SCAR 2020

Antarctic Science - Global Connections

# SCAR OPEN SCIENCE CONFERENCE 2020

## SESSION 20

## THE EFFECTS OF CHANGE ON SOUTHERN OCEAN ECOSYSTEMS: UNDERSTANDING, MODELLING, PROJECTING, AND MANAGING CHANGE IN SOUTHERN OCEAN SPECIES AND FOOD WEBS

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# The state of Adélie penguin colonies in the Ross Sea Region

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Adélie penguin (Pygoscelis adeliae) colonies have been monitored by Antarctica New Zealand in the Ross Sea region since the early 1980s. This region contains around a third of all Adélie penguins in Antarctica and includes their most southerly recorded range. Annual census data are available for many key colonies making for a remarkably robust dataset. Adélie penguins are considered an indicator species due to their sensitivity to climate factors and role within the Antarctic food web. They subsist on a diet of krill and Antarctic silverfish making them primary trophic competitors with emperor penguins, Antarctic toothfish, and various whale species alike.

The harsh reality of life in the Antarctic creates an ecosystem uniquely vulnerable to change. 30 years of Adélie census data are explored to determine the role of environmental covariates as population drivers in the Ross Sea. Changepoint analysis reveals the clear increase in population growth of 5 Ross Island colonies, reinforcing the close link between Adélies and sea-ice conditions. The results highlight that trophic cascades can impose complex and far-reaching consequences on an ecosystem by disrupting the careful balance between Adélie penguins, their trophic competitors, and shared prey. In light of a rapidly changing climate and increasing human presence in Antarctica, continued monitoring of Adélie colonies is necessary in order to fulfil CCAMLR's ecosystem-facing approach to management. Historical observation techniques can be bolstered with novel and exciting remote-sensing technology, building and improving our understanding of ecology in the Ross Sea and wider Antarctic environment.

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# Biomarkers of Antarctic sediments from King George Island as indicators of sources and processes related to oceanographic conditions

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The abundance and biomass of the trophic web in Antarctic marine systems are influenced by the supply of organic matter that promote the plankton and, consequently, the other trophic levels. Although scientific knowledge identifying intense environmental changes, the fragility of this ecosystem is still little perceived. One of the ways to understand the complexity of this environment is the use of biogeochemical tools, such as the characterization of organic matter, together with ceanographic information. This study used sediment samples from Admiralty Bay, King George Island and analised short cores (25cm) collected at different points inside the Bay and in the Bransfield Strait characterizing granulometry, surface area and the molecular composition of lipids (sterols). A biogeochemical model is proposed to assess the biomarkers variability in function of oceanographic and environmental conditions. The total concentrations of sterols at depths of 100, 300, 500, 700 and 1100 m were 8.5, 17.7, 11.1, 8.3 and 13.4 ug/g, respectively. Phytosterol concentrations are higher in relation to animal sterols at all points collected, indicating a greater contribution of photosynthetic organisms to local organic matter. The variations in concentrations in the localities suggest a different deposition dynamic for each sampled point, mainly in 300m, a region that presented the highest concentrations of total sterols. The variability in hydrographic regimes, ice cover, light, temperature, resurgence zones, climate, physical and chemical factors influence the quantity, quality and origin of the organic carbon that reaches this ecosystem.

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# SOOSmap: Southern Ocean data at your fingertips

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Southern Ocean biological and ecological data are scattered and challenging to bring together. However, scientific communities are working to standardise and aggregate observations into useful, circumpolar datasets that can answer broad scientific questions about both process and patterns. The Southern Ocean Observing System (SOOS), as part of its quest to develop a sustainable system of ocean observations, is working to encourage the integration of these datasets. SOOS is committed to helping our community maximise the value of field work in remote areas,

We present SOOSmap (http://www.soosmap.aq/)- a map-based portal where you can filter, query and explore datasets in your browser before downloading just the datasets that you need. SOOSmap is a collaboration between SOOS and the European Marine Observations and Data Network. SOOS is an interdisciplinary community and we are working with a large number of data providers to stock SOOSmap with biological, ecological, chemical, and other datasets.

SOOSmap is the linchpin of our efforts to smooth some of the differences in data sharing cultures among the various scientific disciplines that comprise the SOOS community. The process of negotiating a pathway to make data available through SOOSmap helps find common ground in fundamental issues such as data formats and the balance between the intellectual rights of data producers and the community benefit of making data available for reuse.

SOOSmap is a work in progress and we will share our progress and invite new partners to help us make it work for all Southern Ocean researchers.

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# CCAMLR's challenge in managing the Southern Ocean under environmental change

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Climate change is causing dramatic changes in Southern Ocean ecosystems. The region is experiencing warming, freshening, acidification and reductions in sea ice all with uncertain and complex implications for Southern Ocean ecosystems. The Convention on the Conservation of Antarctic Marine Living Resources demands a precautionary, ecosystem-based approach which includes managing for environmental change. Here we highlight efforts that the Convention's 26-member governing Commission (CCAMLR) has made in managing for climate change. This includes having climate change as an ongoing agenda item, adopting a Climate Change Resolution in 2009 and in 2016 adopting a Conservation Measure towards protecting and studying areas surrounding the Antarctic Peninsula which have experience ice-shelf retreat or collapse. However, in recent years, CCAMLR has struggled to move further and the ongoing threat of climate change and potential overfishing in the Southern Ocean urgently demand more precaution. Efforts to adopt a Climate Change Response Work Plan, to develop climate change implication statements, and to update the outdated 2009 Climate Change Resolution have been met with hard political resistance by some Member States. Meanwhile, CCAMLR has also not created a network of marine protected areas, which can help with resilience to environmental change. Drawing on lessons from around the world, this research highlights best practices for managing marine living resources under climate change scenarios. We close with highlighting CCAMLR's opportunity for leadership to implement best practices, their responsibility to uphold the Convention and the need to work beyond political barriers in moving towards stronger management action on climate change.

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# New challenges to achieve a precautionary and ecosystem management of the krill fishery

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Although the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) has successfully managed fisheries in the Southern Ocean, the observed deep environmental changes, especially in the Atlantic sector, which is the area where krill fishing mainly occur, are imposing new challenges to achieve a precautionary and ecosystem management of the krill fishery. The current catch limits has set over regional scales, overlooking small-scale processes such as the krill availability and predator feeding. Climate-driven contraction of krill distribution, local decrease in krill abundance, recovery of cetacean populations and the potential increase in competition between krill predators and fisheries arise as major concerns that need to be addressed. The increased spatial and temporal concentration of the fleet, coupled with synergistic effects of climate in coastal areas may have impacted penguin populations in years of low productivity. For the first time in more than three decades, fishery-related indicators that had been usually stable, started to show negative trends in last couple of years in some areas that have been persistently used for fishing activities, a warning sign that highlight the need for action. In this regard, environmental monitoring data that can identify increased ecosystem variability associated with climate change, regular acoustic monitoring at multiple scales capable to quantify intra and inter- seasonal krill abundance and flux, and the adoption of MPAs and new spatial regulations (including smaller scales than regional scale) for catches allocation and limits, are key elements in the conservation and ecosystem-based management approach.

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# The importance of Antarctic krill in biogeochemical cycles

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Antarctic krill (Euphausia superba) are best known as prey for whales and penguins - but they have another important role. With their large size, high biomass and daily vertical migrations they transport and transform essential nutrients, stimulate primary productivity and influence the carbon sink. Antarctic krill are also fished by the Southern Ocean's largest fishery. Yet how krill fishing impacts nutrient fertilisation and the carbon sink in the Southern Ocean is poorly understood. In this talk I will present our synthesis which shows fishery management should consider the influential biogeochemical role of both adult and larval Antarctic krill. I will also discuss a new project about to begin linking biogeochemical and ecological numerical models for the Southern Ocean krill ecosystem, and how they can be used to investigate the impacts of climate change and fishing on krill.

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# What will happen to Southern Ocean ecosystem services in the 21st century?

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The Southern Ocean supports ecosystem services that are important at a global scale. Climate change and the impacts of human activities (fisheries, tourism and scientific research) will affect the demand for, and the provision of, these services into the future. This paper synthesizes recent assessments of the current status and expected future changes in Southern Ocean ecosystems to evaluate the consequences of these changes for the provision of ecosystem services, as part of the first Marine Ecosystem Assessment for the Southern Ocean (MEASO). Based on this synthesis, we provide a high-level assessment of potential direction and magnitude of climate change impacts on ecosystem services. We then use a qualitative network representation to explore the implications of connections and interdependencies. This analysis reveals a complex suite of interdependencies, from changes in climate-related drivers to ecosystem services, including feedbacks across other linked drivers such as fishing. We explore this complexity in detail, focusing on three key services (the Antarctic krill fishery, storage of blue carbon and tourism), tracing the consequences of climate change from physical drivers through to biological impacts and on to the benefits obtained by humans. We relate these to current and future demand for the services, and identify the main global and regional policy frameworks that could be used to manage risks to them in a changing climate. Increased consideration of the linkages and feedbacks between drivers and ecosystem services will be required to underpin robust management responses into the future.

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# Oceanic fronts and ecosystems in the Southern Ocean: a review

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A unique aspect of the Southern Ocean's physical environment is that it hosts numerous fronts: sharp boundaries between waters with different characteristics. Fronts are known to be of great importance to the Southern Ocean environment and the ecosystems it supports.

The great advances in biotelemetry tools for animal tracking and the resulting fine-scale animal movement data, coupled with the availability of higher resolution ocean observations from satellites, have recently enabled identification of relationships between marine animals and complex, mesoscale ocean processes. The biota of the Southern Ocean are broadly structured around the principal frontal features of the region: The fronts, by their ability to suppress horizontal exchange of tracers, both create and delimit ecological niches occupied by particular species, supported by water masses with similar characteristics. The challenge for biologists is to integrate observations of animal movements and feeding with the fine-scale physical and biogeochemical properties of Southern Ocean fronts.

Here we review the rapid advances made in understanding Southern Ocean fronts over the last decade and discuss the implications for Southern Ocean ecosystems and the broader climate system. We address the controversy of whether the locations of Southern Ocean fronts have shifted as a result of ongoing climate change, and how the choice of frontal definition can impact the conclusions of a study.

We provide a ‘Southern Ocean fronts User Guide’ aimed at the broader scientific community to facilitate future research with advice on how to best exploit new data and techniques to answer outstanding questions.

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# Trends in hydrological, phytoplankton composition and fluorescence parameters in the Pacific sector of the Southern Ocean

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This study investigates changes in surface (<10 m) hydrological, phytoplankton composition and fluorescence parameters measured along a repeated transect over 10 years in the Pacific sector of the Southern Ocean (40-70°S, 130-160°E). Sea surface temperature and salinity values were high in the Subtropical Zone (STZ) and mostly decreased southward. Salinity was very constant in the Polar Frontal Zone (PFZ) region with seasonal and interannual variability less than 0.1. Nitrate, phosphate and silicic acid concentrations increased southward with the lowest values in the STZ. A marked increase in nitrate and phosphate was observed in the Sub-Antarctic Zone (SAZ) and reached maximum values in the Southern Zone (SZ). In contrast, silicic acid concentrations were low (< 3 uM) in the SAZ, with values greater than 5 uM only observed in the PFZ. Chlorophyll concentrations were moderately high (> 0.1 mg/m3) in the STZ and SZ, but low in the PFZ. Microphytoplankton were abundant in the STZ, low in the SAZ and increased southward reaching a peaked (> 80%) south of the AZ. In contrast, there was an opposite trend in the distribution of nanophytoplankton, which had a maximum abundance in the SAZ. Picophytoplankton were abundant in the STZ but decreased southward. Photochemical quantum efficiency of photosystem II (Fv/Fm) varied across oceanic zones, delineated by the fronts. Similar to the trend of the microphytoplankton, high Fv/Fm values were observed in the STZ and AZ is consistent and low in the SAZ and PFZ.

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# Marine Ecosystem Assessment for the Southern Ocean (MEASO): process, outcomes and strategy for delivery of the first assessment

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The first Marine Ecosystem Assessment for the Southern Ocean (MEASO) aims to provide an up-to-date assessment of the status and trends of marine habitats, species, food webs and ecosystem functioning around Antarctica. The results of the assessment are synthesised to address four challenges for policy makers: (1) maintenance of ecosystem services, (2) identification of areas in the Southern Ocean requiring specific attention, (3) establishing an observing system within the Southern Ocean Observing System (SOOS) that focuses on sentinels of change, and (4) requirements for managing change around coastal Antarctica. The process and outcomes from this assessment will be presented. The strategy for delivering results at the international level to stakeholders, policy-makers and the wider public will be detailed, including using a Summary for Policy Makers (infographics and key messages, e.g. https://twitter.com/MEASO20), on-line resources in the Southern Ocean Knowledge and Information (SOKI) wiki (http://soki.aq/display/MEASO), and the publication of over 20 papers contributing to the assessment in an eBook through the Frontiers in Ecology and Evolution (co-listed in Frontiers in Marine Science, and Frontiers in Environmental Science). The contributions of over 140 marine experts from the Southern Ocean community (including ICED, SCAR, SOOS, CEP, SC-CAMLR, IWC) will be celebrated.

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# Measuring krill avoidance behaviour

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Understanding krill avoidance behaviour will help us assess the efficacy of net sampling and contribute to our understanding of krill predator energetics. Here, we examine the effect of fishing on krill swarm structure during and acoustic-trawl survey carried out in East Antarctica. We extend the conventional two-dimensional (depth-distance) view of active acoustics into three dimensions using multi-beam instruments that enable us to observe, rather than infer krill swarm volume, and so sample krill in a manner in line with krill predators. Krill swarm internal density, inter swarm distribution are related to the local current field and examined in three categories: before, during and after fishing.

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# What is the sea slug Doris kerguelenensis feeding upon in Deception Island (South Shetland Is., Antarctica)?

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Doris kerguelenensis is an Antarctic heterobranch mollusc feeding on several demosponges and hexactinellid sponges. To assess the contribution of several sponge species to its diet at Deception Island we used stable isotopes of C and N, as well as fatty acids. We examined the demosponges Axinella crinita, Dendrilla antarctica, Hemigellius pilosus, Kirkpatrickia variolosa, Mycale acerata, Sphaerotylus antarcticus, and Haliclona sp. We also analyzed the macroalgae Desmarestia anceps and Himantothallus grandifolius, and phytoplankton. D. anceps was the most 13C depleted one and phytoplankton the most enriched. The δ13C values of sponges and D. kerguelenensis laid in between. The δ15N values of A. crinita, D. antarctica, M. acerata and Haliclona sp. suggested a trophic position between 2-3, and for H. pilosus and S. antarcticus between 3-4. Kirkpatrickia variolosa was in between the two groups. The δ15N values of D. kerguelenensis revealed a trophic position from 3-4. All sponges and D. kerguelenensis had high levels of 15:0 and EPA and low levels of arachidonic acid, largely differing from macroalgae. Fatty acid profiles of A. crinita, D. antarctica, K. variolosa, M. acerata, S. antarcticus, and Haliclona sp. were similar to phytoplankton, but D. kerguelenensis and H. pilosus were enriched in 17:0, 20:1n9 and 20:2. D. kerguelenensis, A. crinita, D. antarctica, K. variolosa, Haliclona sp. and S. antarcticus shared a long chain fatty acid absent in phytoplankton and macroalgae. The overall evidence suggests that A. crinita, D. antarctica, K. variolosa and Haliclona sp. are the most likely prey of D. kerguelenensis at Deception Island.

