ELEMENTA Science of the Anthropocene

Plasman, C, et al. 2026. Developing Essential Biodiversity Variables for the Southern Ocean: From data gaps to valuable insights. *Elem Sci Anth*, 14: 1. DOI: https://doi.org/10.1525/elementa.2025.00038

PRACTICE BRIDGE

Developing Essential Biodiversity Variables for the Southern Ocean: From data gaps to valuable insights

Charlie Plasman[1,*], Alyce M. Hancock[2], Ben Raymond[3,4], Narissa Bax[5,6], Denisse Fierro-Arcos[7], Sian F. Henley[8], Abigail Benson[9], Stuart Corney[7], Karen Evans[10], Noémie Friscourt[7], Ruth S. Eriksen[4,7,10], Angus F. Henderson[7], Svenja Halfter[11], Jan Jansen[7], Clive R. McMahon[12], Andrew Meijers[13], Patricia Miloslavich[3], Petra ten Hoopen[13], Inessa Corney[7], Andrea Walters[7], Kerrie Swadling[7], Yi-Ming Gan[1], and Anton Van de Putte[1,14,*]

The Southern Ocean is central to global heat and carbon cycling, connecting all the major ocean basins and regulating Earth's climate system, and hence providing ecosystem services of global significance. However, its ecosystems are increasingly vulnerable to climate change and localized human-induced pressures, such as (biological) resource extraction, pollution, ship traffic, and tourism. Effective conservation and management require systematic and reliable monitoring frameworks. The Essential Variables concept offers a robust approach to integrate fragmented data, to standardize data collection, and to generate policy-relevant data products enabling informed responses to rapid environmental change. This paper synthesizes the key outcomes of a workshop held in Hobart, Australia, alongside the Southern Ocean Observing System Symposium, in 2023. To advance the adoption, development, and operationalization of Essential Variables tailored to the Southern Ocean, researchers with diverse expertise came together to assess current data gaps in ocean observations and to establish monitoring priorities for marine ecosystems. The workshop provided a dedicated forum to identify key Southern Ocean-specific candidate variables, address methodological challenges, and design pathways for developing a systematic, open, and adaptable framework suited to the region's unique ecological and environmental conditions. In this paper, we propose Essential Biodiversity Variables that are tailored to the Southern Ocean and are intended to monitor changes in sea ice, planktonic, benthic, and top predator systems. The adoption of Essential Biodiversity Variables specific to the Southern Ocean can enhance our capacity to track biodiversity trends, assess ecosystem health, and inform policy by transforming fragmented data into a cohesive, policy-relevant framework. However, the success of these efforts is only possible by securing sustained funding and enhancing interoperability and collaborations across research groups.
This paper as well as the Hobart 2023 workshop are activities endorsed by the UN Decade of Ocean Science for Sustainable Development.

Keywords: Southern Ocean, Essential Variables, Essential Biodiversity Variables, Data products, UN Ocean Decade, Ocean observations

[1] Institute of Natural Sciences (INS), OD-Nature, Brussels, Belgium
[2] Southern Ocean Observing System (SOOS), International Project Office, Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, TAS, Australia
[3] Australian Antarctic Division (AAD), Department of Climate Change, Energy, the Environment, and Water, Kingston, TAS, Australia
[4] Australian Antarctic Program Partnership (AAPP), University of Tasmania, Hobart, TAS, Australia
[5] Greenland Institute of Natural Resources, Pinngortitaleriffik, Greenland Climate Research Centre, Nuuk, Greenland
[6] Centre for Marine Socioecology, Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, TAS, Australia
[7] Institute for Marine and Antarctic Studies (IMAS), University of Tasmania, Hobart, TAS, Australia
[8] University of Edinburgh, Edinburgh, UK
[9] U.S. Fish and Wildlife Service, Palm Springs, CA, USA
[10] Commonwealth Scientific and Industrial Research Organisation Environment (CSIRO), Canberra, ACT, Australia
[11] National Institute of Water and Atmospheric Research (NIWA), Wellington, New Zealand
[12] IMOS Animal Tagging, Sydney Institute of Marine Science, Mosman, NSW, Australia
[13] British Antarctic Survey (BAS), Cambridge, UK
[14] Université Libre de Bruxelles (ULB), Brussels, Belgium

* Corresponding authors:
Emails: cplasman@naturalsciences.be; avandeputte@naturalsciences.be

1. Introduction: The need for standardized key metrics capturing biodiversity trends

The Southern Ocean plays a significant role in Earth's climate system, absorbing over 40% of anthropogenic CO_2 and 90% of the excess heat from greenhouse gas emissions (Le Quéré et al., 2018; IPCC, 2022). Beyond climate regulation, it delivers globally important ecosystem services, supporting biodiversity and carbon sequestration (Grant et al., 2013; Cavanagh et al., 2021; Murphy et al., 2021). Its relatively pristine ecosystems, home to iconic species like krill, whales, and penguins, are shaped by oceanographic processes, including the Antarctic Circumpolar Current, upwelling, and sea ice dynamics, which drive nutrient cycling and biological productivity (Constable et al., 2014; Rintoul et al., 2018; Henley et al., 2020). However, environmental shifts such as declining sea ice, ocean warming, freshening, and acidification are disrupting ecological processes, affecting primary production, species distributions, predator-prey relationships, and the survival of calcifying organisms (McNeil and Matear, 2008; Turner et al., 2020; Pinkerton et al., 2021; Reisinger et al., 2022; Swadling et al., 2023; Kawaguchi et al., 2024). These stressors are exacerbated by growing human pressures, including expanding fisheries, particularly for Antarctic krill (*Euphausia superba*), alongside rising tourism and environmental contamination (Hill et al., 2013; Cavanagh et al., 2021; McBride et al., 2021; Tejedo et al., 2022; Bargagli and Rota, 2024). As these stressors interact, they lead the Southern Ocean closer to critical tipping points, thresholds beyond which rapid and potentially irreversible ecosystem shifts may occur (Lenton et al., 2008; Kubiszewski et al., 2024). The risk of cascading tipping points, where changes in one system trigger disruptions in others, remains an underappreciated but serious threat, with far-reaching consequences for global marine biodiversity, climate stability, and society at large. One example for the Southern Ocean is the redistribution of marine species driven by ocean warming. Reports already indicate declines in suitable habitats for sessile benthic invertebrates, cryophilic fish, krill, and other ice-dependent species. Under a high-emissions scenario, up to 80% of emperor penguin colonies could be quasi-extinct by 2100 (Jenouvrier et al., 2020, as cited in Kubiszewski et al., 2024).

Despite the Southern Ocean's global significance, the biodiversity of this vast region remains poorly understood due to spatially fragmented, temporally biased, and taxon-specific data collection (Newman et al., 2019; Bonnet-Lebrun et al., 2023), which has led to critical knowledge gaps that limit the effectiveness of conservation and management strategies (Miloslavich et al., 2018; Bonnet-Lebrun et al., 2023). Resolving these challenges requires tools and frameworks that translate observations efficiently into actionable, policy-ready insights (Press, 2021). Such tools must inform the selection and development of indicators, assessments, and predictions to safeguard biodiversity (Van de Putte et al., 2021). In the Southern Ocean context, they should inform decision-making, ecosystem-based management, the creation of protected areas (such as Marine Protected Areas, Antarctic Specially Protected Areas, and Antarctic Specially Managed Areas), and guarantee the long-term sustainability of the region's ecosystems, realized through the maintenance of key ecological functions, biodiversity, and resilience, within the context of ongoing environmental change (Turner et al., 2014; Brooks et al., 2016; Hindell et al., 2020; Rogers et al., 2020; Constable et al., 2023).

Several global frameworks, with varying degrees of synergy, have been developed to address the need for observations that can contribute to robust trend indicators in monitoring climate, biodiversity, ecosystems, and other environmental changes (see Section 2.2). The Essential Variables (EVs) framework currently encompasses Essential Climate Variables (ECVs), Essential Ocean Variables (EOVs), Essential Biodiversity Variables (EBVs), ecosystem Essential Ocean Variables (eEOVs), and Essential Ecosystem Service Variables (EESVs) (Lindstrom et al., 2012; Constable et al., 2016; Balvanera et al., 2022). While some of these frameworks are fully operational, others are still in development, collectively advancing the understanding of environmental and biological systems with greater scope and precision. By standardizing critical metrics, these tools offer the potential to integrate fragmented observations into cohesive ecosystem monitoring strategies.

The Southern Ocean remains underrepresented in global conservation goals, leading to an underappreciation of its global significance (Chown and Brooks, 2019). Adopting and adapting the EV concept to the Southern Ocean's unique characteristics could help elevate its conservation needs within global priorities, by providing evidence-based insights that support more effective policy and management responses to environmental change and ecosystem vulnerability (Pereira et al., 2013; Constable et al., 2016; Constable et al., 2023). As the United Nations Decade of Ocean Science for Sustainable Development 2021–2030 (hereafter UN Ocean Decade) progresses with its mission to develop "the science we need for the ocean we want" (Intergovernmental Oceanographic Commission, 2021), the Antarctic marine scientific community has a unique and time-sensitive opportunity to advocate for the implementation of this framework to support future decision-making in the Southern Ocean.

The UN Ocean Decade is closely aligned with the United Nations' Agenda 2030 and the Sustainable Development Goals (SDGs), established in 2015 as a global call to eliminate poverty, protect the planet, and ensure well-being for all by 2030 (Constable et al., 2016; Van de Putte et al., 2021; Janssen et al., 2022; Convention on Biological Diversity (CBD), 2025). Southern Ocean-specific EVs can provide useful indicators aligned with SDG 14: Life Below Water (Targets 14.1–14.5) and SDG 13: Climate Action (Targets 13.1–13.3), while serving as a unifying framework across global initiatives. On a broader scale, these EVs, particularly in the context of Southern Ocean fisheries and ecosystem monitoring, align with SDG 2: Zero Hunger (Target 2.4, sustainable food production), SDG 8: Decent Work and Economic Growth (Target 8.4, resource efficiency), and SDG 12: Responsible Consumption and Production (Target 12.2, sustainable resource use). These alignments are particularly relevant as krill fisheries expand and tourism pressures increase in the region, calling for science-driven sustainable practices. Under the Kunming-Montreal Global Biodiversity Framework (GBF) 2022, adopted by the CBD to halt biodiversity loss by 2030, EBVs support Targets 1–4 and 7–8. Additionally, EVs can enhance Global Biodiversity Data initiatives by standardizing biodiversity metrics, integrating data across ecosystems, and supporting global biodiversity assessments such as those led by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (Geijzendorffer et al., 2016; Navarro et al., 2017). By developing Southern Ocean-specific EVs now, the scientific community can better integrate into this broader agenda, creating opportunities for evidence-based conservation strategies and ensuring that Southern Ocean biodiversity monitoring contributes meaningfully to global sustainability objectives. Conversely, this development also ensures that Southern Ocean conservation and management needs are prioritized at higher levels of decision-making.

