as temperature, salinity, depth, chlorophyll *a*, oxygen and nitrate concentration, as well as ocean pH. Once deployed, the floats drift through the oceans, changing depth and collecting data at programmed intervals. The floats dive and surface every five or ten days, collecting data as they ascend. Data is transmitted via Iridium communications satellites when they surface, repeating this cycle for as long as their batteries allow (ca. five years).

During 2022, five schools in the United States of America adopted five floats and named them "Sharkbait Worldwide", "Bobcat's Mission", "CCA Comet's Cruiser", "Floating Flamingo", and "Pacific Tiger". The DFFE OCR Physical Oceanography team deployed these floats along the CrossRoads monitoring line (Fig. 2) during the April/May 2022 Marion Island Relief voyage aboard the SA *Agulhas* II. Water samples were collected and filtered for high-performance liquid chromatography (HPLC) analysis to calibrate the float sensors. This provided additional training opportunities for students on board the vessel, enabling them to learn how to conduct sampling for HPLC analysis.

Although the floats were deployed within ca. five days of each other, they have covered substantially different travel paths and distances to date. Three of them have remained in the Southern Ocean, while "Bobcat's Mission" drifted into the southern Indian Ocean and "Sharkbait Worldwide" drifted into the South Atlantic Ocean. "Sharkbait Worldwide" travelled the furthest (3,060 km), while the "Floating Flamingo" travelled the shortest distance (760 km) over a similar period. These differences emphasise the widely diverse circulation dynamics in the various deployment regions. SOCCOM's dedicated online tracking platform (https://www.mbari.org/data/soccom-float-data/) gives the students the opportunity to view, appreciate, and keep track of such differences.

Such initiatives and partnerships play a crucial role in bridging the gap between students of all ages and scientists conducting high-level research. They also nurture and develop the scientific curiosity of students in a fun way, bringing the youth closer to STEM (Science, Technology, Engineering and Mathematics) disciplines. The South African Environmental Observation Network (SAEON) hosts a similar programme, and strengthened DFFE involvement in such initiatives could help to inspire more South African students to take an interest in oceanography.

Authors: Russo CS, van den Berg MA, Lamont T (OC Research); Matsumoto G (MBARI)

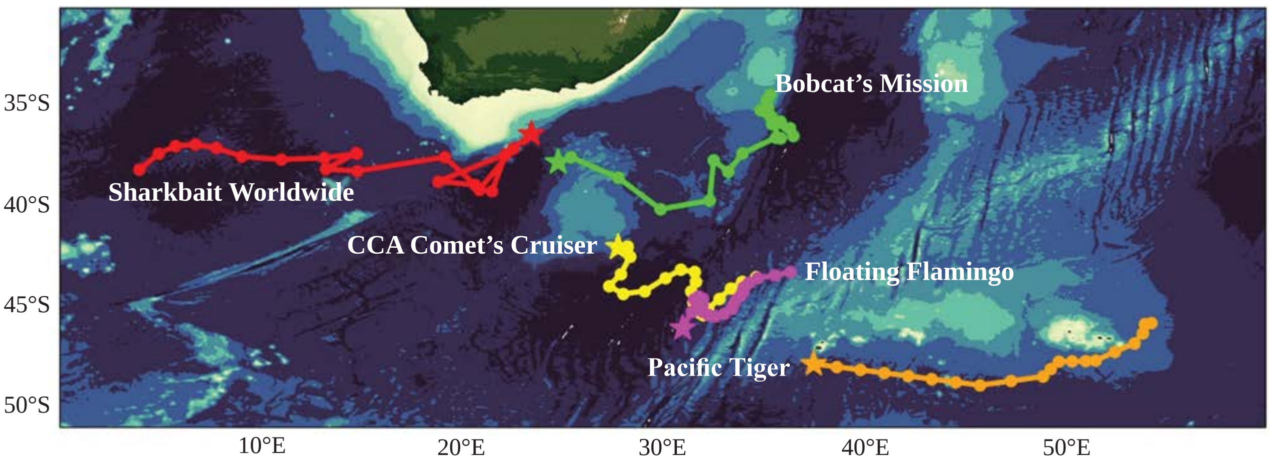

Figure 2. Trajectories of five floats deployed during the April/May 2022 SA *Agulhas* II Marion Island Relief voyage. The stars indicate the respective deployment locations, the dots represent float locations at ten-day intervals, and float names are indicated in white. Background shading indicates bottom depth, with darker blue shading indicating deeper waters, and dark green shading indicating land.