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# Primary productivity and phytoplankton community structure associated with deep chlorophyll maxima (DCM) over the Southern Kerguelen Plateau

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Deep chlorophyll maxima (DCM) occur as distinct peaks of elevated chlorophyll deep within the water column. Despite often being located at depths where light availability is minimal, they can be highly productive and of significant biomass. Their close proximity to deep, nutrient-rich water, may be a possible driver of DCM development. In waters surrounding the Polar Front, high concentrations of silicate and nitrate are believed to support DCMs composed of large diatoms and may contribute to significant carbon and silica flux. However, DCMs are not a persistent feature in the Southern Ocean so their location and biomass cannot be easily predicted or incorporated into models of Southern Ocean productivity. In addition to this, questions still remain about whether phytoplankton cells in the DCM have sunk from surface layer growth or have been entrained there through lateral advection of coastal or sea ice blooms.

An oceanographic and ecological survey (K-Axis) was undertaken during Jan-Feb 2016, over the southern Kerguelen Plateau. In a series of transects, a total of 42 CTD stations were sampled for primary productivity and phytoplankton community composition. A DCM was observed at 24 of these stations, with some comprised of dense diatomaceous mats. Abundant krill, whales and penguins were also observed in these regions. In this presentation, the environmental factors driving the productivity and community composition of DCMs will be assessed. The contribution that DCMs may have on carbon and silica export in this region will also be discussed.

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# Primary Productivity Under a Changing Light Environment

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The ability to adapt to a seasonal light regime is one of the most important prerequisites for the Antarctic seaweeds ecological success. Photosynthesis is markedly seasonal in the Antarctic region and persistence of seaweeds depends on their capacity to maintain a positive carbon balance (CB). Principally, the CB is affected by light availability, and a positive CB in Antarctica is only present during the ice-free periods. Studies were performed in Potter Cove, Isla 25 de Mayo/King George Island where climate warming has induced a severe glacial retreat and has opened newly ice free areas. Seaweeds have been colonizing these areas, potentially resulting in higher productivity and carbon sequestration. Photosynthetically active radiation (PAR, 400-700 nm) and CB calculations of key seaweed species were performed over the last decade with the aim of analyzing changes in CB in response to the changing PAR. The glacier melting process during the austral summer resulted in an increased sediment run-off, and a reduced light penetration into the water column, and negative CB values in seaweeds growing in these areas. On the contrary, warmer winters and springs resulted in earlier sea-ice melting, causing increases in the annual light budget and positive CB. Thus, in this study we discuss changes in primary productivity in response to the changing Antarctic light environment and its potential implications for the seaweed community and the rest coastal ecosystem. Finally, these studies require cross-station and international collaboration, as a way to understanding the regional variability in the responses of the biota.

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# A neoplasm outbreak in Antarctic fish

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Changing Antarctic climates may place organisms under stressors altering disease resistance. During the 2018 austral autumn, we observed a significant number of crowned notothen (Trematomus scotti) bearing substantial neoplasms. The growths affected approximately 30% of over 200 T. scotti individuals collected by trawling in Andvord Bay, West Antarctic Peninsula. The puffy, pink growths covered about 10-30% of the body surface of affected fish excluding the snout and fins and generally in one contiguous patch, rather than many isolated spots. We also found an individual of another species, the painted notothen (Lepidonotothen larseni), with similar growths in North Dallmann Bay, 90 nautical miles north of Andvord Bay, which with other fjords and bays are hotspots of biodiversity and abundance of fish and other megafauna.

Neoplasia are greatly understudied in Antarctic fish. Antarctic fish researchers we contacted reported either not seeing, or rarely seeing specimens with apparently similar neoplasms. We conclude that similar neoplasms may have existed in Antarctica but not at the magnitude of the outbreak we encountered.

To raise awareness of potential pathogenic outbreaks in Antarctic fish, we will: 1) describe the outbreak we observed, 2) provide evidence on the nature of the pathogenic agent, and 3) disseminate suggestions for collecting and preserving samples for identification of the etiological agent and the diagnosis of any new diseased fish encountered.

With global change affecting the WAP more than any other part of the globe outside the North Pole, it is urgent to assess the potential for dormant pathogens to become infective.

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# Quantifying the quality of Southern Ocean sponge data for better monitoring, management, and assessment of impacts

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Sponges can be substantial semi-permanent components of benthic polar seafloor habitats, supporting tens of species and thousands of individual seabed animals per m2. They play a key role in ocean nutrient cycling through filtration and blue carbon storage and burial, due to their sporadic fast reproductive and growth responses, large sizes, dominance in many communities, and long life. Good quality temporal and spatial data coverage of sponge species, high-resolution taxonomy, and life processes, is vital in order to better understand sponge diversity and distribution. This will enable meaningful (VME) monitoring and modelling of impacts to sponge communities. This in turn will aid making authoritative decisions in relation to the management and conservation of vulnerable habitats. Southern Ocean sponge data has been reviewed using newly developed quality control information provided by the World Register of Marine Species. This assessment evaluates the current variability in sponge data quality across the Southern Ocean, including taxonomic, spatial, and temporal resolution; the quality of information in differently protected regions; and areas that are currently or in the future, predicted to be undergoing rapid human-mediated and/or climatic changes. Strengths and weaknesses of our current data on sponges are highlighted. Emphasis is placed on the importance of good quality data on sponges for understanding the impacts of current and future climate and/or anthropogenic impacts and management, as well as the potentially increasingly important role that sponges could play in relation to blue carbon feedbacks on climate change, through sequestration on polar seabeds.

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# Monitoring 20 years of inter-regional changes in phytoplankton biomass off the Antarctic Peninsula using ocean colour remote sensing

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The marine ecosystems off the Antarctic Peninsula are amongst the most impacted by climate change, particularly by ocean warmth and ice melting. One of the main predicted consequences for marine communities are structural changes to the water column, such as increased stratification. Consequently, changes in the structure and composition of more sensitive biological communities, such as phytoplankton, have already been observed. Due to their vital role as the main marine primary producers, it becomes instrumental to monitor phytoplankton biomass and community changes. However, in-situ sampling in the Antarctic Peninsula is scarce, discrete and, typically, highly limited in time and space. Ocean colour remote sensing (OCRS) can complement in-situ data, enabling a continuous flow of data with good spatiotemporal coverage. While sea ice and cloud coverage are strong limitations, the advent of robust, high-resolution, multi-sensor ocean colour products will contribute to establish OCRS as a tool to monitor phytoplankton in Antarctic waters. This work takes benefit of two robust in-situ (10-year) and remote sensing (20-year) datasets to evaluate changes in phytoplankton biomass. Analyses performed were focused on phytoplankton biomass, uncovering its seasonality and identifying and extracting summer trends and anomalies across the Antarctic Peninsula. Subsequently, specific regions were evaluated through OCRS and compared with the in-situ data collected during summer cruises. Results exhibit significant inter-regional variability, as distinct characteristics and trends were observed. Results are expected to contribute to the existent knowledge on biological communities in the Antarctic Peninsula, establishing OCRS as an essential tool for monitoring the Antarctic ecosystem.

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# Springtime rates of coincident inorganic and organic nitrogen and iron uptake across the Atlantic sector of the Southern Ocean

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Southern Ocean phytoplankton are thought to switch from reliance on nitrate to reliance on forms of recycled nitrogen (N) (e.g., ammonium and urea) over the course of the growing season as iron limitation sets in. This switch represents the moment at which the Southern Ocean ecosystem stops sequestering atmospheric $CO_2$. However, the seasonal evolution of the upper Southern Ocean N cycle is poorly understood, in part due to a scarcity of data from non-summer seasons. To better understand springtime N dynamics, we measured size-fractionated rates of net primary production, N (nitrate, ammonium, urea) and iron (labile inorganic and siderophore-bound) uptake throughout the euphotic zone, and characterized the phytoplankton community at four stations (Marginal Ice Zone, Open Antarctic Zone, Polar Frontal Zone, Subantarctic Zone) during the 2019 Southern oCean seAsonal Experiment (SCALE) cruise. At all stations, picophytoplankton (0.3-3 µm; eukaryotes and prokaryotes) were numerically dominant and cell numbers increased northwards. Carbon biomass was dominated by larger phytoplankton groups, mainly diatoms, with a lesser contribution from dinoflagellates and silicoflagellates. Using our measured rates of coincident N and iron uptake, we can determine the primary N source consumed by each phytoplankton size-class, with implications for their role in the biological carbon pump, and evaluate the strategy of each size-class with regards to iron. These data constitute the first springtime rates of coupled N and iron uptake for the Atlantic sector of the Southern Ocean and should yield insights into the driver(s) of the switch from new to regenerated N dependence by phytoplankton.

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# Drift algae accumulation and their important role as ecological subsidies in Antarctica

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Many aquatic communities rely on external subsidies that provide energy and nutrients. Drift algae can function in this way, and in polar regions, the processes producing detached algae and their subsequent accumulation on the bottom can be controlled by ice scouring. Observations made in Fildes Bay (Antarctica) suggest that the local disturbance in shallow soft bottoms by icebergs can produce long and narrow hollows in the seabed (i.e., ice pits). These bottom features tend to accumulate detached macroalgae between depth of 12 and 18 m. These accumulations are usually colonized by conspicuous benthic faunal assemblages. Although drift algae appear to be a major ecological subsidy on soft bottoms in Antarctic, their deposition in ice pits have been poorly described, and their ecological role remains unknown. The objective of this study was to characterize the distribution of drift algae in the subtidal soft bottom habitats in Antarctica and document its importance in creating habitat and driving benthic community diversity. A total of 17 ice pits of 12m2 average area were sampled. A high species richness was observed (16 macroalgae and 25 faunal species) comparable to adjacent benthic rocky reefs. Ice pits thus appear to be key feature of subtidal habitats in soft-bottom regions, where algae accumulated in them provide both habitat and food resources to a surprisingly high biodiversity of invertebrates and are likely important breeding areas for isopods, amphipods and fish. More information is needed o the extent of ice pits and their stability over time.

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# Species distribution models for mapping Antarctic Vulnerable Marine Ecosystems: A review of promising methodologies.

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Many taxa that are key components of benthic Antarctic ecosystems are long-lived, have slow growth rates and low productivity. These qualities make them vulnerable to the impacts of bottom fishing and other activities and collectively these taxa form Vulnerable Marine Ecosystems (VMEs). Globally VMEs are the subject of targeted management actions as required by inter alia UN General Assembly resolution 61/105, and in the Southern Ocean under conservation measures adopted by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). However, the VMEs around the Antarctic continental shelf are poorly known, due to the remoteness of Antarctica and the sparsity of observations. Predictive modelling methods, that combine sparse observations with full-coverage environmental data, can fill this gap and provide continuous mapping of suitable habitat or the likelihood of species' occurrences across broad regions of un-sampled seafloor. There are a plethora of analysis methods suitable for predicting the distribution of species. This study reviews and evaluates state-of-art methods with respect to the characteristics of existing VME taxa observations and likely applications of VME predictive modelling. Some of the approaches considered include joint species distribution models, deep learning algorithms, hybrid models and combined data models. Consideration is given to the ability of methods to assimilate rare species, combine data from different sources, appropriately characterise uncertainty and their propensity for over-prediction. Advantages and disadvantages of the approaches are discussed, and candidate methods identified for further investigation using a continent-wide dataset of annotated seafloor imagery and fine-scale environmental predictors.

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# Vertical variability in the balance between phytoplankton growth and microzooplankton grazing in the Ross Sea region during summer and early-autumn

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The Ross Sea region is one of the most productive areas of the Southern Ocean. The fate of primary production depends critically on the balance between phytoplankton growth and loss rates, which are poorly constrained. In this study we measured growth and microzooplankton grazing rates during two voyages conducted in February-March (2018) and January-February (2019) in oceanic waters off the continental shelf. We conducted dilution grazing experiments at six depths within the euphotic zone to investigate the variability of growth and grazing rates with vertical physico-chemical gradients including irradiance. This depth-resolved approach provided the first parallel estimates of water-column integrated phytoplankton production, consumption and accumulation rates in the Ross Sea region. Growth rates were higher than grazing in the surface mixed-layer, and tended to decrease with depth, while grazing rates remained relatively constant vertically. This resulted in a net accumulation of phytoplankton in the surface mixed-layer that reversed into net consumption below a certain depth. This 'compensation' depth varied among stations. Vertical variability was more evident in the 2019 than the 2018 campaign conducted later in the season and when growth rates were lower (μ.2019 = 0.32±0.19 day-1 , μ.2018 = 0.08±0.11 day-1) and more tightly balanced by grazing (μnet.2019 = 0.25±0.17 day-1 , μnet.2018 = -0.11±0.34 day-1). Understanding the factors that control phytoplankton growth, microzooplankton grazing, and the balance between these rates is crucial to predict the effects that projected environmental changes will have on the trophic and biogeochemical functioning of the Ross Sea region pelagic ecosystem.

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# What over 20 years of sediment trap data can tell us about ecosystem variability

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Our understanding of temporal variability in the Southern Ocean ecosystem is hampered by logistical constraints that come with working in this remote region of the planet. One solution for this problem is automated moorings; for example, at the Southern Ocean Time Series site (SOTS) at 47˚ S in the subantarctic. Sediment traps have been deployed at the mooring site since 1998, located at different depths below the mesopelagic zone to measure the variability in sinking organic carbon flux. These devices also collect “swimmers”; live zooplankton swim into the traps and are killed by preservative but are subsequently separated from the smaller size fraction of passively sinking particles. Zooplankton play an important role in the food web as they transfer energy from phytoplankton to higher trophic levels including fish and marine mammals. Due to their short life span, they are sensitive to environmental change and used as an indicator of the structure and health of the Southern Ocean ecosystem. Here, we will present a look at this zooplankton time-series with a focus on the main groups, i.e. copepods, amphipods, pteropods, chaetognaths and ostracods in relation to carbon flux and environmental drivers such as temperature. With this important time series, we can increase our understanding of seasonal and inter-annual variability of plankton composition and identify environmental drivers responsible for community shifts. Finally, we can predict future changes in ecosystem functioning that can inform conservation and management decisions in the subantarctic Southern Ocean.