The Marine Ecosystem Assessment for the Southern Ocean (MEASO; Constable et al., 2023), an open, participatory, and interdisciplinary initiative, evaluated the status and trends of Southern Ocean ecosystems and their drivers of change. Designed for policymakers, scientists, and the wider public, MEASO synthesized data, scientific literature, and expert knowledge to support ecosystem management, conservation efforts, and global assessments. Since its inaugural conference in 2018, MEASO has provided key scientific insights to guide decision-making (e.g., Constable et al., 2024) and played a crucial role in advising management and conservation agencies on scientific priorities, identifying research gaps, and informing the development of observing systems (Constable et al., 2023). The incorporation of EVs into the MEASO framework would significantly enhance its capacity to track biodiversity changes, climate change impacts, and ecosystem health in a systematic and standardized manner, as EVs provide a structured approach to long-term ecosystem monitoring by integrating diverse data sources, ensuring consistency across studies, and improving the comparability of assessments over time. By adopting EVs, MEASO could strengthen its role as a key provider of actionable knowledge for ecosystem management and policy, reinforcing its contributions to global frameworks such as the CBD, GBF, SDGs, and the UN Ocean Decade. Recognizing this need, a dedicated workshop on Southern Ocean EVs was held in Hobart, Australia, on August 10–11, 2023 (hereafter Hobart-23 workshop).

This paper builds upon the foundations established during the Hobart-23 workshop. By synthesizing the key outcomes of the discussions, it provides a roadmap for advancing biodiversity observation efforts in the Southern Ocean region. Organized by the Scientific Committee on Antarctic Research (SCAR) Antarctic Biodiversity Portal (biodiversity.aq), in collaboration with the Southern Ocean Observing System (SOOS) and the Australian Antarctic Division (AAD), and as a UN Ocean Decade endorsed activity, the workshop brought together experts to advance ecosystem monitoring. The focus was specifically on marine ecosystems, with thematic groups dedicated to sea ice, planktonic, benthic, and top predator systems. Participants created an inventory of marine-focused EVs relevant to the Southern Ocean, building on existing frameworks (see Section 2.2). The workshop discussions led to the proposal of new EVs, including novel variables and adaptations of existing ones to the unique Southern Ocean context. The workshop also identified gaps in current observation infrastructures and highlighted the critical data necessary for implementing these variables effectively.

This paper, along with the accompanying resources (see Supplemental materials), is intended primarily for the scientific community engaged in Southern Ocean research and monitoring. It provides a foundation and bridge for the continued practices of identifying, developing, and operationalizing EVs tailored to the region. While the outcomes may also inform managers and stakeholders, particularly in conservation and policy contexts, the main objective is to support the scientific processes that underpin long-term, ecosystem-based observation. By maintaining an open and adaptable framework, the aim is to enable collaborative progress and ensure that Southern Ocean biodiversity trends are tracked in a standardized, policy-relevant, and scientifically robust manner.

2. The Essential Variables for an integrated marine observation and information system

2.1. An open and interconnected process

To assess changes in the Southern Ocean and mitigate pressures on marine biodiversity effectively, the scientific community requires an integrated system of marine biological observations that is tailored to the Southern Ocean's unique conditions and seamlessly embedded within global monitoring frameworks. Such a system should build upon existing platforms while remaining open to innovation and ensuring transparency, with data, methods, and algorithms adhering to FAIR principles (Findable, Accessible, Interoperable, and Reusable; Tanhua et al., 2019; Van de Putte et al., 2021).

Establishing a structured workflow for data collection, quality control, and management will be key for the effectiveness of an integrated marine observation system. A well-defined framework will enhance data consistency, interoperability, and long-term usability, while also enabling ongoing evaluation of progress, data coverage, and usage to ensure that collected data meaningfully inform conservation and policy decisions. Such a framework could be based on the cyclical architecture proposed by Benson et al. (2018), in which system components (monitoring, protocols, standards, accessibility, modeling, analysis, knowledge, and products) are interconnected and mutually informative. Early planning for data storage, visibility, and accessibility is equally important and will make integration into global monitoring efforts much smoother. A key option for ensuring data visibility and accessibility is the Ocean Biodiversity Information System (OBIS), a global open-access repository that aggregates and standardizes marine biodiversity data, including species occurrences, distributions, and abundance, from a worldwide network of contributors. Recognized under the GBF as the designated "repository for ocean biodiversity," OBIS plays a central role in marine biological data management. By serving as a clearinghouse, it provides the scientific community, policymakers, and conservationists with the necessary data to track progress on GBF targets.

EVs can serve as the cornerstone of this system, providing the structured framework that connects all the constituent physical and biological components, enhances the understanding of the Southern Ocean, and facilitates effective, evidence-based ecosystem policy and management development. To support this, policy and conservation bodies require well-curated data products that transform complex biodiversity information into actionable insights for management and decision-making. While existing EV frameworks provide a strong foundation, they are not always sufficient for addressing the unique characteristics of the Southern Ocean. Many existing variables are developed with global applications in mind, often underrepresenting critical processes in polar environments, such as sea ice interactions, extreme seasonality, and distinct ecosystem dynamics. By proposing a set of Southern Ocean-specific variables, the goal of this paper is to refine and enhance observational capacity in a way that complements existing frameworks. The manuscript explicitly identifies key gaps in current EVs and demonstrates how Southern Ocean variables can better capture the region's ecological and physical complexities. This effort is aligned with broader ocean observing initiatives to ensure interoperability and practical application for research, conservation, and policy.

2.2. The emergence and development of Essential Variables frameworks

Although EV frameworks such as ECVs, EOVs, and EBVs are well-established, their principles remain unevenly adopted across polar research programs. A brief overview is provided to clarify how our proposed Southern Ocean-specific EVs align with and build upon these efforts.

The Global Climate Observing System, under the World Meteorological Organization, first introduced ECVs to monitor Earth's changing climate systematically. These variables are fundamental for assessing the state of the climate system and informing global reports such as those from the Intergovernmental Panel on Climate Change. Building on the ECV framework, the Global Ocean Observing System (GOOS) defined EOVs to track key physical, chemical, and biological oceanic processes, enabling a deeper understanding of the ocean's state and its interactions with the Earth system (Miloslavich et al., 2018). Notably, ocean ECVs and their corresponding EOVs are directly aligned, ensuring compatibility across observing systems. This equivalence allows for seamless deployment and integration, facilitating a more coordinated and efficient approach to ocean monitoring.

Inspired by both the ECV and EOV frameworks, EBVs were introduced by the Group on Earth Observations Biodiversity Observing Network (GEO BON) to standardize biodiversity data collection, sharing, and application for global monitoring (Pereira et al., 2013; Navarro et al., 2017). EBVs harmonize diverse biodiversity observations, whether derived from in-situ monitoring or remote sensing. These variables are versatile, representing measurements from single-location time series to aggregated observations across spatial scales (Schmeller et al., 2017; Jetz et al., 2019; GEO BON, 2025). Collaboration between GEO BON and GOOS enhanced the interoperability of EBV and EOV frameworks, facilitating a synergistic approach to biodiversity and ocean monitoring (Muller-Karger et al., 2018). The relationships and complementarities between the ECVs, EOVs, and EBVs frameworks are illustrated in **Figure 1**.

The SOOS, using the Framework on Ocean Observing (FOO), developed the Southern Ocean-specific eEOVs (Constable et al., 2016). While eEOVs complement broader frameworks such as EOVs and EBVs, they emphasize biomass, diversity, cover, and composition, while prioritizing ecosystem-level properties, including the spatial distribution of taxa, food web structure and function, and anthropogenic pressures. This tailored approach makes eEOVs particularly well-suited to addressing the unique complexities of the Southern Ocean's ecosystems (Van de Putte et al., 2021).

The emerging framework of EESVs aims to represent human-nature relationships and their evolution over time. Designed to monitor progress toward the SDGs and Agenda 2030, EESVs include categories such as ecological supply, anthropogenic contributions, demand, usage, instrumental values, and relational values (Balvanera et al., 2022). These variables provide a structured approach to measuring ecosystem services in the context of sustainability and human well-being.

2.3. Essential Ocean Variables

EOVs are a set of key oceanic parameters that provide information on the state and dynamics of marine systems, supporting the monitoring of ocean health and climate change. They are designed to capture a wide range of oceanic properties, such as sea surface temperature, as well as biogeochemical and ecological processes, including carbon cycling, nutrient fluxes, and primary production. By standardizing the monitoring of these variables, EOVs offer a consistent and comprehensive framework for tracking long-term trends in ocean conditions, which is essential for informed decision-making and management of marine resources (Global Ocean Observing System, 2020). Integrating EOVs into monitoring systems provides an effective way to assess the impacts of climate change, pollution, and overfishing on marine ecosystems.