34 TRAINING CRUISE ON MICROBIAL SAMPLING PROTOCOLS FOR THE ATLANTIC OCEAN

The European Union-funded AtlantECO project set out to "map new and existing knowledge about the microscopic organisms that inhabit rivers, coastal waters, the open ocean, marine sediments and the atmosphere, as well as those found on plastic litter" from pole to pole (see https://www.icm.csic.es/en/news/will-atlantic-marine-ecosystem-services-overcome-threat-climate-change). Through this initiative, partnerships with scientists from South Africa and other countries around the African coast have been established, with the aim of better understanding the Atlantic Ocean.

As part of this initiative, the French research schooner, the *Tara*, made a stop in Cape Town between April and May 2022 on their 'Mission Microbiome' expedition (Fig. 1). During this time, the *Tara* team ran a hands-on training course on standard sampling protocols and analysis of microbiomes (microorganisms in an environment). The main training selected 21 early-career scientists from 14 countries around Africa as trainees. Trainees and other early career scientists (not part of the official training course) were invited on board the *Tara* for a day cruise to a training station off the west coast, near Cape Town.

The *Tara* is often referred to as a floating laboratory, with the use of space on board having been optimised for scientific objectives. The AtlantECO project offers five Standard Operations Protocols for microbial sampling and the *Tara* has the capabilities for three of these set protocols (https://zenodo.org/record/6956974#.ZAGrGnZBxPZ). The microbial sampling setup on the *Tara* consists of a seamless system, with water collection using a Niskin bottle rosette fitted with a CTD. This system (Fig. 2a) has the ability to filter samples from different depths simultaneously. The sampled water (5–10 L) is pre-filtered through a sieve (<200 µm) before being siphoned by peristaltic pumps through a series of membrane filters (3 and 0.2 µm). The training day concluded with trainees analysing samples and related data for their respective projects.

Figure 1. The *Tara* docked in Pier 2, Cape Town, in April 2022 (Photo: Jenny Huggett, OC Research).

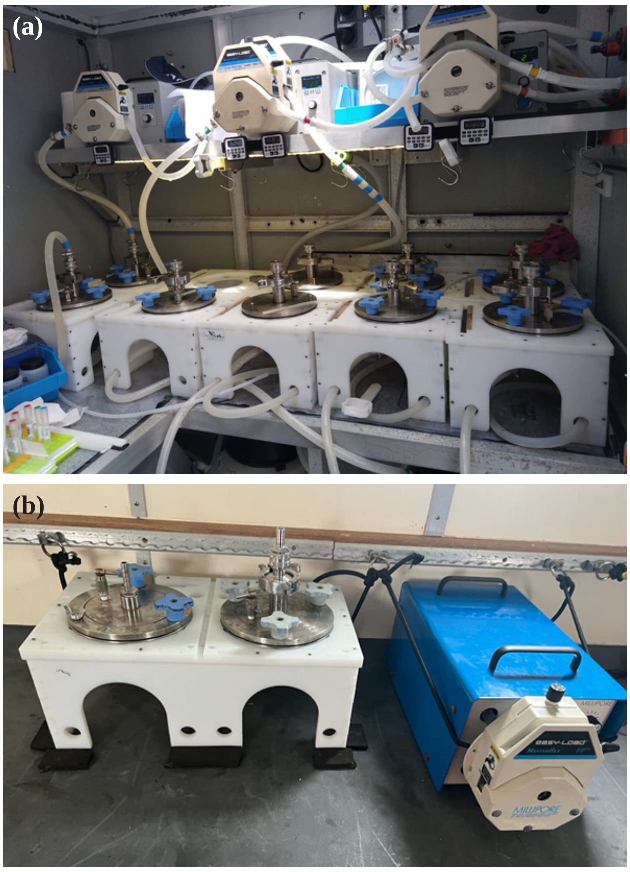

Figure 2. The different filtration setups on the *Tara* (a) and the RS *Algoa* (b).