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# Effects of ocean acidification on Antarctic marine organisms: a meta-analysis

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Southern Ocean waters are amongst the most vulnerable to ocean acidification. The projected increase in the $CO_2$ level will cause changes in carbonate chemistry that are likely to be damaging to organisms inhabiting these waters. A meta-analysis was undertaken to examine the vulnerability of Antarctic marine biota occupying waters south of 60°S to ocean acidification. This meta-analysis showed that ocean acidification negatively affects autotrophic organisms, mainly phytoplankton, at $CO_2$ levels above 1000 µatm and invertebrates above 1500 µatm, but positively affects bacterial abundance. The sensitivity of phytoplankton to ocean acidification was influenced by the experimental procedure used with natural, mixed communities being more sensitive than monospecific cultures. Invertebrates showed reduced fertilization rates and increased occurrence of larval abnormalities, as well as decreased calcification rates and increased shell dissolution with any increase in $CO_2$ level above 1500 µatm. Assessment of the vulnerability of fish and macroalgae to ocean acidification was limited by the number of studies available. Overall, this analysis indicates that many marine organisms in the Southern Ocean are likely to be susceptible to ocean acidification, thereby likely changing the ecosystem structure and dynamics of the Southern Ocean in the future with significant ramifications for not only the Southern Ocean but also the feedbacks it has to global climate change.

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# Effects of iron chemistry for its bioavailability and impact on primary producers and microbial and viral community in contrasting Southern Ocean provinces

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Organic ligands such as carbohydrates and exopolymeric substances (EPS) are known to complex with iron (Fe) and influence its bioavailability to phytoplankton. In this work, we addressed how Fe enrichment associated to organic binding ligands influences Fe chemistry as well as its bioavailability and productivity for phytoplankton, and microbial dynamics in the Drake Passage and the West Antarctic Peninsula. At each station, we performed short-term (24h) and long-term (6d) shipboard incubations with the in-situ microbial community before (control treatment) and after addition of different Fe-binding ligands (total Fe added 0.9 nM), including: the siderophore desferrioxamine B, two carbohydrates (glucuronic acid and carrageenan) and two different bacterial exopolycarbohydrates (L6 and L22, referred as EPS). Our results showed significant correlations between Fe uptake rates and the measured inorganic Fe concentrations, a form that is known to be bioavailable. Better correlation was obtained for larger phytoplankton considering labile Fe concentrations, suggesting that this chemical fraction could be an interesting parameter to estimate Fe bioavailability to large plankton assemblages, relevant to carbon export in the Southern Ocean. Moreover, iron bioavailability was correlated to primary productivity for the 2 Drake Passage sites, suggesting that iron chemical speciation could be used as a first level predictor for productivity in this region. In contrast, more complex parameters are involved in the control of microbial and viral communities, with carbon availability as a potential important driver.

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# Importance of refractory ligands and their photodegradation for iron oceanic inventories and cycling

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Iron is an essential micronutrient that limits primary production in up to 40% of the surface ocean and influences carbon dioxide uptake and climate change. Dissolved iron is mostly associated with loosely characterized organic molecules, called ligands, which define key aspects of the iron cycle such as its residence time, distribution and bioavailability to plankton. Models based on in-situ ligand distributions and the behaviour of purified compounds include long-lived ligands in the deep ocean, bioreactive ligands in the surface ocean and photochemical processes as important components of the iron cycle. Herein, we further characterize biologically refractory ligands in dissolved organic matter (DOM) from the deep ocean and labile ligands in DOM from the surface ocean and their photochemical and biological reactivities. Experimental results indicate that photodegradation of upwelled refractory iron-binding ligands can fuel iron remineralization and its association with labile organic ligands, thus enhancing iron bioavailability in surface waters. These observations better elucidate the roles of biologically refractory and labile molecules and global overturning circulation in the ocean iron cycle, with implications for the initiation and sustainment of biological activity in iron-limited regions and the residence time of iron in the ocean.

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# Coupling environmental drivers to the composition and production of the phytoplankton community in the Ross Sea during summer 2018 and 2019.

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The Ross Sea is one of the most productive regions of the Southern Ocean with an elevated net primary productivity (NPP) in spring-summer that fuels the food-web dynamics and sink of atmospheric CO2. As warming is prominent in the Southern Ocean, the changing environment will ultimately determine phytoplankton contribution to trophic and biogeochemical cycling in the Ross Sea. Samples of primary productivity and microbial community composition were acquired during two cruises conducted across the slope and oceanic region of the Ross Sea during February-March 2018 and January-February 2019. Phytoplankton biomass and composition were examined through the analysis of total and size-fractionated chlorophyll-a, flow-cytometry, microscopy and pigments quantified by High-Pressure Liquid-Chromatography and CHEMTAX. Primary productivity rates were estimated from 24-h 14C-incorporation incubations conducted with seawater collected at 6 discrete depths. Short-term Photosynthesis-Irradiance experiments were performed in parallel and daily water-column productivity calculated from estimated photosynthetic parameters. Chlorophyll a concentration was lower during 2018 (range = 0.025-0.45 mg/m3) compared to 2019 voyages (range = 0.25-2 mg/m3) yet, mostly allocated in the >20-um fraction during both campaigns. The community was dominated by diatoms and prymnesiophytes that often made up over 80% of total chlorophyll. NPP tended to be higher in 2019 compared to 2018. Depth-resolved NPP tended to be lower in 2018 (3 to 12 mgC/m3/day) compared to 2019 (3-25 mgC/m3/day) that occurred later in the season. The relation between oceanographic conditions, phytoplankton community composition and production estimated with different approaches is discussed in the context of projected environmental changes for the region.

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# Detecting, attributing and mapping ecological change in the Southern Ocean using joint species distribution models.

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The Southern Ocean supports exceptional biodiversity and productive and distinctive ecosystems as well as providing a range of critical ecosystem functions. The physical environment of the Southern Ocean has changed over the last 30 years and will continue to do so on a time scale of decades. However, a basic understanding of whether, how and why entire assemblages of species have changed, and are likely to continue to change, in response to environmental and other factors is lacking for most levels of the ecosystem. Here we examine key ecological time series data of demersal fish on the highly productive Kerguelen Plateau. We use the latest developments in spatio-temporal joint species distribution modelling to detect, quantify and map species and assemblage-level changes. Preliminary results will be presented on which species have responded to environmental and other changes, what factors are important in driving these changes, and which areas of the plateau are undergoing the greatest change. We will also discuss what we have learnt thus far in applying these relatively new models and how this information feeds into management initiatives.

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# Investigating the impacts of environmental variability on the Kerguelen Plateau Patagonian Toothfish fishery using spatio-temporal models

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The Kerguelen Plateau is a large, isolated submarine plateau in the southern Indian Ocean. The plateau is home to a significant Patagonian toothfish fishery, worth over USD50 million a year in the Australian sector alone, as well as being home to significant populations of seals, seabirds and whales. In 2016, the Australian longline fishery on the Kerguelen Plateau experienced lower than average catch rates. At the same time, the Kerguelen Plateau experienced a surface heatwave. A preliminary investigation concluded that the declining catch rates were unlikely to be caused by a decline in fish stock biomass, but instead could have been related to a change in fish catchability driven by environmental factors. Here we examine the influence of environmental variability on Toothfish catch rates over the last 20 years at both a coarse and fine spatial resolution. We combine the outputs from satellite products and oceanographic models with detailed catch data using spatio-temporal models. We present preliminary analysis and discuss how much of the variability in catch rates can be attributed to environmental factors, which factors are relatively important and map a time series of spatial changes in catch across the plateau. We also discuss the implications of these models for predicting environmental impacts on future catch and for management within the fishery.

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# Sediment load, iron and macronutrients in icebergs: their relationship and its implications for Antarctic coastal waters

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The sediment load of Antarctic icebergs varies five orders of magnitude from a few mg of sediment per liter to more than 10 g L-1. Similarly, the concentration of total dissolvable iron TdFe (i.e. particulate plus dissolved iron dFe) in Antarctic icebergs spans six orders of magnitude, while the dissolved phase only varies three. Iron fractions are more abundant in icebergs than in Antarctic seawater, indicating the potential fertilizing effect of icebergs in the Southern Ocean. The concentration of N, P and Si in icebergs is two orders or magnitude lower than Southern Ocean waters, pointing out to the possibility of a dilution effect of the macronutrients in areas where melt-water outflow is intense. Besides, when large amounts of sediments are released into coastal waters it can have a negative effect on phytoplankton and zooplankton due to shadowing and disruption of feeding respectively. Higher sediment load of individual icebergs was related only to higher TdFe, whereas the other parameters (i.e. dFe, N, P and Si) did not show any significant relationship. This implies that icebergs with higher sediment load present more iron (TdFe), but does not transform directly into its more bioavailable form (dFe). In summary, higher sediment load will have more severe effects on plankton without providing more nutrients (dFe, N, P or Si) to coastal waters. Therefore, under future freshening and glacier retreat scenarios, where icebergs may carry higher sediments load, their fertilizing effect may be similar while the negative effects on phyto- and zooplankton may become stronger.

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# Evaluation of Iron Sources in the Ross Sea

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A one-dimensional numerical model that includes the complex life cycle of Phaeocystis antarctica, diatom growth, dissolved iron (dFe) and irradiance controls, and the taxa's response to changes in these variables is used to evaluate the role of different iron sources in supporting phytoplankton blooms in the Ross Sea. Simulations indicate that sea ice melt accounts for 20% of total dFe inputs during low light conditions early in the growing season (late November-early December), which enhances early blooms of P. antarctica. Advective inputs of dFe (60% of total inputs) maintain the P. antarctica bloom through early January and support a diatom bloom later in the growing season (early to mid-January). In localized regions near banks shallower than 450 m, suspension of iron-rich sediments and entrainment into the upper layers contributes dFe that supports blooms. A seasonal budget constructed from the simulations shows that uptake by P. antarctica (solitary cells and colonies) accounts for the largest sink of dFe, with uptake by diatoms being the second largest sink. Remineralization of detritus by bacterial processes is the largest biological source of dFe. Sensitivity studies show that surface input of dFe from sea ice melt, a transient event early in the growing season, sets up the phytoplankton sequencing and bloom magnitude, suggesting that the productivity of the Ross Sea system is vulnerable to changes in the extent and magnitude of sea ice.

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# Machine learning for predicting marine invasive species in the Southern Ocean: a case study of the Australian Antarctic and subantarctic regions

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Marine invasive species (MIS) have established around every continent on Earth, except Antarctica. Changes in the climate have the potential to open Antarctic waters to the threat of MIS introduction. We use a novel machine learning algorithm to predict which currently known MIS could survive in shallow benthic ecosystems adjacent to Australian Antarctic research stations and subantarctic islands, where ship traffic is present and represents the most likely pathway by which MIS will arrive via hull fouling. We used gradient boosted machine learning (XGBoost) with four important environmental variables (sea surface temperature, salinity, pH, and nitrate) to develop models of suitable environments for each potentially invasive species. We then used these models to determine if any of Australia's three Antarctic research stations and two subantarctic islands could be environmentally suited for MIS now and under two climate change scenarios. Both seasonal and annual models indicate that the predatory sea star Asterias amurensis is a current and ongoing threat to all locations under both climate change scenarios (except Casey presently under the seasonal model). Up to 13 other species were also shown to be a risk, however the results were sensitive to the model used. Due to their isolation, endemic Antarctic benthic ecosystems are ill-prepared to cope with novel species. These endemic communities are already under threat as a result of climate change, and the addition of MIS could cause irreversible damage to these ecosystems.

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# Projected shifts in the foraging habitat of crabeater seals along the Antarctic Peninsula

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The crabeater seal exhibits one of the most extreme levels of dietary specialisation in mammals, feeding almost exclusively on Antarctic krill, inextricably linking the habitat use, life history, and evolution of this pinniped species to the distribution of its prey. We combined seals' movement and diving behaviour data with environmental variables to build a habitat model for crabeater seals (and putative krill distribution) from the fast-changing western Antarctic Peninsula (wAP). Projections for the future indicate that the foraging habitat of crabeater seals and inferred krill distribution will expand toward offshore waters and the southern sectors of the wAP, as a consequence of warming temperatures and changes in sea ice distribution. As krill biomass will likely be negatively affected by environmental changes, it follows that this expansion will result in a decrease in krill densities. These changes will have implications for land/ice based krill predators, such as seals and penguins, particularly in the northern wAP, the Scotia Sea, and the South Georgia Islands, as these areas depend on krill inputs from the central wAP to support the krill population.

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# A Closed, Subsurface Eddy Increases Residence Times within Palmer Deep Canyon

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Palmer Deep Canyon is a biological hotspot along the Western Antarctic Peninsula. The observation of persistent hotspots in association with submarine canyons along the peninsula has led to the 'canyon hypothesis' which relates local geological and physical oceanographic features to the hotspots. Historically, the upwelling of nutrient-rich Upper Circumpolar Deep Water to the surface mixed layer in the submarine canyon was thought to drive biological productivity, attracting krill and penguins to the region. However, recent observations of low surface residence times, lack of Upper Circumpolar Deep Water in the surface layer, and abundant surface nutrient concentrations at Palmer Deep Canyon have called the upwelling mechanism into question.

Sloped isopycnals and a subsurface particle layer observed over the canyon by three Slocum gliders in 2015 suggest the presence of a deep subsurface eddy. Neutrally buoyant particle simulations using the Regional Ocean Modeling System with 1.5 km horizontal resolution were used to test the hypothesis that residence times increase with depth within the canyon. Particles were seeded on a 4 km horizontal grid, every 2 days, at several depths over a 6-month simulation period in two austral summers. These simulations suggest that the deep eddy increases residence times and is the most coherent during the austral summer. In-situ images and water samples from the subsurface particle layer observed in 2015 and 2020 suggest that small detritus particles are retained within the canyon. These seasonal, retentive features of Palmer Deep Canyon could be critical to the establishment of the biological hotspot.

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# Status, change and futures of zooplankton and krill in the Southern Ocean

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Zooplankton play an important role in global marine ecosystems. In the Southern Ocean, zooplankton represent the largest proportion of biomass and perform a number of vital ecosystem functions. They are involved in sustaining an array of diversity and marine life, functioning as grazers of primary production, as predators, as prey of commercially valuable species (including fish and Antarctic krill) and higher trophic levels (including seabirds and marine mammals), biogeochemical cycling and provisioning international fisheries. Global change is expected to affect the structure and function of zooplankton assemblages in the Southern Ocean, which will have wide ranging implications for the ecosystem and the services they maintain. As a contribution to the Marine Ecosystem Assessment of the Southern Ocean, we review the current understanding of zooplankton assemblages within the Southern Ocean, with a particular focus on key taxa including. We provide an overview of observed and potential future responses of these communities to global change. We also explore areas of future research that can underpin robust projections of changes in these taxa across the Southern Ocean.