Within the GOOS, EOVs are supported by three distinct yet interconnected types of variables. Sub-variables are the measurable or inferred components of an EOV (or ECV) that may be derived from other variables in the observing system. Derived variables are quantities or indicators calculated directly from the EOV or ECV, offering additional insights into ocean processes. Lastly, supporting variables include other EOVs, ECVs, or any additional

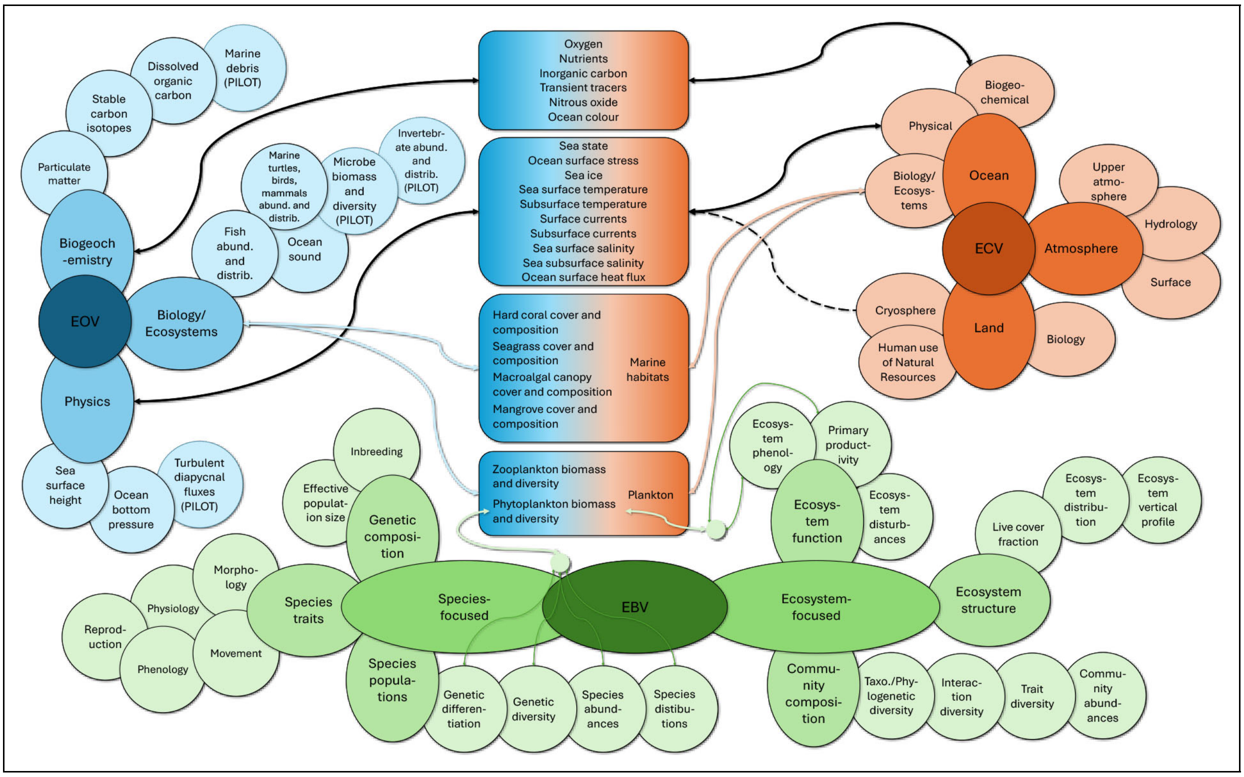

Figure 1. Conceptual alignment of the frameworks for Essential Climate, Essential Ocean, and Essential Biodiversity Variables. Simplified representation of the relationships between Essential Climate Variables (ECVs), Essential Ocean Variables (EOVs), and Essential Biodiversity Variables (EBVs). The hierarchy is structured as follows: at the top level, the EV types (ECV, EOV, EBV; large dark circles) are depicted, followed by their respective categories (oblong shapes) and specific variables (small light circles). All individual variables are shown for EOVs and EBVs, whereas for ECVs, only the subcategories are represented. Note that ocean-related ECVs are functionally equivalent to their corresponding EOVs and can be integrated seamlessly into observing systems, without distinction; these relationships are represented by double-sided continuous black lines. Dashed lines indicate cases where an ECV subcategory contributes to variables within the EOV framework (e.g., Cryosphere–Sea ice). Colored lines illustrate the connections between variable categories and the specific variables they share with another framework. For EBVs, linkages are exemplified using a single EOV, "phytoplankton biomass and diversity," to illustrate connections. A more comprehensive representation of these relationships can be found in Muller-Karger et al. (2018).

measurements needed to fully deliver the EOV. The EOV framework (**Figure 2**) is structured around three categories and is further organized into 34 variables.

2.4. Essential Biodiversity Variables

EBVs are defined in several ways. (1) EBVs are critical variables that capture biodiversity state and changes across time, space, and biological organization levels. They are designed to provide a standardized approach to biodiversity monitoring, enabling the integration of diverse data sources into meaningful metrics (Schmeller et al., 2017). (2) EBVs are an interface between raw data and biodiversity indicators, supporting the detection of critical changes and informing policy at national and global scales (Langer et al., 2022). (3) EBVs are biological variables that contribute critically to the characterization of Earth's biodiversity; they are a minimum set of common, and complementary set of observable, variables across the dimensions of biodiversity that can be used to create indicators of system-level biodiversity trends (Brummitt et al., 2017). (4) The internationally recognized EBV framework facilitates alignment of local observations with larger scale monitoring efforts by targeting essential aspects of biodiversity, enabling the integration of data from diverse sampling programs. It offers a structured means to translate biodiversity data into actionable insights, particularly relevant in understanding the impacts of environmental changes and human activities (Schmeller et al., 2017; Muller-Karger et al., 2018).

The EBV framework (**Figure 3**) is structured around three broad environmental realms, Marine/Coastal, Terrestrial, and Freshwater, and is further organized into six overarching classes: Genetic Composition, Species Populations, and Species Traits, which are characterized as species-focused EBVs, and Community Composition, Ecosystem Function, and Ecosystem Structure, which are characterized as ecosystem-focused EBVs. Each class is subdivided into specific EBV names, with a total of 21 defined variables. For more details, refer to the glossary available on the EuropaBON GitHub page (EuropaBON, 2025).

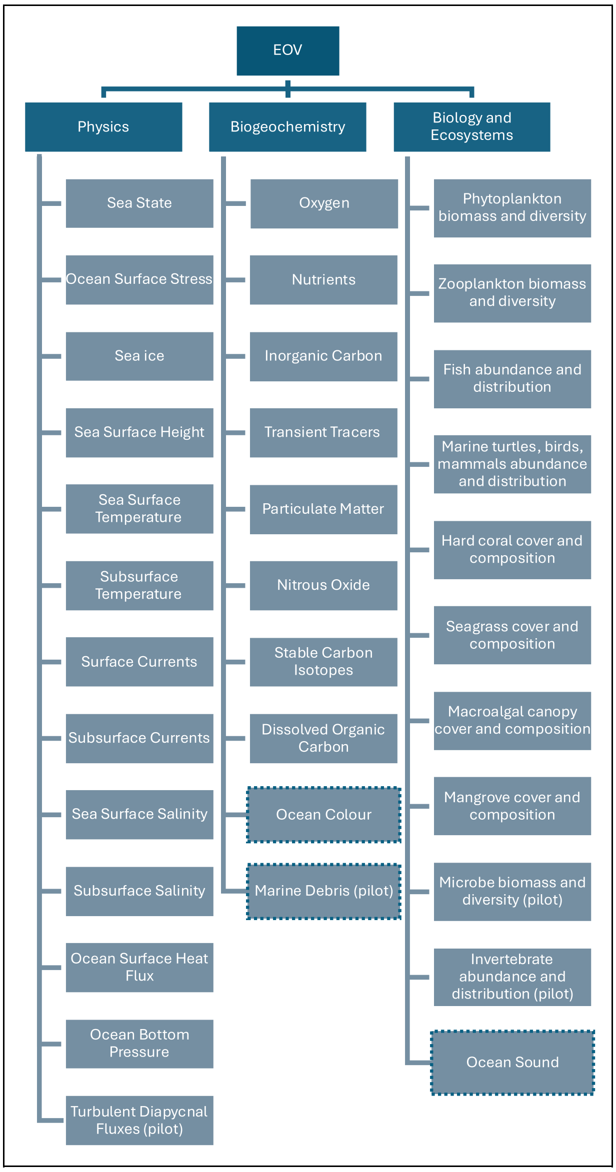

Figure 2. Framework for Essential Ocean Variables of the Global Ocean Observing System. This framework is structured into two hierarchical levels: Level I, with three Essential Ocean Variable (EOV) categories, each overseen by a dedicated Global Ocean Observing System expert panel; and Level II, with 34 individual EOVs. The three variables enclosed in dashed-line boxes indicate cross-disciplinary relevance.

3. Designing Southern Ocean-specific Essential Variables

3.1. Hobart-2023 workshop

The methodology adopted to identify Southern Ocean-specific EVs began with engagement across the scientific, management, and stakeholder communities. Online surveys helped assess initial priorities and identify gaps in existing systems. These preliminary findings shaped the agenda for the Hobart-2023 hybrid workshop, where in-person and online participants engaged in plenary discussions and focused breakout sessions to refine priorities and strategies collaboratively.

The workshop aimed to:

1. compile an inventory of EVs relevant to the Southern Ocean;
2. assess data requirements for calculating these EVs and identify critical data gaps;
3. prioritize EVs based on their ecological importance, policy relevance, feasibility, and urgency for integration into monitoring efforts;
4. map existing workflows and tools for processing biological data, evaluating their applicability, and identifying necessary improvements/developments; and
5. develop a framework to transform raw, publicly available data into Southern Ocean-relevant EVs by outlining methodological steps for data integration, standardization, and quality control, ensuring consistency and reliability.

This structured approach lays the foundation for a robust and scalable system that integrates Southern Ocean biodiversity monitoring seamlessly within global frameworks while addressing the unique challenges of the region. To ensure alignment with these efforts, workshop participants were encouraged to base their suggestions on existing frameworks, particularly leveraging GEO BON and GOOS work on EBVs and EOVs.

The workshop methodology emphasizes broad community engagement to elicit a comprehensive understanding of needs and gaps by inviting participants from diverse disciplines, openly identifying and evaluating priorities, and maintaining a living, accessible document. This participatory approach has already been successfully replicated in a second workshop ("*Essential Biodiversity Variables Framework for Terrestrial Antarctic and Sub-Antarctic Ecosystems*" held in Cambridge, UK, and online in September 2024), which focused on Antarctica's terrestrial ecosystems. For further details on the workshop outcomes, consult the full report (Plasman et al., 2025). This iterative, inclusive process is essential to integrate expertise and knowledge at every stage, ensuring that the development of Southern Ocean-specific EVs is both scientifically rigorous and operationally relevant.