The AtlantECO protocol was adapted off the RS *Algoa* at selected stations during the August and November 2022 Integrated Ecosystem Programme (IEP) cruises. The August cruise provided the opportunity to conduct a pilot study and to test the equipment required for a chosen standard protocol (Fig. 2b). This contributed to the IEP's Microbial project, which will map microbes by measuring their abundance in the water column and couple that with genomic (genetic structure, function, and evolution of an organism) sequencing. Although less advanced than the *Tara*'s setup, the setup on the IEP was adequate for successful participation in AtlantECO's 'All Atlantic Ocean Microbiome Sampling - 2022 Pilot Phase' during the November IEP cruise.

Authors: Gebe Z, Mdazuka Y (OC Research); Rocke E (MARIS, UCT); Dames NR (UCT).

35. TRAINING COURSE ON CONTINUOUS PLANKTON RECORDER OPERATIONS

The Continuous Plankton Recorder (CPR) Survey (https://www.cprsurvey.org/) is a world-renowned marine monitoring programme. The CPR is a mechanical device designed to be towed from merchant ships on their normal trading routes, allowing underway collection of phytoplankton and zooplankton. Plankton are trapped between two layers of silk, which are spooled together and preserved in formalin for subsequent laboratory analysis.

Staff with logistics, maritime and engineering expertise work with the shipping industry to facilitate CPR tows from volunteer merchant vessels, towing in excess of 100,000 nautical miles per year. Since the first tow with a merchant vessel in 1931, the CPR Survey has provided the scientific and policy-making communities with a basin-wide and long-term measure of the ecological health of marine plankton. These data are used to examine strategically important aspects such as climate change, human health, fisheries, biodiversity, pathogens, invasive species, and ocean acidification, among others.

The DFFE and the Marine Biological Association (MBA, UK) have recently collaborated on a new initiative to achieve regular tows across the entire South Atlantic (project AtlantECO; see Report Card 18). To ensure that operations are conducted safely and are compliant with international regulations, the need for efficient training was identified (Fig. 1). Consequently, the MBA facilitated a 6-day training course for DFFE OC Research officials in Cape Town during July 2022. This training included: (1) the setup and preparation of CPR operations for both long tows on merchant vessels and shorter multiple tows from research vessels; (2) sample preservation; (3) tow gear examination; (4) international transportation, for example of chemicals like formalin; and (5) the importance of recording metadata.

Feedback from participants indicated that the training was informative and useful, and they particularly enjoyed the hands-on practical modules, whilst observing and learning from each other. The training course builds on a long-standing collaboration between DFFE and the MBA in support of the South African CPR Survey (SA-CPR), which has been conducting tows routinely in the Southern Ocean since 2011. The course was particularly timely given the recent completion of a containerised laboratory with appropriate extraction facilities to enable the off-site processing of CPR silks under safe conditions. This will facilitate the in-house analysis of DFFE's growing collection of samples from the SA-CPR Survey.

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Figure 1. Clockwise, from top left: demonstration of the CPR internal mechanism, on board the research vessel RS *Algoa*; adjusting the silk spooling mechanism; retrieving the CPR between tows in the South Atlantic, on board the merchant vessel MV *Lodur*; learning about annotating the silk, and sample shipping protocols; CPR maintenance includes machining parts in the DFFE workshop; the trainees are presented with their certificates following completion of the course.

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