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# Integrating Climate and Ecosystem Dynamics in the Southern Ocean (ICED) programme

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The Integrating Climate and Ecosystems Dynamics in the Southern Ocean programme (ICED) is an international multidisciplinary programme focused developing integrated circumpolar analyses of Southern Ocean climate and ecosystem dynamics. ICED is a co-sponsored programme of the Scientific Committee on Antarctic Research (SCAR). ICED was developed with the support of SCAR, in conjunction with the Scientific Committee on Oceanic Research (SCOR), and the International Geosphere-Biosphere Programme (IGBP) and is a regional programme of Integrated Marine Biosphere Research (IMBeR). ICED is focussed on understanding the climate interactions in this globally important ocean, the implications of change for ecosystem dynamics, and the impacts on biogeochemical cycles. These aspects are crucial for supporting conservation and sustainable management approaches and evaluating the role of Southern Ocean ecosystems in the Earth System. ICEDs priority research areas over the coming years include 1) understanding and quantifying the state and variability of Southern Ocean ecosystems, 2) improving scenarios and projections of future Southern Ocean ecosystems at multiple scales, and 3) supporting sustainable Southern Ocean governance. ICED will also remain open to emerging ideas, new analytical approaches and technologies as aspects of Southern Ocean climate, ecosystem and biogeochemistry research progress. ICED will also continue to coordinate and develop a range of planned national fieldwork campaigns, foster integration through capacity development and outreach, and ensure alignment of our activities with other international research programmes. We encourage wide participation in the research goal and objectives of the ICED programme.

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# Lowered cameras reveal hidden seasonal and diel shifts in krill behaviors and vertical distributions

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For decades, Antarctic krill were considered to spend their adult lives occupying epipelagic depths. These surface layers form the focus of stock surveys crucial for fisheries management. However, recent research has revealed significant parts of the krill population are found deeper, often near the seabed, throughout the year. Using >125 hours of video observations of krill collected by a camera system profiling the entire water column, up to depths of 625m, along the Western Antarctic Peninsula during two seasons, we were able to quantify seasonal and diel krill vertical distributions and behaviors which have remained hidden from traditional survey methods. Our results suggest that most krill observed were either at depths too deep (i.e., < 200m) or densities too low (i.e., < 2 krill m-3) for traditional survey methods to detect. We can explain seasonal shifts in krill vertical distributions through changes in individual krill movement behaviors, which provides mechanistic insight and predictive powers. These individualized observations revealed krill were faster in late spring than autumn and were feeding primarily in the water column in spring and at the seabed in autumn. Besides presenting video footage of these krill behaviors, we will demonstrate the results through simulations of krill vertical distributions and energetic requirements from measured krill vertical velocities and swimming speeds. These observations provide quantitative insights into the role of krill in pelagic and benthic food webs and vertical nutrient fluxes, as well as for conducting stock surveys which underpin krill fishery management.

420

# Krill biomass survey for krill monitoring and management in CCAMLR Division 58.4.2-East

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Australia plans to conduct an Antarctic krill biomass survey in CCAMLR Division 58.4.2 East (50-80°E) from 23rd January to 25th March 2021, using the Marine National Facility RV Investigator. Historical fishing patterns suggest that future fishing grounds will likely form to the east of the 50°E meridian in the Indian Ocean Sector, which is within the target area of this survey. This area was last surveyed in its entirety fourteen years ago, therefore, by using the survey results we will update the krill biomass estimate with a view to revising the precautionary catch limit for krill in this area. Three krill observatory mooring systems will also be deployed during the survey to enable long-term monitoring of krill dynamics within the seasonal ice zone. The survey is also designed to improve our understanding of the connectivity of krill populations, and the overlap between krill and predator populations. Information obtained through the voyage will support design a tractable and sustainable long-term monitoring plan and spatial management of the krill fishery in East Antarctica. We will present an overview of both the voyage plan and how the information obtained from the voyage will be used to inform krill fishery management.

550

# A data-model comparison of marine primary productivity in the Last Glacial Maximum and the Last Interglacial

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We present a data-model comparison of marine primary productivity in the Last Glacial Maximum (LGM; 21,000 yr BP) and the Last Interglacial (LIG or marine isotope stage 5e; 127,000 yr BP), focusing particularly on the Southwest Pacific and the Southern Ocean. These two time slices represent a colder-than-present (LGM) and a warmer-than-present (LIG) climate, allowing us to evaluate the model's ability to represent contrasting climates. The simulations are run using the intermediate-complexity UVic ESCM v2.9, modified to include a calcifying plankton functional type and a prognostic iron cycle. We evaluate the model skill using the anomaly from a pre-industrial control simulation. Key metrics include surface air temperature, sea surface temperature, sea ice extent in the Southern Ocean, plankton biomass and net primary productivity (NPP), and sediment CaCO3 content. We focus on the relative change in marine ecosystems and primary productivity (both abundance and distribution) over glacial – interglacial timescales and infer what this could mean for future change over the next century.

1594

# A comparison of estimations of net community production in the Amundsen Sea polynya, Antarctica

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In Antarctic Polynya, where productivity is known to be high, it is important to estimate NCP accurately to understand the marine carbon cycle and further air-sea $CO_2$ flux by biological pumps. We used the difference of dissolved inorganic carbon (DIC) contents in the water column between the surface water and underneath the mixed layer deep water to determine NCP assuming that the deep water preserves the winter characteristics of dissolved inorganic content. This is true in the Amundsen Sea polynya (ASP) as the winter water is detected below the mixed layer. Various literature shows ambiguous definition of the reference depth between the surface and deep waters. We estimated NCP in the Amundsen Sea polynya applying various reference depths relevant to the biological production and vertical mixing. We employed the results from the expedition conducted in ASP during austral summer in 2011. Five reference depths were selected to represent the winter water for which biological activity paused; (1) potential temperature minimum depth (pTmin), (2) euphotic depth (Ed), (3) mixed layer depth (MLD), and (4) 100 m and (5) 200 m nominal depths. The ratio of DIC to total alkalinity (DIC/TA) was altered by biological activities in the surface water. When the DIC/TA ratio is close to the value of deep water, it closely matches the pTmin of the reference depth. The NCP is estimated using this method, 94 ± 43 mmol C/m²d (n=11) in the Amundsen Sea polynya.

1249

# Project SWARM: An integrated polar ocean observing system mapping the physical mechanisms driving a food web focused on an Antarctic biological hotspot

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The physical mechanisms that maintain and deliver phytoplankton and Antarctic krill biomass, potentially increasing prey availability to predators, are not well understood. For example, the short surface ocean residence time of 1-2 days over Palmer Deep is in conflict with the prevailing hypothesis that local growth supports phytoplankton at the base of the food web. Coincident measurements of phytoplankton, prey fields, and predator locations in their advective context are being made to establish the ecological importance of horizontal flow. To better understand these important mechanisms, we have deployed an integrated polar observatory consisting of high frequency radar, coordinated gliders, small boat surveys, and moorings. This integrated polar observatory enables us to simultaneously sample across the entire food web from the phytoplankton and prey fields to the top predators to understand the ocean features that support life in these polar systems. For the first time in this region, we have: 1) integrated sensors and technologies to simultaneously map phytoplankton blooms, krill aggregations, and top predator foraging relative to dynamic ocean features; 2) integrated these observations with a high-resolution (1.5 km) 3-D dynamic model simulation of the entire WAP coastal ocean to generalize our field measurements to other known hotspots along the WAP through simulation, and analyzed which physical mechanisms lead to the maintenance of these hotspots. Instead of local upwelling, we find that horizontal dynamics and tidal flows are more important to maintain these biological hotspots.

683

# Fish parasites as indicators of the state marine ecosystems in West Antarctic: parasite community of Notothenia coriiceps as an example.

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Environmental changes caused by the global warming and anthropogenic factors observed around the world are the most pronounced in Polar Regions. The aim of our study was to analyze the role of metazoan parasites of rock cod Notothenia coriiceps as potential indicators of marine ecosystem state of the Argentine Islands Archipelago, West Antarctica. The study was performed in 2014–2015 at the Ukrainian Antarctic station "Akademik Vernadsky". Totally more than 8,500 specimens of helminths were collected from 106 specimens of N. coriiceps and identified.
All fishes (100%) were found to be infected with helminths; 24 helminth species were identified. Eight species of acanthocephalans were recorded in 96.4% of fish with mean intensity (MI) 25.3. Five species of nematodes were found in 96.2% fishes; MI=14.8. Seven species of digenean trematodes were found in 94.3% of fishes; MI=33.7. Larval stages of cestodes were registered in 78.7% of fish; MI=10.3. Comparison of our data with the results of previous studies performed at the "Akademik Vernadsky" station in 2002 with the same methods (Zdzitowiecki, Laskowski, 2004) revealed significant changes in structure of the parasite community of N. coriiceps. Prevalence and abundance of six helminth species have changed in 3–20 times during last decade; the most prominent changes were documented in trematodes and cestodes with complex life-cycles which include 2–3 intermediate and paratenic hosts. In our opinion, these six species can be considered as potential indicator species for future monitoring studies of ecological and environmental changes in the Antarctic coastal and marine ecosystems.

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# Calving event modifies bloom phenology in the Mertz polynya

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Polynyas are areas of open waters surrounded by ice. They are subject to variability in winds and ocean circulation and are important sites of ecological productivity. In February 2010, the B09B iceberg collided with the Mertz Glacier Tongue, calving a 78x40 km giant iceberg which modified the entire icescape and primary productivity of the Mertz Polynya. In this study, we use satellite-derived ocean color and sea ice remote sensing to investigate the inter-annual variability trends and drivers of phytoplankton in the Mertz polynya over the past 21 years, with a focus on contrasting the pre-calving (1997 – 2010) and post-calving (2010 – 2018) periods. During the bloom period, we found so far: (i) an increase in sea-ice concentration, (ii) a later bloom start, (iii) a later ice-retreat time and (iv) a decrease in bloom duration. We attribute these results to the post-calving period, which clearly drove the trends in this study. The calving event resulted in significantly higher chl-a concentration, higher sea-ice concentration and lower sea surface temperature. Our results suggest a clear relation between the phytoplankton bloom and the sea-ice phenology. While satellite data are a useful tool to study long term variability in inhospitable areas like the Southern Ocean, we highly recommend the deployment of in situ platforms such as biogeochemical Argo floats in polynyas. The additional parameters would strengthen our comprehension of phytoplankton and physics changes that may have consequences for global circulation, carbon export, primary production, and higher trophic levels.

769

# Zooplankton community structure and dominant copepod population structure on the southern Kerguelen Plateau during summer 2016

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The influence of environmental factors on the horizontal community structure of zooplankton over the southern Kerguelen Plateau was investigated during summer in 2016. Zooplankton abundance ranged from 1,490 to 363,484 ind. 1000 m-3, with highest numbers observed in the eastern and central areas. Based on cluster analysis the zooplankton were divided into 6 groups (A–F), although their distribution was not definitively associated with water masses and frontal systems. Groups A to C had abundant zooplankton and were consistent with areas of high chlorophyll a concentration. Group D represented low abundance near the southern Antarctic Circumpolar Current front, while group E was clustered south of the Southern Boundary and group F comprised two stations to the east of the Fawn Trough. General linear modelling (GLM) highlighted both fronts and primary production as drivers of overall zooplankton distribution. This was not the case for drivers of population structure of key species, a result of species-specific life history strategies.

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# Oceanographic processes and biological responses around the Northern Antarctic Peninsula: the case of cryptophytes.

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The Northern Antarctic Peninsula (NAP), which encompasses the Bransfield Strait, the southernmost section of the Drake Passage, the northwestern Weddell Sea and the region north of the Western Antarctic Peninsula (WAP) shelf, is primarily important because of the evolving changes on ecosystems and ocean-atmosphere-cryosphere dynamics related to climate change issues. The Brazilian High Latitudes Oceanographic Group (GOAL) was formed in 2002 within the scope of the Brazilian Antarctic Program (PROANTAR) aiming to contribute to the understanding of the relationship between the marine biota, from microorganisms to top predators of the Southern Ocean food web, and the physical-chemical environment. For 15 years, we have been studying the ecology of the phytoplankton community around the NAP. We have observed that cryptophytes are gradually outgrowing other phytoplankton groups (e.g. diatoms and Phaeocystis antarctica) in areas under the influence of both sea-ice and glacial melting processes. Under such conditions, very shallow upper mixed layer depths confine cryptophytes near the surface (0–25 m), exposing them to high irradiance. This study shows that the recurrent growth and dominance of cryptophytes in the NAP region can be attributed to their unique abilities not only to grow at low micronutrient conditions, but also to thrive under extreme light levels normally found in confined stratified upper layers in summer. Such conditions are becoming more frequent and intense in NAP coastal waters and will probably have significant implications for the primary producers' community structure and, therefore, to the regional food web and biodiversity patterns in the region.

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# Variability and adaptation of Phytoplankton community in the frontal zones of Southern Ocean

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Phytoplankton biomass (chlorophyll-a) and community in the water column were analyzed in various frontal regions in the Subtropical front (STF), Sub-Antarctic front (SAF), Polar Front-1 (PF1) and Polar Front-2 (PF2) in the Indian Ocean sector of the Southern Ocean (SO) during the austral summer (January-February) of 2013 and 2015. The surface chlorophyll-a (Chl-a) was maximum in PF1 (0.77 mg m-3) followed by the SAF (0.5 mg m-3), STF (0.26 mg m-3) and PF2 (0.21 mg m-3) in 2013. The Chl-a was maximum in the SAF (0.56 mg m-3) followed by PF1 (0.32 mg m-3), PF2 (0.28 mg m-3) and STF (0.20 mg m-3) during 2015, suggested that the average surface biomass along the track was higher in 2013. The deep chlorophyll maximum (DCM) was located at 50 m in STF and SAF for 2013 and 2015. However, it was found at 75 m (100 m) in PF1 (PF2) during 2013. Diagnostic pigment index indicated the Diatoms in the surface and water column increased from the STF to PF. In contrast, the community Flagellates and Prokaryotes were decreased from the STF to PF. The Flagellates were uniformly distributed throughout the water column. The Prokaryotes were homogenously distributed up to the DCM level and then progressively declined towards the deeper region. The nitrate, phosphate and silicate were increased considerably from the STF to PF through SAF. Results indicate the biomass and community variation in the frontal regions were due to the influence of physical, chemical, and biological processes in varied environmental conditions

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# Overview of the results of the multidisciplinary marine ecosystem survey in the Indian sector (80-150°E) of the Antarctic during 2018/19 season by the Japanese survey vessel, Kaiyo-maru

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A multidisciplinary ecosystem survey in the eastern Indian sector of the Antarctic (80-150°E) was carried out by Kaiyo-maru during the 2018/19 season for 53 days. RMT tows were carried out at 72 stations. SUIT tows were carried out at 28 stations. Quad NORPAC tows were carried out at 44 predetermined stations. Narrowband echosounder data to estimate biomass of Antarctic krill were recorded along predetermined tracklines for 2,519 n.miles. Broadband echosounder data were recorded at 24 targeted RMT stations to estimate length distribution and swimming angles of Antarctic krill acoustically. SADCP and PDR data were continuously recorded along the tracklines. A total of 101 CTD and 150 XCTD casts were made for physical and chemical oceanographic studies. Six types of autonomous profiling floats and buoys were deployed at 18 locations. Surface oceanographic environment data were continuously recorded along the tracklines. Sea ice (18 samples) and iceberg (15 samples) were collected for physical and chemical oceanographic studies. A total of 26 CTD casts were made for biological oceanographic studies. A total of 339 schools with 552 individuals of marine mammals were sighted during 1,249 n.miles of sighting effort along the tracklines. A total of 8,616 individuals of seabirds were sighted during 1,257 n.miles of sighting effort along the tracklines. Biological video recordings were made 25 times using 6 types of video recording devices. A number of detailed analyses using obtained samples and data are in preparation and the results will be presented to the Antarctic scientific community.