The focus was specifically on marine ecosystems, with thematic groups dedicated to sea ice, planktonic, benthic, and top predator systems. A fifth thematic group dedicated to the mesopelagic theme was planned for discussions, but lack of sufficient expertise and time during the Hobart-2023 workshop limited the extent to which this theme was addressed.

This gap may reflect a broader issue in Southern Ocean research: despite the critical ecological role of mesopelagic systems (e.g., carbon sequestration), the understanding remains incomplete. Mesopelagic fish, which constitute the majority of mesopelagic biomass, are understudied, leaving significant gaps in the knowledge of their biodiversity, abundance, biomass, and the processes that influence their distribution, life cycles, and behavior. On a global scale, (meso-)pelagic ecosystems are notably underrepresented in marine biodiversity databases,

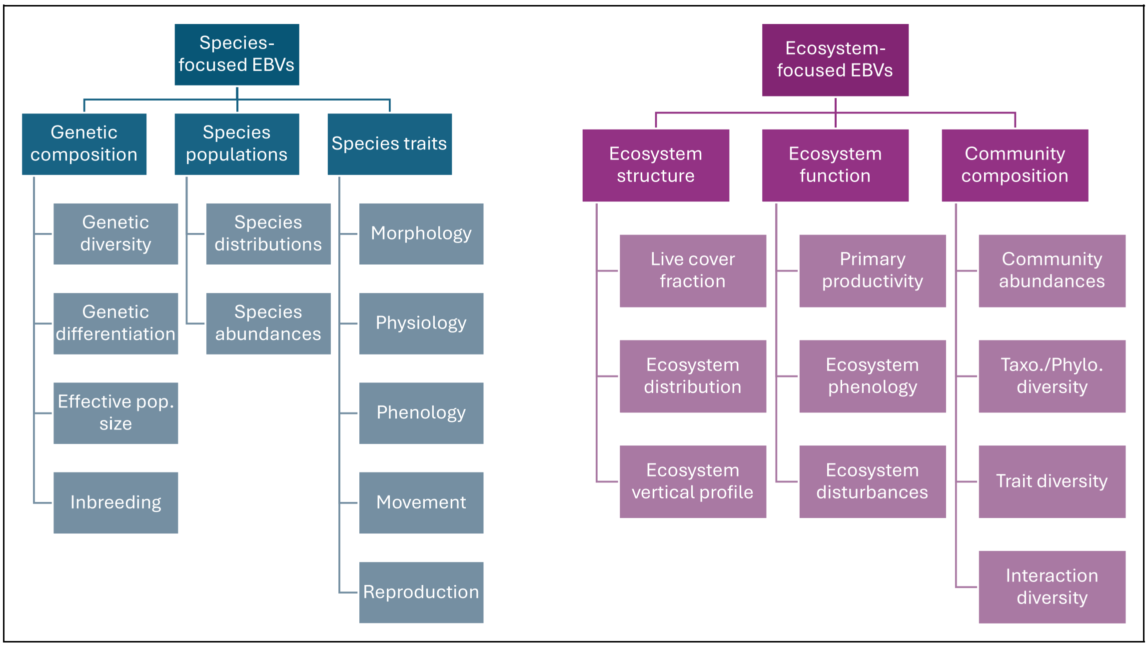

Figure 3. Framework for Essential Biodiversity Variables of the Group on Earth Observations Biodiversity Observing Network. This framework is structured into three hierarchical levels: Level I, with two Essential Biodiversity Variable (EBV) categories; Level II, with six EBV classes; and Level III, with 21 individual variables.

highlighting a substantial knowledge gap that calls for increased attention and targeted research efforts. We stress in this paper a keen interest in receiving participation and inputs around this theme in future activities and rounds of engagement. The iterative nature of EV development will help address this gap progressively by enabling the inclusion of additional variables as new data, methodologies, and priorities emerge.

In reviewing EOVs, EBVs, and eEOVs, two breakout groups, sea ice and top predators, chose to align with the GOOS EOV framework. In contrast, the planktonic and benthic groups focused on GEO BON's EBVs to better capture biodiversity-specific dynamics. Additionally, the benthic group explored the FOO eEOVs, emphasizing ecosystem-level processes. A total of 47 EO/EB (sub-)variables were identified, all of which are listed and described in Section 4. For additional context and detailed discussion, readers are encouraged to consult the SOOS workshop report “Designing Southern Ocean E(B)V workflows, from data collection to data products” (Plasman et al., 2024), which provides further background on the selection and relevance of these variables. To facilitate collaboration and iterative improvement, candidate variables will be documented on a dedicated GitHub wiki (Biodiversity.aq, 2025). This platform will allow to propose enhancements, suggest additions, and contribute to refining the framework, ensuring a dynamic and inclusive development process.

3.2. Challenges in the Southern Ocean region

Workshop participants first reviewed existing frameworks for Essential Variables to assess their applicability in the Southern Ocean. Given the environmental extremes of the Southern Ocean, such as presence of sea ice and its variability, strong winds, and low temperatures, along with its logistical constraints (spatially and seasonally limited accessibility and high operational costs) and ecosystem complexity (strong seasonality and regionally distinctive food webs), data collection presents unique challenges. Sampling efforts in the Southern Ocean are often more difficult to conduct than in other oceanic regions, requiring careful planning and interdisciplinary approaches.

To address these challenges, participants identified gaps in current observing strategies and explored how emerging technologies could enhance data collection and analysis. Leveraging advancements in autonomous observing systems, remote sensing, environmental DNA (eDNA), and machine-assisted identification, can help optimize monitoring efforts, enhance spatial and temporal coverage, and supplement costly ship-based surveys. Identifying the most adaptable and scalable approaches is crucial for overcoming logistical limitations and was a key focus of the Hobart-2023 workshop, where participants discussed existing solutions, identified gaps, and explored innovative approaches to improve data collection and integration in the Southern Ocean.

3.3. Scaling to include both polar systems

Building on these discussions, participants also explored how defined variables might be scaled beyond the Southern Ocean to other polar ecosystems. The framework has the potential to integrate both Arctic and Antarctic environments, leveraging their shared climatic and ecological significance (e.g., Gaffey et al., 2024). By scaling the engagement process and integrating expertise across all these ecosystems, the methodology could identify shared challenges and knowledge gaps, such as cryosphere loss and biodiversity shifts, while designing EVs to region-specific needs. Extending this effort to the Arctic should actively involve Indigenous knowledge and rightsholders and other key stakeholders throughout the process, as well as researchers from diverse institutions, disciplines, and cultural contexts. Supported by coordinated infrastructure, like icebreakers, satellites, and Deep Argo Floats, such scaling of our framework developed for the Southern Ocean could establish a unified, infrastructure-backed toolkit for polar research.

The structured framework provided by EVs can help address some of the challenges related to fragmented and inconsistently standardized polar data, particularly in the context of long-term monitoring applications. As highlighted by Gaffey et al. (2024), while 34 major polar databases were listed, their accessibility and standardization vary due to differing data-sharing policies. EVs can address this issue by defining a core set of parameters needed for understanding polar ecosystems, ensuring that data collected across repositories are consistent and comparable. This standardization reduces variability caused by differing methodologies and enables the creation of interoperable datasets, which are essential for establishing informatic gateways between existing repositories. By prioritizing EVs, streamlined access through centralized systems with consistent Application Programming Interfaces can be ensured, enabling cloud-based workflows and facilitating meta-analyses and big-data studies, and align with successful global initiatives such as the Global Biodiversity Information Facility and the Barcode of Life Data System, which rely on standardized variables to integrate diverse datasets. Applicability for each polar region hinges on adapting the methodology to diverse governance structures (e.g., the Arctic Council vs. the Antarctic Treaty System) and cultural contexts (Gaffey et al., 2024), but adopting such an approach for polar research by enhancing data accessibility could considerably strengthen international collaborations and accelerate the advance of our understanding of polar ecosystems.

4. Proposed Essential Variables for the Southern Ocean

To provide a consolidated overview of the candidate EVs identified for the Southern Ocean, we present a summary figure (**Figure 4**). A comprehensive list of these candidate EVs, along with their associated processes, thematic domains, EV classifications, and justifications, is available in Table S1. The aim of this paper is to synthesize and provide an overview of the workshop discussions. As such, the candidate variables presented here reflect the scope and emphases of those discussions, and not necessarily