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# Summer krill availability in Adélie and gentoo penguin foraging areas south of Anvers Island

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The Palmer submarine canyon, located south of Anvers Island along the West Antarctic Peninsula, is a biological hotspot with high primary productivity, abundant krill, and Adélie and gentoo penguin rookeries. Many studies have focused on physical mechanisms that spur the canyon's productivity, and foraging behaviors of the local penguin populations. However, little is known about krill distribution and abundance within the canyon. Palmer Station's recent acquisition of an EK80 120kHz echosounder and small boats capable of traveling further afield presented an opportunity to fill this gap in understanding. Our study focused on the physical and biological drivers of summer krill availability in two major penguin foraging areas. Survey grids were designed in recurrent Adélie and gentoo foraging areas based on 10 years of penguin satellite tag data. These acoustic surveys were run weekly from January to March and included cross-shelf CTD casts measuring temperature, salinity, and fluorescence. Results showed an increase in krill biomass from January to March independent of the peak phytoplankton bloom, indicating an inshore summer krill migration due to life history rather than food availability. Krill aggregations were mostly found near shallowing bathymetry including canyon walls and seamounts. Aggregations were significantly deeper in the gentoo foraging area than in the Adélie, concurrent with penguin foraging dive depths in each area. The mean depth of krill aggregations deepened through the summer, decoupling from the depth of the chlorophyll maximum in March. This study provides a baseline understanding of krill availability in penguin foraging areas undergoing significant environmental change.

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# A community-driven Southern Ocean contribution to the UN Decade of Ocean Science for Sustainable Development

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The UN Decade of Ocean Science for Sustainable Development 2021-2030 presents a once-in-a-lifetime opportunity to deliver scientific knowledge, foster technological innovation, and build capacity to achieve the 2030 Agenda and reverse the decline of ocean health. The Southern Ocean community will combine efforts to contribute to the UN Decade of Ocean Science, through leverage of existing efforts and development of new initiatives and partnerships where possible.

The first planning workshop for the Southern Ocean contribution was held in February 2020 and was the first step towards identifying the potential scope of a Southern Ocean contribution to this global initiative. Building on these initial discussions, the community is now invited to engage in drafting a strategy for implementation, structured around 6 UN Themes of societal deliverables and 5 Cross-Cutting Themes. This presentation will provide an overview of the key outcomes of the first Planning workshop, and propose a way forward that enables full community engagement and collaboration across industry, research, monitoring, policy and nations.

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# Glacial Discharge and its Impact on Phytoplankton Community Composition in an Western Antarctic Fjord and Continental Shelf

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The impact of ice-ocean interaction on the Southern Ocean is expected to intensify in the future. However, the influence of glacial discharge on phytoplankton community composition remains an open question. The Antarctic Peninsula fjords offer an ideal system to understand the effect of ice-ocean forcing on phytoplankton community, providing an extreme in the spatial gradient from the glacio-marine boundary to the Western Antarctic Peninsula (WAP) continental shelf. We found that glacial meltwater input altered surface salinity and was enriched in dissolved iron and nitrate. The three major groups of phytoplankton fueled by glacial input were: cryptophytes, diatoms, and a group of unidentified small flagellates. Deep learning algorithms for predicting community abundance captured the effects of these environmental factors on the phytoplankton community. Our results show that the fjord has relatively high phytoplankton biomass combined with high macro- and trace nutrient concentrations when compared to other WAP regions. We confirm that flagellates can be the dominant taxon in Antarctic fjords and we suppose iron concentration alone is insufficient to predict diatom growth. Furthermore, marine terminating glaciers enrich the fjord with nitrate even if the main circulation is not driven by glacier meltwater discharge. As glacial meltwater continues to alter the phytoplankton taxonomic composition, it will have an important implication for higher trophic levels and add significant uncertainties to the prediction of regional ecosystem dynamics and biogeochemistry.

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# High-resolution surface phytoplankton community composition and implications for biogeochemical cycling across the Atlantic Southern Ocean: group-specific contributions to chlorophyll-a and particulate organic carbon

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Phytoplankton community size structure and taxonomic composition play a key role in trophic carbon transfer, biogeochemical cycling, and food-web dynamics. In the Southern Ocean, high-resolution in situ measurements of phytoplankton community composition are scarce despite the expectation that climate change will drive large shifts in species distributions and ecological functioning. We used pulse-shape recording flow cytometry to evaluate live phytoplankton community composition, cell size and biovolume at high resolution (every ~40 km) across the Atlantic Southern Ocean from the subtropics to the Marginal Ice Zone (MIZ) in winter and spring 2019. In winter, pico- (<3 µm) and nanophytoplankton (3-20 µm) were 10-100 times more abundant than microphytoplankton (>20 µm). While these small phytoplankton contributed less to biovolume than microphytoplankton, their contribution to chlorophyll-a fluorescence was four-fold higher, suggesting that they were more active during this season. In spring, the abundances and chlorophyll-a contributions of small and large phytoplankton were similar, but large phytoplankton contributed more to biovolume (~70%). In winter, dinoflagellates and diatoms dominated north and south of the Polar Front, respectively, while in spring, dinoflagellate abundance was highest in the Subantarctic Zone (SAZ) and diatoms (e.g. Chaetoceros spp., Fragillariopsis) were similarly (and dominantly) abundant across the entire transect, except in the SAZ. Large diatoms were particularly abundant in the MIZ, consistent with an ice-edge bloom. Along with their implications for ecosystem functioning, high-resolution taxonomic data such as those presented here are required to ground-truth satellite measurements of ocean colour, which are used to estimate primary production at large scales.

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# Enhancing E. superba conservation management by evaluating krill fishery data and its use for krill variability analysis

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Krill, Euphausia superba, are both a key component in the Southern Ocean food web and a key target of one of the largest fisheries in the Southern Ocean. In 1982 the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) was established to conserve Antarctic marine life by, amongst other things, managing the Southern Ocean fisheries. Since 1992 under CCAMLR's scheme for international scientific observation, krill fishing vessels carry a scientific observer to collect biological data from the harvests. This unique dataset can provide an insight into the spatial and temporal changes in krill variability from a new perspective. The expansion of high quality data sources and research methods is crucial for enhancing the effectiveness of current management strategies, and it is therefore important to evaluate the quality of krill fishery data and determine further uses for it. The main focus of this presentation is to evaluate data derived from fishing vessels and data derived from research vessels to determine possible gaps in collection methods. With predicted changes in environmental conditions and increased pressure from the fisheries, enhancing data quality through collection diversification is crucial for future management strategies.

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# Monitoring and projecting change in the lower food web of the Southern Ocean using the SCAR Continuous Plankton Recorder survey: how can it help to prioritise and evaluate large-scale spatial protection?

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The SCAR Southern Ocean Continuous Plankton Recorder Survey (SO-CPR) has covered over 238,000 km in the Southern Ocean since 1991. We present an analysis of circumpolar zooplankton distributions in relation to satellite and oceanographic model hind-cast data over the period 1997–2019. Statistical methods based on modelling environmental suitability are used to extrapolate SO-CPR measurements in space and time. Seasonal and spatial patterns in modelled environmental suitability for 6 key groups of zooplankton are summarised. Trend analysis suggests that between 1997 and 2018 the environmental suitability for copepods (both cyclopoid and calanoid), foraminifera, and larvaceans has increased, especially in frontal regions of the Indian sector. In contrast, the environmental suitability for pteropods in some areas, particularly over the Ross Sea shelf, has significantly worsened over the last 20 years. Linearised analysis is used to explore the environmental drivers of the projected changes in zooplankton, especially in the context of changing patterns of primary productivity observed by ocean colour satellites. The patterns of change provide an observational basis to help prioritise large scale spatial protection in the Southern Ocean.

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# Following the pathway of Circumpolar Deep Water intrusions into Maxwell Bay – Antarctic Peninsula

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The western Antarctic Peninsula (WAP) have experienced the impact of global physical drivers. An increase in the westerlies have provided an increase of the inputs of circumpolar deep water (CDW) onto the continental shelf, the transport of this water mass has been linked to an increase of ocean heat and identified as a driver of marine glaciers retreat. The objective of this study is to provide observational and modeling evidence of the pathway, frequency and exchange of the CDW intrusions into a coastal embayment. The study area is Maxwell Bay located in the South Shetland Islands (SSI) Antarctic Peninsula. The pathway of intrusions of CDW was simulated using a high-resolution circulation model implemented with the Regional Ocean Modeling System (ROMS). Additionally, observations of salinity and temperature at different depths were undertaken during oceanographic campaigns during summers 2017-2020 at Maxwell Bay. The results showed that intrusions of modified CDW (mCDW) are a permanent feature in the circulation of the SSI, the intrusions were observed entering the Bransfield Strait through a gap between Smith and Snow Islands and continuing along the continental slope south of the SSI, observations from oceanographic cruises were consistent with the vertical structure and signature of the mCDW. There was no evidence of the mCDW entering Maxwell Bay. These results suggested that ocean circulation via intrusions of mCDW is not the main driver of Maxwell Bay glaciers retreat, other physical drivers like atmospheric forcing should be further explored.

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# Iron requirements in Southern Ocean phytoplankton species change with light availability

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Phytoplankton blooms constitute regions of intense primary production, facilitating the sequestration of anthropogenic carbon dioxide. The Southern Ocean is considered a high-nutrient low-chlorophyll region, abundant in nitrate and silicate but often characterised by low chlorophyll concentrations due to iron limitation of phytoplankton growth. However, the Southern Ocean is also a high-latitude ocean where phytoplankton can be limited by light, particularly in winter or when cells are deeply mixed by upper ocean turbulence. Consequently, a mechanistic understanding of how phytoplankton are co-limited by iron, light and the environmental conditions that control their respective supply, is critical to better model and predict primary productivity and carbon uptake in the Southern Ocean.

We conducted a series of incubation experiments during a research cruise off East Antarctica during the Austral summer of 2019 to investigate the effects of iron and light co-limitation on phytoplankton growth. The results from the incubations confirm that iron limitation has a stronger effect under high-light conditions, but substantial spatial differences were observed in treatment responses. We employed underway and satellite data to explore the differences between stations and how the effects of iron and light co-limitation are influenced by physical properties in the area such as mixed layer depths and frontal boundaries. Here we will present a synthesis of our findings based on experiments and ancillary environmental data.

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# Diatom-driven patterns of cobalt and vitamin B12 uptake in Antarctic Seas

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Antarctic coastal waters are limited primarily by iron and co-limited by cobalamin (vitamin B12), an essential micronutrient for most eukaryotic phytoplankton that is only produced by prokaryotes. The ecological cycling of B12 and its metal co-factor cobalt influence primary productivity also community composition, with ramifications for carbon export and biogeochemical feedbacks in the region. A thorough understanding of the cycling of cobalt and B12 is limited by the lack of in situ measurements of uptake into the marine microbial community. In this study, we conducted radiotracer incubation experiments across 15 sites to measure concurrent uptake rates of cobalt and B12 during the Cobalamin and Iron Co-Limitation of Phytoplankton Species expedition from the Amundsen Sea to Ross Sea and Terra Nova Bay, Antarctica (Dec 2017 - Feb 2018). Uptake rates integrated with nutrient, hydrographic, and pigment data, reveal that diatoms dominate the uptake of cobalt and B12, consistent with prior shipboard nutrient-amendment studies. The highest uptake rates occurred in the upper 75m in regions of fresher water masses, indicative of glacial and sea-ice melt. There is minimal cobalt uptake at depth, confirming the nutrient-like dynamics of cobalt in Antarctic waters. Lastly, the relatively high cobalt and especially B12 uptake rates suggest vitamin stress and higher cobalt stress than previously observed in this region. To date, this study is the largest collection of cobalt and B12 uptake rates from Antarctic waters and will help constrain the ecological cycles of cobalt and B12 and ground truth model development.

979

# Nutrient stoichiometry in zooplankton and the implications on biogeochemical cycles

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Zooplankton serve as trophic links between primary producers and higher trophic levels, and represent effective vectors for carbon export. Recent evidence suggest that zooplankton also represent an important source of regenerated nutrients fuelling phytoplankton production. Despite these emerging studies, quantifying the contribution of zooplankton to phytoplankton production proves difficult because a) zooplankton nutrient stoichiometry varies by an order of magnitude and b) biogeochemical components of global ocean models assume a fixed nutrient stoichiometry which allows for nutrients to be recycled in a predictable manner. We examined the nutrient stoichiometry (iron:phosphorus, copper:phosphorus, cadmium:phosphorus, manganese:phosphorus, nickel:phosphorus, cobalt:phosphorus and zinc:phosphorus) in zooplankton across 5 size fractions to identify the drivers of observed variability. Some nutrients (manganese, cobalt and nickel) showed no significant difference in stoichiometry between size fractions. In contrast, zinc, iron, copper and cadmium showed a significant difference in stoichiometry between size fractions. We find that nutrient stoichiometry in zooplankton reflects a combination of phytoplankton stoichiometry and physiological demand. Phytoplankton nutrient stoichiometry can span an order of magnitude and higher than seawater nutrient stoichiometry. This is especially pronounced for iron, where some phytoplankton undertake luxury iron uptake which can drive the high iron stoichiometries measured in zooplankton. Zinc and copper are required for enzymatic activities in zooplankton. Copper is further required for respiration. Consequently, zooplankton demonstrate higher zinc and copper stoichiometries relative to other nutrients. Overall, our study highlights differential nutrient uptake by zooplankton driven by diet and demand which influences model estimates of oceanic nutrient recycling.

907

# Regional and local drivers of Antarctic krill distribution in the South Orkney Islands region: modelling the impact of physics and behaviour

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Antarctic krill, a key species in the Southern Ocean ecosystem, is unevenly distributed around Antarctica on circumpolar, regional and local scales. Ocean currents are a key driver of their transport and distribution patterns, but behaviour also plays a major role. In this study, we focussed on the South Orkney Islands region, situated in the southwest Atlantic sector of the Southern Ocean and one of the main fishing grounds for Antarctic krill. We explored the effects of physical and behavioural drivers on krill distribution using an individual based model (IBM), incorporating key relevant behavioural traits, specifically vertical migration and association with sea ice. We used two complementary suites of model experiments. At the large scale, the IBM was forced by ocean and sea ice fields from a 1/12° ocean-sea ice model, whilst at the regional scale it was forced by output from a high-resolution (~2.5 km) regional model. The behaviour of krill under sea ice had a significant impact on distribution patterns: association with sea ice increased the probability of transport from the western Antarctic Peninsula to the South Orkney plateau, and decreased transport times. Strong regional oceanic flows had a weaker influence on transport pathways, and local recruitment and retention tended to decrease. Of particular interest for fisheries is a canyon on the northwest of the plateau where krill aggregations frequently occur. We will present first results of simulations investigating the effects of high-frequency variability in the flow field (e.g. tides) on flux into and retention in the canyon.

1600

# Temporal and spatial variations of the fCO2 in the surface waters of Terra Nova Bay polynya of the Ross Sea, Antarctica

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We present the direct observations of $fCO_2$ in the Terra Nova Bay polynya of the Ross Sea by a long-term monitoring near the Korean Antarctic base, Jang Bogo, since February, 2015, and by survey of the $fCO_2$ in the surface waters of the TNB polynya onboard R/V Araon during summer season. The TNB polynya opens small area (~1000 km²) in winter while exposing to the atmosphere in larger than 8 times of the winter polynya in summer enhancing air-sea gas exchange. The long-term monitoring indicates that the difference of $fCO_2$ ($DfCO_2$) between the surface seawater and overlying air varied widely from ~-200 µatm in February to ~40 µatm in early October. On the other hand, the spatial mean $DfCO_2$ by ship-borne survey gives a half of the value of the spot observations suggesting heterogeneous distribution of $fCO_2$ in the TNB polynya. Daily mean of air-sea $CO_2$ flux in the TNB polynya widely varied from ~-3 g C/m²/d to ~0.5 g C/m²/d. Based on these observations of $fCO_2$ in the TNB polynya, the annual uptake of $CO_2$ came up with ~30 g C/m², which takes into account the fraction of sea-ice concentrations estimated from AMSR2 microwave emission imagery. Extrapolating to all polynyas surrounding Antarctica, we expect the annual uptake of ~ 10 Tg C of $CO_2$ from the atmosphere. This is comparable to the amount of $CO_2$ degassed into the atmosphere south of the Antarctic Polar Front (62°S).

1429

# Eddy-modified iron, light, and phytoplankton cell division rates in the simulated Southern Ocean

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We examine the effects of Southern Ocean eddies on phytoplankton cell division rates in a global, multi-year, eddy-resolving, 3-D ocean simulation of the Community Earth System Model. We first identify and track eddies in the simulation and validate their distribution and demographics against observed eddy trajectory characteristics. Next, we examine how simulated cyclones and anticyclones differentially modify iron, light, and ultimately population-specific cell division rates. We use an eddy-centric, depth-averaged framework to explicitly examine the dynamics of the phytoplankton population across the entire water column within an eddy. We find that population-averaged iron availability is elevated in anticyclones throughout the year. The dominant mechanism responsible for vertically transporting iron from depth in anticyclones is eddy-induced Ekman upwelling. During winter, in regions with deep climatological mixed layer depths, anticyclones also induce anomalously deep mixed layer depths, which further supply new iron from depth via an increased upward mixing flux. However, this additional contribution comes at the price of deteriorating light availability as biomass is distributed deeper in the water column. Therefore, even though population-averaged specific division rates are elevated in Southern Ocean anticyclones throughout most of the year, in the winter severe light stress can dominate relieved iron stress and lead to depressed division rates in some anticyclones, particularly in the deep mixing South Pacific Antarctic Circumpolar Current. The opposite is true in cyclones, which exhibit a consistently symmetric physical and biogeochemical response relative to anticyclones.

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# Application of Dynamic Energy Budget (DEB) models to Antarctic case studies

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In ecological modeling, the Dynamic Energy Budget (DEB) approach concerns individual metabolism, for which food is converted to reserve, which is mobilized for maintenance, growth (of structure) and maturation or reproduction, in ways that depend on temperature.
DEB models can rely on both experimental and/or literature-mined data to quantify the age, body length and weight of the different organism's life stages, and provide information on reproduction, growth and metabolic rate according to environmental conditions. DEB models can be used in a wide range of organizational scales from the organ to the individual, population, or species levels. They also have a broad range of applications, for example in delineating the effects of (toxic) chemical compounds or global change on individuals' physiology; comparing species performances; understanding the geographic distribution of species or populations; and optimizing bio-production (aquaculture, agriculture) or support stock management and conservation decisions. To date, DEB models constitute one of the most powerful approaches to characterize metabolic performances of individuals and can be calibrated for data-poor animals. So far, DEB parameters have been estimated for more than 2,000 animal species and applications to polar case studies are growing.

In the proposed poster, the different steps of model calibration are presented through several applications and case studies. Finally, a call is launched to all Antarctic biologists who are interested and willing to apply DEB modeling to their own case studies.

515

# Individual-based model of population dynamics in Abatus cordatus, a sea urchin endemic to the Kerguelen Plateau, under changing environmental conditions

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The Kerguelen Islands is a sub-Antarctic archipelago of the French Southern Lands. Emerging close to shifting oceanic fronts, they are likely to be challenged by climate change, and coastal marine areas are particularly at risk. Assessing the responses of species and populations to environmental changes in such remote areas is challenging and ecological modelling can be a helpful approach to address conservation issues. In the present work, a DEB-IBM model (Dynamic Energy Budget – Individual-Based Model) was generated to simulate population dynamics for the echinoid Abatus cordatus, an endemic species of the Kerguelen Plateau characterized by dense demes in shallow, sheltered marine habitats of the Kerguelen Islands. The model relies on a DEB approach initially developed at the individual level. Then, it is upscaled to the population level for which an IBM enables to model population dynamics as a product of individual physiological responses to changing environmental conditions. The model was first calibrated for a reference site to simulate the response of a population to variations in food resources and sea water temperature. It was then projected to predict population dynamics at other sites as a response to IPCC scenarios RCP 2.6 and RCP 8.5 of climate change. Applied for the first time to a sub-Antarctic benthic and brooding species, such a dynamic model can prove useful to address conservation issues in regions where access and bio-monitoring are true challenges.

1378

# Implementation of the Long Term Ecological Research network of the French Southern and Antarctic Lands (LTER ZATA " Zone Atelier Antarctique et Terres Australes"): toward an overall monitoring of the southern ecosystem through its marine and terrestrial communities

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Since 2000, the French Long Term Ecological Research network of the French Southern and Antarctic Lands (LTER ZATA " Zone Atelier Antarctique et Terres Australes") has endeavoured to monitor the dynamics of biodiversity in Antarctic and sub-Antarctic marine and terrestrial ecosystems. Our LTER encompasses multiple scientific programs and can provide access to long term monitoring of more than 40 marine, freshwater and terrestrial vertebrate species (including 27 bird species), 20 terrestrial and freshwater plant and invertebrate species. For some species, monitoring was initiated well before the 2000s, as earlier as the years 1960-1970. More recently, monitorings have been initiated at the community level for pelagic and coastal marine biota, and were complemented by eco-physiological, eco-epidemiological and stress observing projects focussing on multiple species and communities. The main objective of our LTER is to provide a general dashboard to assess health of southern ecosystems along with the selective pressures and overall resilience due to environmental changes. The French LTER ZATA has strongly benefited from sustained support from the French Polar Institute over decades, clearly linking fundings and resource allocations to our capacity to assess and understand southern ecosystems. In this talk, we will give a first picture of this dashboard based on our existing databases. We will also present future developments and strategies that, for sure, have now to be integrated at the international level.

1424

# Biogenic substrates-associated macrofauna in the Antarctic benthic food web: organic matter sources and habitats for a highly diverse and abundant community

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Many organisms are capable to produce changes in the surrounding environmental conditions, generating new habitats that can be used as shelter, food, and even as reproduction sites for other organisms. In this work, we studied the diversity, composition and structure of macrofauna associated to three biogenic (algae, sponges, and hydrozoans) substrates related to main trophic levels of a community (producers, filter-feeders, and carnivores, respectively) and one non-biogenic (rocky) substrate, and we quantify the main organic matter sources of surrounding habitats (sediment, water, and meltwater) in four sites of the Antarctic peninsula during the Chilean Antarctic Scientific Expedition (ECA-54). Biogenic substrates showed that organic matter was higher in the lower trophic level (algae, 60.2%) than higher level (carnivore, 20.6%). Water (1.3%), meltwater (2.4%), and sediment (1.4%) samples showed low content of organic matter. The benthic bottom was characterized for presenting gravel as main sedimentary fraction (55.4%). A total of 19,365 organisms belonging to 22 higher taxa were collected. Amphipods (40.6%) and isopods (9.9%) were associated to producers, while gastropods (26.2%) and polychaetes (5.8%) to carnivore substrates, being the most abundant taxa across sites and substrates. Despite this, community composition showed a high overlap among biogenic substrates, while community structure showed a differentiation between producers and carnivores vs filter-feeders vs rocky (CV=51.1%) substrates. We suggest to assess the isotopic functional role of biogenic substrates to obtain a better comprehension of the relationships between substrates and associated macrofauna.

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986

# Molluscan diversity patterns associated to biogenic substrates at the South Shetland islands, Antarctic peninsula

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Antarctic region includes more than 8,000 species of animals, which 88% belong to benthic species, and more than 50% being endemic species. Among molluscs, gastropods and bivalves are the dominant taxa with more than 890 and 380 species, respectively. Only a few studies have reported molluscan diversity relationships associated to biogenic substrates. In this study, a total of 16,750 molluscs belonging to 25 genera and 34 species associated to three biogenic and one non-biogenic substrates were collected, which were sampled in three sites at the Antarctic peninsula during austral summer of 2017. This sampling allowed to estimate quantitatively the species abundance associated to biogenic substrates to test whether molluscs confirm predictions of specific associations between community and substrate. The higher richness and abundance of molluscs were associated to algae, where stand out the gastropods Lissarca mirialis (62.9%), Laevilitorina umbilicata (15.4%), and Laevilacunaria antarctica (8.0%) as the most important components of the molluscan assemblage. Though molluscan diversity did not follow a clear distribution pattern among biogenic substrates, changes in species composition were dominated by the habitat type, independently to the local-scale variability, suggesting that substrates biological composition condition structure of these assemblages.
Funding: Instituto Antártico Chileno (INACH) project #RT_45-16 to RDS.

1531

# Scratching the surface, yet grasping the big picture: a coincidental learning from a compromised research voyage in Southern Ocean

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Assessing the state and variability of Southern Ocean ecosystems is critical to conservation as much as it is of scientific importance. Multidisciplinary observations of sufficient intensity and frequency, however, are costly and difficult to maintain. Basic, still diagnostic characterization of ecosystems based on simpler measurements will be extremely useful. We present a set of surface measurements from a disturbed research voyage in Amundsen Sea that was compromised due to an unforeseen rescue mission and unfavorable sea ice conditions and subsequently resulted in a detour journey through Ross Sea back to Amundsen Sea and then off to Pine Island Bay. A suite of data including surface temperature, fluorescence, $pCO_2$, and limited near-surface plankton samples allowed for a description of three different regimes, each in varied status and stages in terms of dominant plankton species (Phaeocystis, diatoms, krill and others) and carbon uptake dynamics. This is corroborated by satellite imagery and biological acoustics, although the lack of data on water column structures remains a serious deficit. We hypothesize that interaction between different temperatures, length of calm periods, and water masses generated such variability. Surface observations, appropriately designed, can greatly contribute to the understanding of the ecosystem variability across regions and years. This capacity will be vastly improved by employing underway CTD, image flow cytometry, nutrient sensors and so on. There is an obvious need to fully utilize the current and future Southern Ocean surveys, and we propose a preliminary framework, with bio-regionalization taken into account, to integrate the findings from such campaigns.

1108

# Biogeochemical controls on ammonium accumulation in the surface ocean during winter in the Southern Ocean south of Africa

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The production and consumption of ammonium are essential components of the upper Southern Ocean (SO) nitrogen cycle. However, the processes driving these fluxes are not well understood in the SO, especially in winter. Nutrients, community composition, size-fractionated rates of ammonium uptake, and rates of ammonia oxidation were measured in winter 2017 across the SO between South Africa and the Marginal Ice Zone (61.4°S). Ammonium concentrations, measured 4-hourly, were lower north of the Sub-Antarctic Front (SAF) (0.01-0.26 µM) compared to south of the SAF (0.19-0.70 µM), indicating that ammonium accumulates in wintertime SO surface waters, particularly in the Polar Frontal and Antarctic Zones. Ammonium uptake rates were highest near the Polar Front (PF) at 13.2 ± 0.3 nM/day and decreased steadily south of the PF to 3.0 ± 0.5 nM/day near the ice, likely due to declining sea-surface temperatures (2°C to 0°C) and light. By contrast, ammonia oxidation rates changed very little latitudinally (12.8 ± 0.5 nM/day). Nano- and picophytoplankton dominated numerically across the region, with a higher relative abundance of heterotrophic organisms corresponding to maxima in ammonium concentrations and nanophytoplankton corresponding to minima. We attribute the accumulation of ammonium during winter to sustained ammonium production by heterotrophs in autumn and winter that outweighs ammonium consumption by temperature-limited ammonia oxidizers and temperature- and light- (and possibly iron-) limited phytoplankton. High wintertime surface ammonium concentrations, and the drivers of biological ammonium cycling, may have implications for the air-sea flux of ammonia, which is important for new particle formation and atmospheric acidity.

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# Distribution of dissolved iron in an East Antarctic biological hotspot

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Primary productivity in the Southern Ocean is limited by scarce concentrations of the trace metal iron, despite high concentrations of macronutrients. Inputs such as vertical mixing or spring ice melt release iron into the marine environment, stimulating productivity. These inputs vary on both spatial and seasonal scales. Once this iron has been exhausted, microorganisms rely on biological recycling to sustain nutrient levels.