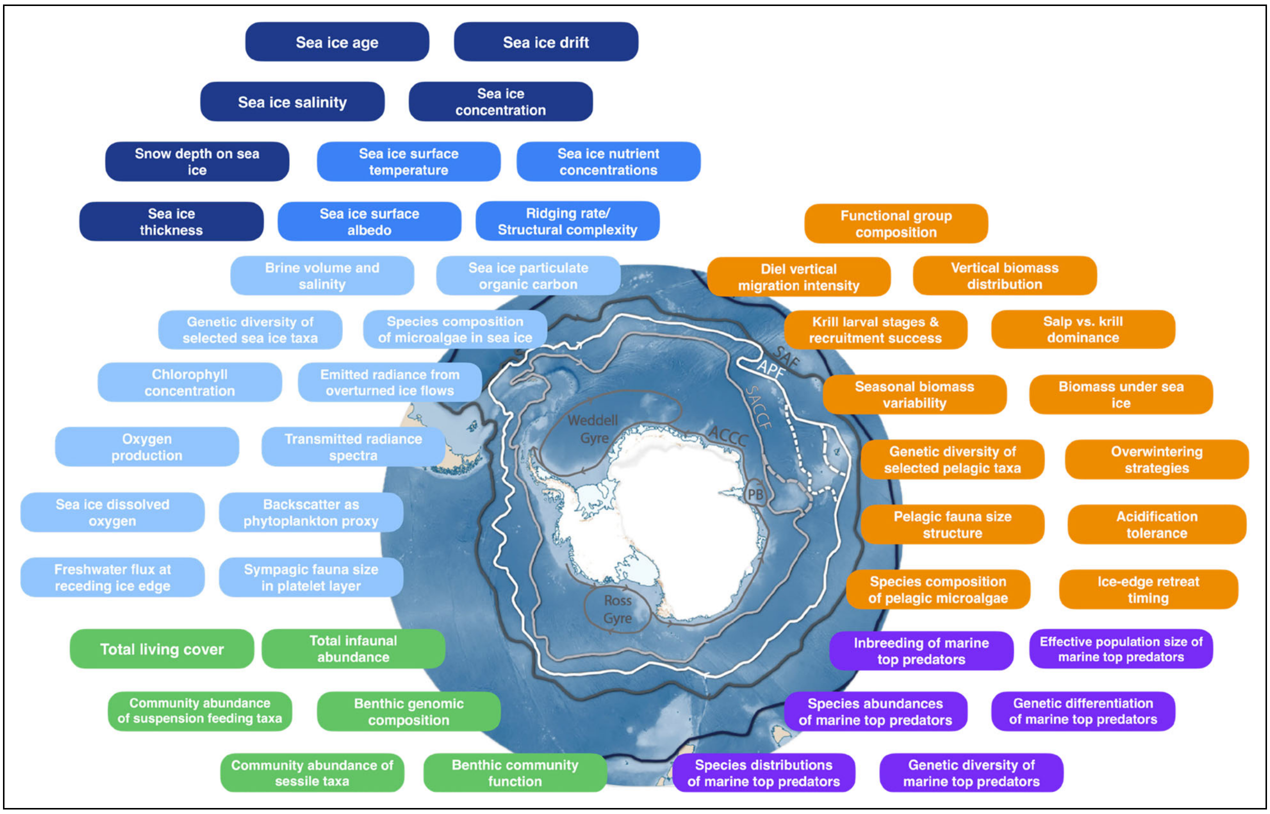

Figure 4. Summary of candidate Essential Variables for the Southern Ocean. Candidate variables are grouped into four thematic domains: sea ice (blue), pelagic (orange), benthic (green), and top predators (purple). For the sea ice domain, a blue color gradient represents the level of integration of each candidate variable within existing Essential Ocean Variables: dark blue indicates variables already well-defined within the current EOV framework; medium blue, variables that require adaptation; and light blue, those that remain to be developed. Southern Ocean map taken from Maroni and Wilson (2022), based on Quantarctica 3.2 (Matsuoka et al., 2018), with gyre information from Vernet et al. (2019), Roach and Speer (2019), Nunes Vaz and Lennon (1996), and Williams et al. (2016).

the full range of factors known to influence Southern Ocean ecosystems.

To complement the list of proposed candidate EVs, we also provide a synthesis of current data availability, major knowledge gaps, and suggested monitoring priorities across key ecosystem domains: sea ice, plankton, benthic systems, and top predators. This overview is presented in Table S2.

4.1. Sea ice

A significant portion of the cataloged variables are ECVs/EOVs related to sea ice and its properties, such as sea ice concentration, thickness, and age. Sea ice plays a crucial role in numerous marine physical, chemical, and biological processes and serves as a key indicator of climate variability and change in the Southern Ocean (Hobbs et al., 2016; Steiner et al., 2021; Fraser et al., 2023; Swadling et al., 2023). The foundational work established by GOOS for sea ice was acknowledged, and the need to adapt many existing sub-variables to better capture the unique characteristics of the Southern Ocean cryosphere was emphasized. Sub-variables, which are components of an EOV, may be measured directly, derived from other EOVs, or inferred from different elements of the observing system. Organizing and adapting this existing repository of information could provide a robust foundation for advancing sea ice monitoring. Some of these EOVs will require additional calculations, standardization, or even direct observational data to become sufficiently insightful in the Southern Ocean context (Table S1).

While some EOV sub-variables (see definition in Section 2.3) were already noted as specific to sea ice, others, such as pelagic EOVs, could also be measured within the sea ice environment (Constable et al., 2016). For instance, nutrient concentration and species composition are relevant beyond open waters and could be adapted for sea ice studies. Identifying which pelagic EOV sub-variables should be modified for sea ice applications is essential, as well as which can be used without alteration to avoid duplication of efforts. In the case of carbon export, assessing the flux of ice-derived carbon may require multiple sub-variables and potentially new ones to accurately capture the distinct regional characteristics of sea ice. While sea ice algal and planktonic communities are critical to Antarctic ecosystems, their study is often limited by logistical challenges tied to their close association with the ice (Meiners et al., 2012; Thomas, 2017). Overcoming barriers such as accessibility and operational constraints is essential to improving our understanding of these understudied components of the sea ice environment. For instance, under-ice remote sensing using transmitted radiance spectra, deployed via remotely operated vehicles, and potentially Biogeochemical-Argo Floats equipped with under-ice avoidance capabilities could provide a novel perspective on sea ice ecosystems (Katlein et al., 2017). Additionally, leveraging marine predators as autonomous environmental samplers could further expand sampling efforts (Roquet et al., 2013; Roquet et al., 2014). These animals, equipped with sensors, can deliver direct physical and biogeochemical measurements from under-sampled regions, including beneath the ice, complementing traditional approaches (McMahon et al., 2025). Such methods address logistical challenges by accessing areas previously difficult to study (Hindell et al., 2020; McMahon et al., 2021). Furthermore, leveraging hydroacoustic methods, such as using backscatter as a phytoplankton biomass/concentration proxy, and employing camera work with advanced image analysis (e.g., hyperspectral imaging) could also expedite and standardize traditional methods, such as microscopy, for the identification of ice algal species composition (Cimoli et al., 2017). Studies like Cimoli et al. (2019; 2020) demonstrated that hyperspectral imaging can capture fine-scale algal biomass and distribution in Antarctic sea ice, offering a more efficient and precise alternative to conventional approaches.

To better define the sea ice ecosystem, specific components or habitats including the sea ice itself, the snow cover on top, the platelet layer beneath, and the leads (open water areas) within the ice were deemed important to consider during the Hobart-2023 Workshop. These elements collectively shape the Southern Ocean sea ice environment, influencing algal growth, nutrient cycling, and habitat availability for organisms like krill and marine mammals. Variables may need to be adapted for each of these components, but not all variables will be relevant across all four realms. One example is ice algal biomass, which is highly relevant within the sea ice and platelet layer where algae grow, but not directly relevant for the snow cover or leads. This variable may need to be adapted based on the physical characteristics of each habitat; for example, in the platelet layer, it would involve assessing algae suspended within the interstitial spaces, whereas in the solid sea ice matrix, it would require sampling within the bottom layers where most algal production occurs.

A major consideration that remains is the definition of the appropriate spatial resolution to measure these sea ice variables. While horizontal resolution is already defined within the sea ice ECV/EOV framework, vertical resolution has not yet been standardized, highlighting the need for the community to establish an appropriate scale for global application. A suggestion that vertical resolution should align with prevalent ice core sampling and analysis practices, often conducted in approximately ten-centimeter increments, would ensure compatibility and coherence with already established methodologies. The horizontal resolution would benefit from being higher than that employed for in-water measurements, due to the strong spatial heterogeneity within the complex sea ice matrix. This more nuanced approach should have the potential to enhance the accuracy and granularity of collected data. Also recognized is that, while sea-ice-specific ECVs (Lavergne et al., 2022) were recently updated through the implementation plan of the Global Climate Observing System (revised every five years) and are generally cost-effective for describing the physical properties of sea ice, they remain limited in their ability to capture processes and properties occurring at or beneath the ice bottom. Addressing these gaps will be crucial for improving our understanding of sea ice dynamics.

4.2. Plankton

Phytoplankton forms the base of the (pelagic ice-free) Southern Ocean food web, and along with their zooplankton grazers, drive the main biogeochemical cycles. Prokaryotic microbial communities and sea ice algae are also recognized as significant contributors, but they were not consistently discussed during the workshop, largely due to the expertise of participants and the framing of the sessions. Their limited treatment in this paper therefore reflects the scope of the workshop rather than their importance in Southern Ocean biogeochemistry and food web dynamics. In contrast, phytoplankton and zooplankton were discussed in sufficient detail to warrant focused treatment here, and we therefore centre the following sections on their roles.

Through photosynthesis, phytoplankton fuels primary production and the region's biological carbon pump, drawing CO_2 from the atmosphere and supporting marine life (Smetacek and Nicol, 2005). Zooplankton, including krill, serve as a vital link between primary producers and higher trophic levels, feeding fish, seabirds, and marine mammals (Murphy et al., 2012). Given their sensitivity to environmental changes, such as warming, ocean acidification, and shifts in sea ice cover, monitoring both groups is essential for assessing ecosystem health and predicting future changes (Constable et al., 2014; Swadling et al., 2023). Changes in biogeochemical cycles, particularly silica availability, can significantly impact community composition for silica-dependent taxa, such as diatoms, parmales, and silicoflagellates, altering primary productivity and food web dynamics. Similarly, the effects of ocean acidification on calcifying organisms (e.g., coccolithophorids, pteropods, and foraminifera) are complex, potentially affecting total abundance and species diversity in ways that require long-term, integrated monitoring efforts (Johnston et al., 2022). Additionally, plankton are highly sensitive to environmental changes, and shifts in their phenology, community composition, and nutritional value can have cascading impacts across the entire Southern Ocean food web (Ratnarajah et al., 2023; Swadling et al., 2023; Queirós et al., 2024). Alterations in the timing of phytoplankton blooms can lead to mismatches with the life cycles of zooplankton grazers like Antarctic krill, potentially disrupting energy transfer to higher trophic levels such as fish, seabirds, and marine mammals (Johnston et al., 2022; Thomalla et al., 2023). Likewise, changes in phytoplankton community composition, such as a shift from diatom dominance to coccolithophores, can affect the nutritional quality available to zooplankton and higher consumers, influencing growth, reproduction, and overall ecosystem dynamics (Krumhardt et al., 2022; Thomalla et al., 2023).

A key example of long-term plankton monitoring in the region is the Continuous Plankton Recorder (CPR) program, which provides one of the most consistent biological data streams available for the Southern Ocean. While CPR sampling is subject to some of the same logistical constraints as other traditional methods, such as limited spatial and temporal coverage and biases toward larger plankton, it remains an invaluable resource for tracking long-term trends in zooplankton abundance, distribution, and community composition. The Southern Ocean CPR (SO-CPR) database has contributed significantly to understanding plankton variability, ecosystem shifts, and climate-driven changes in the region. While not a standalone solution, CPR data can inform specific EVs, particularly those related to plankton community dynamics and phenological shifts (Zooplankton/Phytoplankton EOVs, Ecosystem function EBV). The data can be complemented by emerging approaches such as eDNA and autonomous sampling technologies, enhancing the ability to monitor ecosystem changes at broader spatial and temporal scales. Zooplankton and phytoplankton EOVs for biomass and diversity have already been established and are currently being updated through the GOOS process, following their first iteration in 2016 (UNESCO IOC GOOS, 2025a; 2025b). While those two existing EOVs offer a strong foundation, adapting them to the Southern Ocean context requires specific adjustments (Table S1).