In the summer of 2019, we sampled seawater for dissolved trace metals at 19 stations across the continental shelf of East Antarctica (between 63-67°S, 135-155°E), in areas with and without icebergs. Dissolved iron concentrations ranged from below detection limit (0.04 nmol/kg) in surface waters, to 0.58 nmol/kg in deeper waters. Iron was found to be supplied from two primary sources: rising circumpolar deep water and shelf sediment resuspension. Despite these inputs however, iron concentrations were observed to remain limiting throughout all water columns (Fe* = -0.78). Correspondingly, average satellite chlorophyll a concentrations (for February, over a 16 year time period) ranged from 0.8–5 mg/m³, with highest concentrations found over the continental shelf.

Sources of iron are key to primary productivity in this region, supporting feeding grounds for Antarctic krill and thus higher trophic levels. Here, complimentary data of krill catches and whale sightings are assessed in relation to identified iron sources. By understanding the dynamics of iron cycling in this highly productive region, we can increase our ability to appropriately manage living resources and model future Southern Ocean ecosystems under changing climate conditions.

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# The environmental drivers of the physiological condition of young-of-year and mature female Antarctic krill at the Western Antarctic Peninsula: Implications for krill recruitment

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Southern Ocean pelagic productivity relies on the abundance of Antarctic krill, Euphausia superba, which fluctuates on a 5-7-year cycle and is a function of recruitment and survival. Studies attempting to explain these population oscillations suggest it is an integrated response to biological, environmental and climatic factors. We sought to understand the environmental drivers of young-of-year (YOY) and mature female (MF) condition factor (CF; g/mm3) and assessed the relationship between CF and recruitment. Krill and environmental data were collected along the Western Antarctic Peninsula (WAP) during the Palmer Antarctica Long Term Ecological Research summer cruises from 1993-2008, and climate data were obtained from online databases. Data were divided between north (Adelaide to Anvers Islands) and south (south of Adelaide Island) WAP. In the north, we found negative winter Southern Annular Mode anomalies corresponded with high YOY CF, while high diatom concentrations corresponded with high MF CF. In addition, MF CF was high when day of sea ice advance was either anomalously early by ~10 days or anomalously late by ~30 days. In the south, MF CF increased with lower chlorophyll concentrations and a shallower mixed layer. Similarly, YOY CF was greater when diatom concentrations were reduced. Krill recruitment was positively related to MF CF the preceding summer, likely in response to increased reproductive output. Our findings suggest that environmental variation affects krill population dynamics by altering krill recruitment through variability in MF CF and subsequent reproductive output, and through variability in YOY CF, potentially impacting their likeliness of survival to adulthood.

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# Food web modelling to explore environmental drivers, fishing and marine protected areas on the Kerguelen Plateau

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The Kerguelen Plateau in the sub-Antarctic Indian Ocean is located at the centre of temperature and salinity gradients associated with the Antarctic Circumpolar Current and influenced by the westerly winds that drive this current. Warming and intensifying winds have influenced marine species in this region, with likely consequences for food web dynamics. The Kerguelen Plateau food web supports commercial fisheries for France and Australia, however, ecosystem studies investigating the environmental drivers of the food web are relatively few. Ecopath with Ecosim is a useful food web modelling tool for bridging the gap between data and understanding food web dynamics. In this study we used Ecosim to explore the potential of fishing and environmental processes as drivers of Kerguelen Plateau food web dynamics through time and Ecospace to explore the use of marine protected areas (MPAs) in ecosystem-based management. Results from our Ecosim model did not identify fishing as a driver of biomass trends over time, however sea surface temperature (SST) and wind were highlighted as potential bottom-up influences on food web dynamics. SST and wind were related to phases of the Southern Annular Mode, a cyclic climate driver in the Southern Ocean. Our model confirmed single species results from other studies and suggested that fishing activity in the future should consider climate variables when setting catch limits. Our Ecospace model captured the spatial distribution of food web dynamics on the Kerguelen Plateau and identified important biological areas to consider for the assignment of future MPAs.

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# Capturing open ocean biodiversity: eDNA could become an efficient alternative to the continuous plankton recorder

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Environmental DNA (eDNA) is emerging as a simple and objective tool to monitor biodiversity in the open ocean. Traditionally, continuous plankton recorders (CPR) have been used in the open ocean to monitor zooplankton biodiversity. Organisms were identified morphologically through microscopy, or, more recently, genetic metabarcoding. To assess whether eDNA can capture similar biodiversity and community composition as CPR, we compared small volumes eDNA samples (1 L) to morphological CPR samples (two transects) and genetic CPR samples (two transects; 1500 L filtered seawater per CPR sample) between Hobart and Macquarie Island. For genetic metabarcoding we used a cytochrome c oxidase I (COI) marker to characterize metazoan diversity, and an 18S ribosomal RNA marker to characterize overall diversity. eDNA samples were remarkably effective at detecting metazoan species using the COI marker: across two transects spanning the subtropical front eDNA samples consistently detected almost two thirds of the species detected with genetic CPR, despite the vast difference in sampled water volume and even though genetic CPR samples had up to 50 times more metazoan sequence reads than eDNA samples. There was a large overlap of detected species, and both sampling methods detecting similar drivers of community differentiation. In comparison to morphological CPR sampling, eDNA detected up to 1.6 times more species in two transects of the same area, which showed highly repeatable results for both sampling methods. With a refinement of eDNA sampling and processing methods and standardization between studies, eDNA sampling has the potential to create an unprecedented biodiversity monitoring capacity.

1402

# Biological responses to change in Antarctic sea ice habitats

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The seasonal cycle of Antarctic sea ice extent represents the largest seasonal physical change on the surface of the Earth, varying between approximately 3.1 million km2 in February and 18.5 million km2 in September. This seasonality in coverage, along with a pronounced annual cycle in light, regulates biological cycles in ice-covered waters. Sea ice is predicted to decrease in extent and duration in the coming decades and this will affect the small organisms that live in the ice as well as those that live under the ice. This work presents qualitative network models for fast ice and pack ice ecosystems and examines the effects of environmental changes on the ice and its associated biota. The quality and quantity of sea ice will be influenced by warming sea temperatures and increased precipitation. We examine how sea ice variability in future will affect algae, invertebrates and fish and explore what this means for an important Antarctic habitat.

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# The Role of Climate Variability on Krill Habitat: insights from the CESM Large Ensemble

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Climate change is rapidly altering the environment of the most abundant keystone species of the Southern Ocean food web, Antarctic krill (Euphausia superba). However, there remains limited understanding of how krill habitat quality will be impacted by projected changes in oceanic conditions. Moreover, the Southern Ocean is highly dynamic, displaying dramatic fluctuations on interannual to decadal timescales, complicating interpretation of observed trends. This research uses future projections from a large ensemble of the Community Earth System Model (CESM) coupled with an empirically-derived krill growth model to assess current and future krill habitat throughout the Southern Ocean. We use the large ensemble framework to explicitly make the separation between drivers of ecosystem variability and attribute variations in krill habitat to naturally varying processes versus forced trends. This allows us to quantify the the role of climate variability as a driver of fluctuations in krill habitat, putting human-driven climate change into this important context. Our results quantify the point in time when trends forced by human-driven climate change can be formally distinguished from natural variability. Overall this research builds toward providing critical scientific information for krill fishery management in the Southern Ocean. We reflect on how our findings can be incorporated into current and future management strategies.

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# Report on the status and trends of Southern Ocean Zooplankton based on the SCAR Southern Ocean Continuous Plankton Recorder (SO-CPR) Survey

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The Continuous Plankton Recorder (CPR) can collect surface zooplankton continuously for 450 nautical miles during a single tow at normal ship speed. It is an effective and efficient monitoring tool for detecting surface zooplankton abundances, species composition, and distribution patterns over large oceanic scales. Zooplankton are a crucial link in the Antarctic marine ecosystem and changes in the zooplankton are likely to have substantial flow on effects through the rest of the food web. The Southern Ocean CPR (SO-CPR) Survey provides the largest comprehensive and systematic Antarctic zooplankton data set, spatially and temporally, using a consistent sampling methodology ideal for the purpose of mapping the seasonal, inter-annual, long-term and spatial variation in plankton diversity, as well as to use plankton as sensitive indicators of environmental changes to monitor the health of the Southern Ocean. Since launching in 1991, much of this work has already been published in 68 CPR based research papers, chapters, atlases, and reviews. This report highlights the achievements from over nearly 30 years of SO-CPR activities, and also includes new analyses identifying trends in relation to changes in zooplankton abundance and community composition. The continuation of the current SO-CPR program, the monitoring and mapping of zooplankton, with the continued accumulation of data, will further improve our baseline information on zooplankton abundances and distributions allowing us to detect and hopefully help understand the effects climate change impacts on the ecosystem.

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# The future of Antarctic krill at South Georgia: identifying limits to their physiological capacity

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The pelagic ecosystem at South Georgia is extremely productive and supports high biomass levels of Antarctic krill (Euphausia superba) on which many higher predators depend. Sea-surface temperatures around South Georgia oscillate between 0 and 5.5°C seasonally and these warmer temperatures are already beyond the upper lethal limit of Antarctic krill populations located further south. This suggests that thermal responses of Antarctic krill differ between locations. In this study, routine metabolism of South Georgia Antarctic krill was measured across two temperature ranges, 0 to 5.5°C, the natural range at South Georgia, and 5.5 to 12.5°C, an extreme range to consider physiological limits. Comparisons were made with previously published measurements on stocks from colder locations further south. Within the natural temperature range, respiration rate data from both the present and previous studies were adequately fitted by a single Arrhenius regression (Q10 of 2.6), although South Georgia krill showed an upward deviation from this regression between 0° and 2°C. Metabolic compensation (i.e. the comparative lowering of respiration rate) at the high temperatures experienced at South Georgia was not apparent, although the higher than predicted metabolic rates at low temperatures suggests acclimation to a warm water lifestyle. South Georgia krill showed no further increase in respiration rate when exposed to acute temperatures (5.5 to 12.2°C), indicating that they were already at the limit of aerobic capacity by 5.5°C. Results indicate that even small degrees of additional warming to South Georgia waters are likely to make conditions there metabolically unsustainable for Antarctic krill.

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# Size Does Matter: Krill Life Cycle Drives Particulate Organic Carbon Flux off the West Antarctic Peninsula

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The rate and pattern of carbon sequestration in the world's oceans will influence the pace of future warming, yet, the drivers of carbon export to the deep ocean remain poorly understood. To understand the mechanisms that drive carbon export in the West Antarctic Peninsula (WAP), a 21-year sediment trap timeseries from the Palmer region of the WAP, is analyzed. Analysis of the sediment trap data has found that particulate organic carbon (POC) flux is dominated by a semi-decadal cyclicity. It was found that POC flux in the WAP is mechanistically linked to the 5–6-year krill life cycle, where mean body size of the krill population is the dominant driver of driver of POC flux. Years of high POC flux are positively correlated with years where the vast majority of the krill population (83.51% ± 5.82%) is comprised of old, large adults ≥ 41 mm in length, indicating they were 5–6 years of age. Years of anomalously low POC flux were positively correlated with years where recruitment of juveniles were high and less than 40.50% ± 8.80% of the krill were ≥ 41 mm in length. These findings suggest that only the largest of krill produce fecal pellets that are large enough to sink out of the upper mixed layer, contributing to carbon export to depth, whereas young juvenile krill (16–30 mm) produce small fecal pellets that are mostly retained and remineralized in the mixed layer.

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# Tracing carbon sources of POM in meltwater runoff and coastal waters in Antarctica by compound specific amino acid δ13C patterns

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Under a scenario of continued glacial melting in the Antarctic Peninsula, the fluxes of particulate organic matter (POM) from land to coastal Antarctic waters are expected to change in terms of quantity and composition. Marine POM represents a protein-rich food resource for marine organisms, while terrestrial POM has very low food value. The aim of this work is to trace main carbon sources in meltwater flow from Collins Glacier to Maxwell Bay, King George Island, Antarctica applying a novel approach based on δ13C values of essential amino acids (EAAs) in suspended POM. This approach is based on the usefulness of EAAs as recorders of primary production since animals cannot synthesize EAAs de novo. To discern among different carbon sources, we applied a Principal Component Analysis (PCA) with our data combined with data from literature. Bacterial carbon sources of POM dominated in the meltwater stream that flows from Collins Glacier, runs nearby Artigas Base and discharges in nearshore waters. This signature may be related with the export of diagenetically altered carbon from land to the sea. In contrast, diatoms and other marine algae carbon sources of POM predominated in offshore stations with high marine influence, which is probably related to primary production. Our results showed very negative δ13C pool of amino acids that characterize possible end-member for Antarctic primary productivity, so, they represent relevant data for future studies based on this approach in Antarctica.

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# Tidy your biological data, transform your science

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Ever since its inception, the Antarctic treaty has placed the exchange and free availability of observation at its core. This concept is gaining traction globally. A fundamental part of this concept are the FAIR principles that require that data created by machines and humans be made findable, accessible, interoperable and reusable.

All too often, data management is treated as an afterthought in the research cycle. Time spent on data management is often conceived as less time spent on science. This view is incorrect. Data are an integral part of reproducible science and without good data management, good reproducible science is not possible. Good data management will strengthen the quality of your science and actually save time by reducing the amount of data munging needed not only by your future self but also future students, collaborators and colleagues.

350 years ago the scientific paper revolutionised the way research was shared. Since then technology has changed dramatically allowing for much more direct sharing of observations, analyses and interpretations. Biological data standards such as darwincore have continued to evolve allowing a wider range of biodiversity data.

In this presentation we focus on data management of biological data from the perspective of a researcher. We provide an overview of the direct benefits to your research of data standards such as Darwincore, data repositories such as the Ocean Biogeographic Information System, and data sharing principles such as the FAIR Principles. We look at the common pitfalls and how to address them.

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# the SCAR Antarctic Biodiversity Portal, current status and perspective

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The SCAR Antarctic Biodiversity portal (biodiversity.aq) is a gateway to a wide variety of Antarctic biodiversity information and tools. It finds its roots in the Census of Antarctic Marine life (2005-2010). It started as the SCAR - Marine Biodiversity Information Network (SCAR-MarBIN, scarmarbin.be) and the Register of Antarctic Marine Species (RAMS, marinespecies.org/rams/), the system has grown in scope from purely marine to include terrestrial information.
Currently the portal is supported by Belspo (Belgian Science Policy) as one of the Belgian contributions to the European Lifewatch-European Research Infrastructure Consortium (Lifewatch-ERIC). The goal of Lifewatch is to provide access to: distributed observatories/sensor networks; interoperable databases, existing (data-)networks, using accepted standards; high performance computing (HPC) and grid power, including the use of the state-of-the-art of cloud and big data paradigm technologies; software and tools for visualization, analysis and modeling.
Here we provide an overview of the most recent advances in the biodiversity.aq online ecosystem as well as an overview of future directions.
Through SCAR, Biodiversity.aq builds on an international network of experts that provide expert knowledge on taxonomy, species distribution,and ecology. It provides a strong and tested platform for sharing, integrating, discovering and analysing Antarctic biodiversity information originating from a variety of sources into a distributed system.

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# Sea ice connections with Antarctic krill recruitment in the southwest Atlantic.

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Antarctic krill are a key Southern Ocean prey species and support the region's largest commercial fishery. Understanding climate change impacts on krill populations is crucial to understanding present and future change in the Southern Ocean, as well as proactively managing fisheries and ecosystem interactions.

Recruitment – the survival of larval krill over their first winter – is a strong driver of interannual krill abundance and population dynamics. It is thought that larvae depend on sea ice for overwinter survival, cause for concern as sea-ice extent is projected to decline significantly under unmitigated climate change scenarios. However, holistic projections of climate change impacts on krill remain hampered by knowledge gaps in how ice functions as an overwintering habitat, and which sea-ice characteristics contribute to good habitat quality.

Drawing from the findings of previous localized and large-scale recruitment analyses, we hypothesize that sea-ice drivers of krill recruitment are likely to be spatially nonuniform. We therefore employ a regionally structured study design to re-examine krill recruitment across the southwest Atlantic. Regionally explicit recruitment indices are developed using a novel mixture method to identify modes of recruits from KRILLBASE length frequency distributions. Estimates of sea-ice characteristics which are expected to be important for sea-ice habitat quality (concentration, thickness and ridging rate) are drawn from a coupled sea-ice ocean model (COCO) forced by observations. By analysing for spatial correlations between regionally specific recruits timeseries and sea-ice characteristics across the domain, we present a description of relationships and teleconnections throughout the southwest Atlantic sector.

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# Working with the fishing industry to address key questions on Antarctic krill lipid dynamics with respect to a changing ocean.

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Lipids are the key currency in polar seas. The Southern Ocean ecosystem is largely driven by energy derived from Antarctic krill lipids. A key question is how krill lipid dynamics will be affected by warming and ocean acidification. To address this question fine scale seasonal and temporal data is required. We collaborated with a commercial krill fishing company operating in the South Atlantic region to access fine scale samples. Here we present total lipid, lipid class and fatty acids profiles of fishery-derived samples of Antarctic krill analysed every fortnight over six years. These data provide high-resolution information on the seasonality of krill lipids. Krill lipid profiles varied significantly within and between seasons. We demonstrate the dynamic seasonal relationship between specific lipid biomarkers and krill lipid classes. Additionally, we utilised remotely-sensed data (Chlorophyll a and sea surface temperature) coupled with krill lipid data to examine within and between year variation of krill biochemistry. Results from a long-term experiment are also presented on the effects of rising ocean pCO2 on krill physiology and krill lipid biochemistry. Outcomes from these combined analyses suggest that Antarctic krill are remarkably adaptable to a changing environment.

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# Exploration of Patagonian toothfish-fishery-ecosystem interactions, and responses to environmental change on the Kerguelen Plateau through qualitative network modelling

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Patagonian toothfish (Dissostichus eleginoides) is an important component of the marine ecosystems around subantarctic islands, and is also a valuable fishery target species. Around Heard Island and McDonald Islands in the Indian Sector of the Southern Ocean, there was a sharp decline and subsequent strong fluctuations in fishery catch rates of this species over a short period in 2016, coinciding with a marine heatwave in the area. This suggested that changes in fish behaviour, rather than the toothfish population, were the underlying cause of the observed catch rate fluctuations, and raised questions of how toothfish and the ecosystem will respond to future environmental change, and how this may affect fishery indicators and viability into the future.

To better understand the mechanisms through which environmental changes affect toothfish and their behaviour, we constructed qualitative network models representing toothfish, the ecosystem and the fishery. These models were assembled based on expert opinions from industry, managers and scientists, draw on concurrent quantitative analyses, and are designed in a way that facilitates testing of alternative hypotheses for environmental and fisheries drivers of changes in catch rates in the region. We present results showing the likely response of this system to different scenarios of change, the mechanisms by which environmental change can propagate through the system, and how sensitive the predicted responses are to particular model components. This work will guide future monitoring programs by identifying important indicators of change, and furthers our understanding of the fishery-ecosystem-climate dynamics on the Kerguelen Plateau.

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# Life stage matters when estimating the ecological functional roles of Southern Ocean pteropods

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Southern Ocean pteropods play important functional roles in biogeochemical cycling and in providing trophic links between primary producers and secondary consumers. However, compared to krill and copepods, very little effort has been made to differentiate pteropod life stages in much zooplankton-related research, which may consequently limit the wider ecological picture. I present results from our investigations into population and flux dynamics, as well as spatial pattern modelling of pteropods. Pteropods from all life stages were taken from two sediment trap experiments as well as from preserved samples, all representing three separate voyages throughout the Indian Sector. In both sediment trap experiments, highest fluxes were measured for veliger-stage Limacina helicina antarctica (<0.3 mm) relative to all pteropod species and age classes. Among a suite of variables tested, fluorescence and sinking particulate organic and inorganic carbon had the most explanatory power for the abundances of shallow water thecosome age class and species composition. Gymnosomes were largely influenced by increasing adult L. helicina antarctica counts. Egg mass abundances were primarily driven by spatial covariates, temperature, and the presence of larger pteropods. Changes to pteropod population and community dynamics in response to near-future climate change will have cascading effects throughout Antarctic epipelagic food webs, and these results provide a small-scale regional snapshot of patterns in structure from the under-surveyed region of the Southern Ocean, and demonstrates the need to incorporate all life stages to measure climate change responses as each are potentially governed by different variables.

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# Estimating fecundity in the Southern Ocean thecosome pteropod, Limacina helicina antarctica, using image analysis

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The quantitative analysis of physical form and shape, or morphometrics, can be a powerful tool when applied to investigating life history strategies of organisms. When the shape and size of organisms are microscopic, challenges in morphometric analyses can be minimised with the use of image analyses software platforms. Pteropod egg masses possess hundreds, sometimes thousands, of eggs within their matrices and manually estimating counts can be time consuming and prone to error. Image analyses can effectively automate processes involved with performing egg counts and early life stage morphometric measurements and has shown to possess high levels of success compared to more traditional, manual methods. Software platforms such as ImageJ have been effectively employed in experimental work estimating the effects of future ocean acidification conditions on the brooding strategies of other marine gastropod species. There is potential to expand this application towards estimations of fecundity in thecosome pteropods, known to be sentinels of ocean acidification in the Southern Ocean. Little effort has been made to estimate fecundity in Southern Ocean pteropods based on their egg masses. Using preserved samples from three research voyages, we aimed to better understand early life history strategies in the common Southern Ocean thecosome, Limacina helicina antarctica. Using ImageJ, we developed an automated technique to count eggs within egg masses and tested the accuracy against manual counts. A linear prediction made between both methods was determined as statistically significant ($R_2 = 0.92$, $p < 0.05$), suggesting this to be a promising technique to investigate sensitive microscopic organisms.

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# Fatty-acid composition of 34 species of Antarctic macroalgae across a gradient of annual mean ice cover

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The western Antarctic Peninsula supports a diverse assemblage of subtidal macroalgae, covering more than 80% of the benthos on hard substrates in depths of up to 40 m in some regions. The algal community is dominated by several large perennial brown algae but over 100 species are known on the Peninsula. Macroalgal detritus may provide key support to benthic food webs, however, the trophic links between algae and basal consumers on the Antarctic Peninsula are not well described. Algae synthesize fatty acids (FA) which are nutritionally valuable for consumers and useful as biomarkers for tracking trophic pathways in marine foodwebs. In April-May 2019, we collected a diverse assemblage of subtidal algae at 13 sites along the western Antarctic Peninsula from Anvers Island (64 deg S) to Marguerite Bay (69 deg S), spanning a gradient of annual mean ice cover from 40-90%. We analyzed the FA composition of 250 samples from 34 taxa of subtidal algae (8 Ochrophyta, 24 Rhodophyta, 1 Chlorophyta, and 1 Bacillariophyceae) across this geographical range. We compared the multivariate FA composition of a core list of seven algal taxa that we collected at multiple locations across this ice cover gradient, to test whether the FA signatures of macroalgae differ with proportion of ice cover, and used the more comprehensive list to test the similarity of FA between closely related species. As expected, we found both high order taxonomic structure to the FA signatures of macroalgae determined by phylogeny, and within-species variation associated with collection location.

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# 20-years of observations at the Australian Southern Ocean Time Series (SOTS) deliver an important baseline for the biological carbon pump (BCP) and its natural interannual variability

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Particle fluxes at SOTS in the Subantarctic zone (SAZ) south of Australia, ~47°S, 142°E, were collected with sediment trap moorings from 1997 – 2017, with nominal depths of 1000m, 2000m and 3800m. Annually integrated POC fluxes were close to the global median (1.2 ± 0.4 g m-2 yr-1 to 1.0 ± 0.2 g m-2 yr-1 at 1000-3800m), indicating that the SAZ exports considerable carbon to the deep sea despite high-nutrient, moderate chlorophyll characteristics. The particle composition (% w/w) was dominated by biogenic ballast minerals especially carbonates (63 - 69%) and opal (10 – 12%). POC contributed between 5 and 8%. Seasonality was moderate, with lower but non-zero fluxes in winter. Interannual variations in peak and non-peak fluxes caused the period required to collect 50% of the mass flux to vary from ~50 to 150 days (much of the global range). Nearly 80% of this flux variance is represented by strong spring and moderate late summer export episodes. This characteristic of moderate seasonality with significant interannual variations, yet relatively constant annual fluxes is likely to be useful to select appropriate models for the simulation of environmental-ecological coupling and its role in controlling the BCP. The large proportion of biogenic carbonates makes SOTS important for monitoring ocean acidification impacts on the BCP. Over the 20 yr record, no trend has yet been detected in total, PIC, or POC flux, and this will serve as an important baseline against which potential future changes in this globally significant region can be measured.

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# Crustacean guide for predator studies in the Southern Ocean: A Legacy of SCAR

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Crustaceans are an important component in the diet of numerous predators of the Southern Ocean (water masses located south of the Subtropical Front). As identifying crustaceans from food samples using conventional methods is not easy, a crustacean guide was written to aid scientists working on trophic relationships within the Southern Ocean. Having the needs of the scientists in mind, we gathered information from > 100 species from 53 families of the most relevant crustaceans in the diet of subantarctic and Antarctic meso- and top predators, including information on distribution, their relevance in predator diets, sizes, availability of allometric equations and practical procedures to differentiate crustacean species within each family. Additional information of bibliography is added if families possess more that the species mentioned in this book. It is noted that a large number of species still has no allometric equations and taxonomic status of some species has to be (or remains to be) clarified. This presentation aims to describe the book that was produced within the international effort under the Scientific Committee on Antarctic Research (SCAR) programs, expert and action groups, namely SCAR AnT-ERA, SCAR AnT-ECO, SCAR EGBAMM and ICED.

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# Comparative structure of Antarctic benthic communities

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Understanding the trophic interactions in the context of a food web is a fundamental requisite to elucidating ecosystem processes and functions. To explore the structure of two nearshore benthic communities we compare by Leyman's metrics the main trophic groups inhabiting Fildes Bay and South Bay (Doumer Island) in the Antarctic Peninsula. The analyses that nitrogen ranges (NR) and the horizontal breadth of the food web (CR) in South Bay were higher than Fildes Bay, revealing more diversity of prey from different trophic levels and a wide diversity of food sources assimilated by consumers. MNND and SDNND metrics indicate a smaller trophic redundancy (individuals with dissimilar trophic ecologies) and a more uneven trophic niche (uneven individual packing) in the benthic community of South Bay than the benthic community of Fildes Bay. In summary, these results indicate food-limited system in Fildes Bay in comparison with the benthic community of South Bay, which could be suggesting a reduction in habitat heterogeneity in Fildes Bay, where specialists feeding behavior are being replaced by a more generalist feeding behavior.

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# The autumn dietary changes of Antarctic krill in the Antarctic Peninsula for the past half-decade.

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Antarctic krill (Euphausia superba) in the Antarctic Peninsula, the keystone species in the Southern Ocean, not only provides the energy supply for the marine predators for the summer reproduction, but also support fishery for almost all seasons. Accumulation of nutrition for overwintering has been explored a lot on this species, but little is known on the diet of krill around the Antarctic Peninsula region in autumn. In this study, we used krill samples collected from commercial fishery that sampled around the Antarctic Peninsula and in the Bransfield Strait in autumn 2015 to 2019. Biomarker fatty acid contents of individual krill were analysed to investigate the annual, regional and sexual variation in diet of krill. Both year and sex brought significant differences in most of the biomarkers. Of all variables, the factor year was the dominant one, diet of krill in autumn thus can be divided into three types, a very similar diet compositions that contributed high PUFA accumulation in 2015 and 2016, a more diversified and inclusive food sources diet in 2017 and 2018, and a concentrated diatom-indicator herbivory intake with particular higher diatom-indicator fatty acid and lower carnivory indicators of C20:1 and C22:1 levels in 2019. Using fishing vessel as the sampling platform to long-term monitor trophodynamics of krill, particularly during the poor-studied seasons and regions, can enhance the understanding on ecology of krill.

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# Seasonal variation in natural growth rate of Antarctic krill (Euphausia superba) in the Antarctic Peninsula region

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Antarctic krill (Euphausia superba) is the keystone species in the Southern Ocean, however the key biological parameters, such as growth rate, are kept unclear, particularly in the poor-studied seasons. This information is limited to develop fishery management and conservation of this species. The natural growth rate of Antarctic krill is usually calculated using the instantaneous growth rate (IGR) method. So far, this work has mostly been carried out in austral spring and summer, and several related studies in winter and autumn have been based on land-based aquarium. However, significant differences in physiological implications of krill may be overlooked between land-based aquarium and natural environment. Therefore, work on growth estimation based on in-situ aquarium with simulated natural environment can provide important data to seasonal growth estimation of krill in nature. In the study we estimated the growth of krill in the Antarctic Peninsula region during different seasons (early autumn to mid-winter). Negative growth or shrinkage was obvious during this period, especially in winter (July), the lowest growth rate reached -0.10371 mm day-1. Significant differences are also occurred between seasons. The reasons that related to growth of krill, such as temperature, food quality, sea ice, area are further discussed. Our study, for the first time, estimated the seasonal growth rate of krill during autumn to winter using in-situ simulated natural environment. The results derived in this study are updated the information on growth of krill and can further be used to stock assessment model of krill population as the input variables.


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