The Southern Ocean is highly seasonal, with strong fluctuations in sea ice extent, light availability, and primary productivity shaping zooplankton communities. During summer, extensive phytoplankton blooms fuel zooplankton growth, whereas in winter, organisms rely on stored energy reserves or alternative food sources (Deppeler and Davidson, 2017). Antarctic krill, a key species of the Southern Ocean ecosystem, depends on sea ice both as habitat during critical life stages and as a source of primary production. Monitoring krill populations is therefore essential for understanding how changes in sea ice affect their reproduction and larval survival. Beyond krill, copepods (e.g., *Calanus spp.*), salps (e.g., *Salpa thompsoni*), and amphipods contribute significantly to ecosystem functioning. Shifts in salp versus krill dominance, driven by climate variability, could have deep implications for food web structure and carbon sequestration (Krumhardt et al., 2022). Additionally, the mesopelagic and deep-sea realms, often overlooked in global monitoring programs, play a key role in the biological carbon pump through vertical migration and detrital transport. Expanding zooplankton monitoring into these deeper layers will improve the understanding of carbon cycling and ecosystem resilience in a changing climate (Atherden et al., 2024). Given the logistical constraints of traditional sampling in the Southern Ocean, improving spatial and temporal coverage is an essential step. Large areas remain under-sampled, particularly beneath sea ice and in remote deep-sea basins.

To overcome observational challenges in the Southern Ocean, the ongoing revision of biological EOV specification sheets presents a key opportunity to acknowledge and incorporate the broad range of available observing technologies, including tested, new, and emerging methods. By integrating these advancements into the Zooplankton biomass and diversity EOV, the monitoring capacity in remote and extreme environments such as the Southern Ocean can be enhanced significantly, ensuring more comprehensive and scalable long-term observations. Autonomous platforms, optical and acoustic methods, and molecular tools can help fill existing gaps and improve data resolution (Ohman et al., 2019). Bioacoustic monitoring, using multi-frequency echosounders, can provide high-resolution estimates of krill and mesopelagic zooplankton biomass across broad spatial scales (Haris et al., 2021). Emerging eDNA approaches offer a non-invasive method to assess zooplankton diversity and detect rare or cryptic species, complementing traditional net sampling (Yang and Zhang, 2020; Zhang et al., 2024). Autonomous underwater vehicles and gliders, equipped with imaging and environmental sensors, enable continuous surveys in remote and ice-covered regions (Dowdeswell et al., 2008). Similarly, deep-sea observatories can enhance the understanding of mesopelagic and bathypelagic zooplankton dynamics, particularly their role in carbon sequestration (Claustre et al., 2021). Biogeochemical-Argo floats with zooplankton sensors provide long-term, high-resolution data on biomass fluctuations, offering an unprecedented look at ecosystem variability (Haëntjens et al., 2020). By integrating these technologies, the scientific community can improve monitoring, start to bridge seasonal and geographic gaps, and ensure that zooplankton observations in the Southern Ocean are both scalable and sustainable.

4.3. Benthic

In contrast to other marine environments, where extensive surveys have already provided valuable data on benthic communities, the Southern Ocean seafloor remains significantly underexplored, leaving a gap in ecological knowledge (Brandt et al., 2014; Brasier et al., 2019; Brasier et al., 2021). This knowledge deficit is concerning, given the region's role in global carbon cycling and its higher vulnerability to global change and pressures like fisheries and mining (Clark et al., 2015). This underrepresentation comes from the difficulties linked to deep-sea research.

The Southern Ocean seafloor hosts a diverse and highly endemic fauna, including sponges, corals, echinoderms, and infaunal communities, that contribute to habitat complexity and ecosystem processes (Griffiths, 2010; Griffiths et al., 2024). These organisms are key players in carbon cycling, storing organic matter, and influencing sediment processes critical for long-term carbon sequestration in deep-sea environments (Barnes, 2017; Griffiths et al., 2024).

There are already EOVs addressing some benthic and deep-sea specificities, including "Coral" and the developing "Sponge" EOV. Additionally, the Invertebrate Body Size EOV, developed by the Deep Ocean Observing System (Ruhl et al., 2023), provides a comprehensive framework for integrating benthic invertebrate observations across body-size classes, improving data availability and usability for ecosystem monitoring and management. For the Southern Ocean, incorporating a dedicated benthic EV is essential to overcoming challenges such as spatial heterogeneity, seasonal variability, and logistical constraints. Size-based approaches, as outlined by Ruhl et al. (2023), could be particularly relevant for tracking benthic biomass, biodiversity, and carbon cycling. Expanding standardized methodologies, including eDNA, seabed imagery, and machine-assisted identification, would enhance the ability to assess ecosystem function, detect biodiversity shifts, and inform conservation measures such as Marine Protected Areas. Without dedicated EVs, the capacity to detect and mitigate the impacts of environmental change on these habitats will remain severely limited. The ongoing revision of EOV specification sheets presents an opportunity for experts to refine existing benthic variables, develop new standardized approaches (e.g., Standard Operating Procedures) that can be deployed at scale, and ensure that these variables provide insights not only into ecosystem functioning but also for policy and decision-making. Aligning Southern Ocean benthic EVs with global efforts, such as those led by the Deep Ocean Observing System, would enhance integration into broader marine monitoring frameworks, facilitating long-term assessments of climate change impacts and human activities on benthic ecosystems (Table S1).

4.4. Mesopelagic

Addressing the mesopelagic theme was challenging, given the absence of a dedicated group during the Hobart-2023 workshop, and more broadly, due to the noted global gap. Nonetheless, this paper stresses here the significance of the mesopelagic zone within the Southern Ocean ecosystems. The mesopelagic zone of the Southern Ocean, ranging from 200 m to 1000 m depth, plays a significant role in this ocean's ecosystem dynamics and in global biogeochemical cycles (McMahon et al., 2019). This portion of the water column hosts a large biomass, dominated by mesopelagic fish (particularly myctophids), alongside zooplankton, cephalopods, and gelatinous organisms such as salps (McCormack et al., 2020; Woods, 2022). These fish serve as key intermediaries in the food web, linking lower trophic levels (e.g., krill, copepods, and other zooplankton) to higher predators such as king penguins, Antarctic fur seals, and elephant seals (Catul et al., 2011; Saunders et al., 2019; Caccavo et al., 2021; Dornan et al., 2022). They provide alternative pathways of major energy and matter flows and may be equally or more important than krill-based ones, particularly in regions and/or seasons where krill abundance is low (Murphy et al., 2007; Dornan et al., 2022).

Beyond their ecological role, mesopelagic fish significantly contribute to the biological carbon pump by consuming organic matter near the surface and transporting carbon to deeper waters through diel vertical migrations (Dornan et al., 2022). They enhance the efficiency of carbon sequestration by packaging organic material into fast-sinking fecal pellets and carcasses, which accelerate carbon export to the seabed. They connect the pelagic and benthic realms and thus affect benthic productivity and biogeochemical cycling (St. John et al., 2016; Cavan et al., 2019; Henley et al., 2020). Their influence extends to global greenhouse gas sequestration, yet they remain one of the least studied components of Southern Ocean marine ecosystems (St. John et al., 2016; Henley et al., 2020; Ljungström et al., 2021; Marina et al., 2024). This knowledge gap is primarily due to logistical challenges, including the remoteness, vast scale, and high spatio-temporal variability of mesopelagic organisms, which make direct observation and sampling difficult (Woods, 2022). In the Southern Ocean, limited acoustic and trawling studies, combined with the relative inefficiency of existing sampling methods, have slowed efforts to map the distribution and abundance of mesopelagic species (McMahon et al., 2019). As a result, historical biomass estimates for these fish have varied widely, from 70 Mt to 191 Mt, before being revised to the current range of 274–570 Mt (Lancraft et al., 1989; St. John et al., 2016; Dornan et al., 2022). Alongside the long-established Antarctic krill fishery, there is growing commercial interest in mesopelagic fish as a potential new source of aquafeed (St. John et al., 2016; Ljungström et al., 2021; Quang et al., 2024). Recent modeling and database compilation efforts have improved the understanding of the circum-Antarctic biogeography of mesopelagic fish (Freer et al., 2020; Woods, 2022; Woods et al., 2023). However, significant limitations persist in predicting species distributions, including a lack of species-specific abundance and biomass data, failure to account for species interactions, and a focus on only a subset of common species (Gordó-Vilaseca et al., 2024).

Given their ecological and biogeochemical significance, as well as growing fisheries interest, improving monitoring efforts, and integrating mesopelagic-specific EVs is crucial for effective management and conservation in the Southern Ocean. However, current observational frameworks lack standardized metrics, making difficult the proper tracking of changes in abundance, distribution, and functional roles of mesopelagic fish, which are highly dynamic organisms exhibiting diel vertical migrations, seasonal shifts in biomass distribution, and strong environmental dependencies (Dornan et al., 2022).

To improve long-term monitoring, the already existing GOOS fish abundance and distribution EOV and its sub-variables can be adapted to account for the unique ecological dynamics of the Southern Ocean. Standard indicators such as fish abundance, biomass, and size distribution provide critical insights into population structures and ecosystem roles but require modifications to address challenges specific to mesopelagic species, including deep vertical migrations, sparse distributions, and difficulties in direct sampling due to their occurrence in remote and deep environments. Acoustic survey techniques, commonly used to assess fish biomass, require adjustments to frequency ranges to better detect mesopelagic scattering layers, while net sampling could be integrated with eDNA to validate species composition. Additionally, calibrating biomass estimates is essential, considering the high lipid content of many mesopelagic fish. Among derived indices, size-based indicators (e.g., mean fish size, size spectra) could be particularly useful for tracking community shifts in response to climate variability or fisheries pressure. Similarly, food web indicators, such as the proportion of predatory fish, may need refinement due to the complex trophic interactions of mesopelagic species, which frequently serve as both predators and prey in the Southern Ocean. Developing mesopelagic-specific sub-variables within the Fish Abundance and Distribution EOV would facilitate the integration of diverse data sources (e.g., acoustic surveys, camera-based systems, eDNA, ecosystem modeling) and enable coordinated monitoring efforts across observing networks such as SOOS (Ljungström et al., 2021). These EVs should focus on species biomass, vertical distribution patterns, trophic interactions, and contributions to carbon sequestration, ensuring that mesopelagic processes are captured within broader Southern Ocean ecosystem assessments (Table S1).

Recognizing these needs, SCAR established a new working group, SCARFISH, in early 2025 to serve as a platform dedicated to Southern Ocean fish research. SCARFISH aims to enhance collaboration between the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) and the broader Antarctic research community by facilitating data exchange, fieldwork coordination, and research synthesis, while also identifying critical research gaps, policy initiatives, and shared priorities (SCARFISH, 2025).

4.5. Top predators

Top predators in the Southern Ocean, such as seals, penguins, and cetaceans, play a critical role in maintaining marine ecosystem balance (Young et al., 2015; Bestley et al., 2020). As apex consumers, they regulate populations of lower trophic levels, including fish and krill, making them valuable indicators of ecosystem health. Their presence, abundance, and behavior can provide crucial insights into environmental change and the impacts of fisheries (Hazen et al., 2019; Bestley et al., 2020).

Recognizing their ecological importance, the CCAMLR established the CCAMLR Ecosystem Monitoring Program (CEMP) in 1989. CEMP's primary objectives are to detect and monitor changes in key marine system components and to differentiate between natural environmental variability and the effects of fishing. To achieve this goal, CEMP collects data on "dependent species," marine predators whose diet consists primarily of commercially harvested species, such as Adélie penguins (*Pygoscelis adeliae*) and Antarctic fur seals (*Arctocephalus gazella*; Agnew, 1997). Some of these dependent species also serve as indicator species, meaning their population size, reproductive success, body mass, and foraging behavior can reflect changes in the availability of harvested prey. The spatial and temporal scales at which CEMP parameters reflect ecosystem changes vary widely. Some indicators, such as foraging trip durations and offspring growth rates, capture short-term changes occurring within days and relatively small spatial scales near breeding sites. In contrast, breeding success provides insights over months, while population size indicators integrate multi-annual trends, reflecting adult survival, condition, and juvenile recruitment, offering a broader perspective on ecosystem dynamics.

Rather than developing separate EVs for top predators, a more effective approach is to integrate CEMP data into existing EV frameworks. While CEMP provides valuable species-specific data, EVs offer a standardized approach to integrating multiple data streams across ecosystems. Aligning CEMP parameters with relevant EVs, particularly within the Biological and Ecosystems EOVs, would ensure a more consistent and comprehensive assessment of key species, such as seals, penguins, and killer whales, strengthening ecosystem-based management efforts in the Southern Ocean. The Marine Mammal EOV already includes key parameters related to abundance, distribution, and demography, but some short-term ecological indicators, such as foraging trip durations and offspring growth rates, may not yet be explicitly standardized. These fine-scale biological metrics, well-established within CEMP, could be refined or included as sub-variables within the Marine Mammal EOV to enhance its ability to track ecosystem variability across multiple temporal scales. Similarly, long-term indicators such as population size, juvenile recruitment, and survival rates are central to both CEMP and the Marine Mammal EOV, yet their alignment across monitoring frameworks could be improved. For example, there are differences in data collection methods: CEMP focuses on species-specific monitoring (e.g., tracking Adélie penguins and fur seals in relation to krill availability), while the Marine Mammal EOV is designed for global applicability, potentially leading to inconsistencies in how the same metrics are measured. There are also variations in spatial and temporal resolution: CEMP primarily monitors colonial breeding species at known sites, whereas the Marine Mammal EOV may aim for broader population-scale assessments, leading to different spatial coverage and monitoring frequencies. Finally, there could be potential gaps in data integration: if population trends recorded in CEMP are not incorporated systematically into the Marine Mammal EOV, opportunities for a more comprehensive, ecosystem-wide analysis may be missed (Table S1).

5. Discussion

5.1. Ongoing challenges and priorities for developing EBVs for the Southern Ocean

A key priority is identifying the primary users and stakeholders for Southern Ocean-specific EVs. These include scientists, policymakers, conservation organizations, and resource managers, each relying on EVs for distinct purposes such as research, policymaking, and ecosystem management. Ensuring that EVs are both relevant and actionable requires a clear understanding of how these end-users will integrate them into their work. By aligning variable development with user needs, while keeping the outcomes of the Hobart-23 workshop in mind, the scientific community can better frame discussions and establish priorities for future efforts.

One of the most pressing challenges is securing sustained funding for long-term monitoring programs. Evaluating the impacts of environmental change requires continuous data acquisition, which is particularly difficult in the Southern Ocean, where many areas remain inaccessible during winter (Janssen et al., 2022). Without dedicated long-term financial support, efforts to monitor biodiversity and ecosystem changes risk being fragmented or discontinued.

Beyond data collection, managing and integrating EV data into global monitoring systems is another critical challenge. The interoperability, collation, and accessibility of EV datasets must be ensured, allowing them to be easily discovered and used across different platforms. The OBIS data products catalog, currently under development, could provide a structured and accessible repository for EV-related data, as it will be sorted according to EOV/EBV frameworks and variable category structures.

Essential to increasing the impact of Southern Ocean-specific EVs is to map their use, assess observational coverage, and identify gaps in data collection. Geospatial maps of EV coverage could be invaluable when proposing and designing new observing networks such as the Troll Observing Network and large international initiatives like Antarctica InSync. These efforts would support the strategic expansion of observation networks, ensuring that future programs prioritize under-sampled regions and critical ecosystem processes.

5.2. A Framework for Southern Ocean EVs

Developing a robust framework for EVs suited to the Southern Ocean requires a structured workflow that ensures scientific rigor, transparency, and practical application. A critical step is assessing whether existing EVs already capture the necessary measurements or if they can be adapted to include Southern Ocean-specific observations. This approach prevents redundancy and ensures alignment with global frameworks. Due to time constraints, this assessment could not be fully conducted during the Hobart-23 workshop, highlighting the need for follow-up analyses and dedicated studies on specific EV subsets (e.g., mesopelagic theme). By timestamping the outcomes of the Hobart-23 workshop, this paper lays the foundation for continued refinement, providing a baseline upon which future studies can build. A key takeaway was the need for precise and unambiguous terminology when defining those EVs.

There are several steps to transition from a candidate EV to a mature, standardized workflow. The first step is formal adoption, for which GOOS has outlined a detailed proposal procedure and criteria (OceanExpert, 2025). A clear scientific justification must establish the variable's ecological and policy relevance while considering cost implications. This process often relies on voluntary expert contributions and can be slow, at a pace that is unaffordable given the accelerating rate of environmental change in the Southern Ocean. Streamlining this transition by prioritizing critical EVs, securing expert engagement, and accelerating methodological standardization is essential for timely operationalization.

Data collection methods must be detailed explicitly, covering field sampling techniques, archival standards, and quality control protocols to guarantee reproducibility. Reference implementations in code are essential for transparent, peer-reviewed data processing, enabling validation, error correction, and future refinements. The rOpenSci community could play an important role in reviewing and maintaining such codes, ensuring seamless data processing, quality control, and interoperability.

A critical step in this process is assigning unique identifiers (e.g., DOIs, persistent metadata tags) to datasets, ensuring their long-term traceability and interoperability across research networks. FAIR datasets should be deposited in TRUSTed (Transparency, Responsibility, User focus, Sustainability, Technology) repositories such as Zenodo. However, with multiple existing platforms, a key challenge is streamlining data integration and enhancing cross-platform interoperability. Strengthening connections between GOOS and OBIS will ensure EV-related datasets are efficiently catalogued and linked across systems, supporting seamless data discovery and long-term usability for both scientific research and policy applications.

5.3. Ensuring usability and policy integration

Adapting and designing EVs for the Southern Ocean is a critical step toward addressing key knowledge gaps and informing conservation strategies. A well-defined, scalable, and adaptable EV framework will enhance the capacity to monitor and protect this important region in the face of rapid environmental change. To achieve this goal, international collaboration and systematic approaches must be prioritized to ensure that EVs contribute effectively to both regional and global assessments.

The increasing demand for “State of the Climate”-style reports highlights the potential of EVs in informing policy and decision-making. Discussions at recent Antarctic Treaty Consultative Meetings and CCAMLR meetings underscored the growing recognition of EVs as fundamental tools for assessing ecosystem health and guiding conservation efforts. In this context, MEASO would be significantly strengthened through the incorporation of EVs, allowing it to integrate diverse datasets (e.g., see McMahon et al. (2025) for an example of integrating physical and biological data), improve tracking of biodiversity changes, and enhance its role in global reporting frameworks such as the CBD, GBF, SDGs, and the UN Ocean Decade.

Essential to ensuring the success of Southern Ocean EVs is to rapidly engage dedicated groups that can conduct targeted follow-up analyses and establish collaborative forums. For example, initiatives such as SCARFISH could provide a platform for refining the mesopelagic component of the fish EOV, ensuring that these variables align with broader observing frameworks while addressing specific ecological challenges.

A key consideration in EV development is ensuring that selected variables remain scalable and applicable across local, regional, and global assessments. Defining EVs too narrowly, based on methodologies that lack broad applicability, risks limiting their usefulness for large-scale decision-making. Instead, a flexible yet comprehensive set of variables should be established, allowing for consistent monitoring of status and trends across multiple spatial and temporal scales. Rather than developing entirely new EVs for mesopelagic ecosystems in the Southern Ocean, a more effective strategy can be to integrate mesopelagic-specific elements into existing EOVs, in alignment with GOOS principles. Engaging with the Biology and Ecosystems expert panel of GOOS will be crucial in ensuring that these modifications remain aligned with international efforts while being practical for Southern Ocean implementation.

Ultimately, the successful development and implementation of Southern Ocean EVs will rely on open data access, collaborative research, and the transformation of raw data into user-friendly products that support informed decision-making, as well as their alignment with international initiatives such as GOOS and SCAR, ensuring coherent integration into global monitoring and decision-making processes (Van de Putte et al., 2021).

6. Conclusion

The Southern Ocean’s significant role in global climate regulation and biodiversity underscores the urgent need for a robust monitoring framework to address accelerating environmental changes and human pressures. This paper, building on the Hobart-2023 workshop, advances the development of Southern Ocean-specific EVs as a critical tool to bridge data gaps, standardize observations, and deliver actionable insights for conservation and management. By proposing tailored EVs for sea ice, planktonic, benthic, and top predator systems, the scientific community can address the region’s unique ecological dynamics while ensuring alignment with global frameworks such as GOOS. These EVs enhance the capacity to track biodiversity trends, assess ecosystem health, and inform policy, thus having the potential to strengthen initiatives like MEASO and contribute to international goals (e.g., SDGs, GBF). However, success hinges on overcoming challenges: securing sustained funding, enhancing data interoperability, and rapidly operationalizing EVs through collaborative, open-access efforts. We, the authors, call on the scientific and conservation communities to refine and implement this adaptable framework, ensuring it remains scalable across local-to-global scales and responsive to stakeholder needs. By transforming fragmented data into a cohesive, policy-relevant system, Southern Ocean EVs can help safeguard this vital ecosystem and elevate its priority in global sustainability efforts.

Supplemental files

The supplemental files for this article can be found as follows:

Supplemental materials.docx.

Acknowledgments

This paper stems from a workshop organized in collaboration with SOOS, SCAR, and biodiversity.aq. This workshop was held in August 2023 in Hobart, Tasmania. SOOS is an international initiative of the Scientific Committee on Antarctic Research and the Scientific Committee on Oceanic Research. We thank Luke Brokensha, Nicole Hill, Heike Link, Anna MacDonald, Klaus Meiners, Irene Schloss, Katherine Tattersall, Sophia Volzke, and Joel Williams for their valuable participation in the workshop that helped shape the discussions leading to this paper.

Workshop participants: AVdP, AMH, BR, NB, DFA, AB, SC, KE, RSE, NF, AFH, SFH, JJ, AMa, CRM, PM, PTH, IC, AW, KS, LB, SH, NH, HL, AMe, KM, IS, KT, SV, JW.

Funding

The workshops and paper were supported through funding from the Belspo ADVANCE project (RT/23/ADVANCE).

Competing interests

The authors have declared that no competing interests exist.

Author contributions

Contributed to conception and design: CP, AVdP.
Drafted and/or revised the article: CP, AVdP, AMH, BR, NB, DFA, SFH, AB, SC, KE, RSE, NF, AFH, SH, JJ, AM, CRM, PM, PTH, IC, AW, KS, YMG.
Approved the submitted version for publication: CP, AVdP, AMH, BR, NB, DFA, SFH, AB, SC, KE, RSE, NF, AFH, SH, JJ, AM, CRM, PM, PTH, IC, AW, KS, YMG.
Workshop organization: AVdP, AMH, BR.

AI disclosure statement

This document was refined with the assistance of AI to enhance wording and clarity; it was further refined by the editor prior to acceptance. The manuscript presented remains original and the result of collective work.

References

Agnew, DJ. 1997. The CCAMLR Ecosystem Monitoring Programme. *Antarctic Science* **9**: 235–242. DOI: https://doi.org/10.1017/S095410209700031X.

Atherden, F, **Slomska, A**, **Manno, C.** 2024. Sediment trap illustrates taxon-specific seasonal signals in Southern Ocean zooplankton. *Marine Biology* **171**(9): 173. DOI: https://doi.org/10.1007/s00227-024-04487-2.

Balvanera, P, **Brauman, KA**, **Cord, AF**, **Drakou, EG**, **Geijzendorffer, IR**, **Karp, DS**, **Martín-López, B**, **Mwampamba, TH**, **Schröter, M.** 2022. Essential ecosystem service variables for monitoring progress towards sustainability. *Current Opinion in Environmental Sustainability* **54**: 101152. DOI: https://doi.org/10.1016/j.cosust.2022.101152.

Bargagli, R, **Rota, E.** 2024. Environmental contamination and climate change in Antarctic ecosystems: An updated overview. *Environmental Science: Advances* **3**: 543–560. DOI: https://doi.org/10.1039/D3VA00113J.

Barnes, DKA. 2017. Iceberg killing fields limit huge potential for benthic blue carbon in Antarctic shallows. *Global Change Biology* **23**(7): 2649–2659. DOI: https://doi.org/10.1111/gcb.13523.

Benson, A, **Brooks, CM**, **Canonico, G**, **Duffy, E**, **Muller-Karger, F**, **Sosik, HM**, **Miloslavich, P**, **Klein, E.** 2018. Integrated observations and informatics improve understanding of changing marine ecosystems. *Frontiers in Marine Science* **5**: 428.

Bestley, S, **Ropert-Coudert, Y**, **Bengtson Nash, S**, **Brooks, CM**, **Cotté, C**, **Dewar, M**, **Friedlaender, AS**, **Jackson, JA**, **Labrousse, S**, **Lowther, AD**, **McMahon, CR**, **Phillips, RA**, **Pistorius, P**, **Puskic, PS**, **de A Reis, AO**, **Reisinger, RR**, **Santos, M**, **Tarszisz, E**, **Tixier, P**, **Trathan, PN**, **Wege, M**, **Wienecke, B.** 2020. Marine ecosystem assessment for the Southern Ocean: Birds and marine mammals in a changing climate. *Frontiers in Ecology and Evolution* **8**: 566936.

Biodiversity.aq. 2025. Essential Variables for the Antarctic and Southern Ocean descriptions. *GitHub*. Available at https://github.com/biodiversity-aq/ASO-essential_variables/wiki/Home. Accessed July 1, 2025.

Bonnet-Lebrun, A-S, **Sweetlove, M**, **Griffiths, HJ**, **Sumner, M**, **Provoost, P**, **Raymond, B**, **Ropert-Coudert, Y**, **Van de Putte, AP.** 2023. Opportunities and limitations of large open biodiversity occurrence databases in the context of a marine ecosystem assessment of the Southern Ocean. *Frontiers in Marine Science* **10**: 1150603.

Brandt, A, **Griffiths, H**, **Gutt, J**, **Linse, K**, **Schiaparelli, S**, **Ballerini, T**, **Danis, B**, **Pfannkuche, O.** 2014. Challenges of deep-sea biodiversity assessments in the Southern Ocean. *Advances in Polar Science* **25**: 204–212. DOI: https://doi.org/10.13679/j.advps.2014.3.00204.

Brasier, MJ, **Barnes, D**, **Bax, N**, **Brandt, A**, **Christianson, AB**, **Constable, AJ**, **Downey, R**, **Figuerola, B**, **Griffiths, H**, **Gutt, J**, **Lockhart, S**, **Morley, SA**, **Post, AL**, **Van de Putte, A**, **Saeedi, H**, **Stark, JS**, **Sumner, M**, **Waller, CL.** 2021. Responses of Southern Ocean seafloor habitats and communities to global and local drivers of change. *Frontiers in Marine Science* **8**: 622721. DOI: https://doi.org/10.3389/fmars.2021.622721.

Brasier, MJ, **Constable, A**, **Melbourne-Thomas, J**, **Trebilco, R**, **Griffiths, H**, **Van de Putte, A**, **Sumner, M.** 2019. Observations and models to support the first marine ecosystem assessment for the Southern Ocean (MEASO). *Journal of Marine Systems* **197**: 103182. DOI: https://doi.org/10.1016/j.jmarsys.2019.05.008.

Brooks, CM, **Crowder, LB**, **Curran, LM**, **Dunbar, RB**, **Ainley, DG**, **Dodds, KJ**, **Gjerde, KM**, **Sumaila, UR.** 2016. Science-based management in decline in the Southern Ocean. *Science* **354**(6309): 185–187. DOI: https://doi.org/10.1126/science.aah4119.

Brummitt, N, **Regan, EC**, **Weatherdon, LV**, **Martin, CS**, **Geijzendorffer, IR**, **Rocchini, D**, **Gavish, Y**, **Haase, P**, **Marsh, CJ**, **Schmeller, DS.** 2017. Taking stock of nature: Essential biodiversity variables explained. *Biological Conservation* **213**: 252–255. DOI: https://doi.org/10.1016/j.biocon.2016.09.006.

Caccavo, JA, **Christiansen, H**, **Constable, AJ**, **Ghigliotti, L**, **Trebilco, R**, **Brooks, CM**, **Cotte, C**, **Desvignes, T**, **Dornan, T**, **Jones, CD**, **Koubbi, P**, **Saunders, RA**, **Strobel, A**, **Vacchi, M**, **Van de Putte, AP**, **Walters, A**, **Waluda, CM**, **Woods, BL**, **Xavier, JC.** 2021. Productivity and change in fish and squid in the Southern Ocean. *Frontiers in Ecology and Evolution* **9**: 624918.

Catul, V, **Gauns, M**, **Karuppasamy, PK.** 2011. A review on mesopelagic fishes belonging to family Myctophidae. *Reviews in Fish Biology and Fisheries* **21**(3): 339–354. DOI: https://doi.org/10.1007/s11160-010-9176-4.

Cavan, EL, **Belcher, A**, **Atkinson, A**, **Hill, SL**, **Kawaguchi, S**, **McCormack, S**, **Meyer, B**, **Nicol, S**, **Ratnarajah, L**, **Schmidt, K**, **Steinberg, DK**, **Tarling, GA**, **Boyd, PW.** 2019. The importance of Antarctic krill in biogeochemical cycles. *Nature Communications* **10**(1): 4742. DOI: https://doi.org/10.1038/s41467-019-12668-7.

Cavanagh, RD, **Melbourne-Thomas, J**, **Grant, SM**, **Barnes, DKA**, **Hughes, KA**, **Halfter, S**, **Meredith, MP**, **Murphy, EJ**, **Trebilco, R**, **Hill, SL.** 2021. Future risk for Southern Ocean ecosystem services under climate change. *Frontiers in Marine Science* **7**: 615214. DOI: https://doi.org/10.3389/fmars.2020.615214.

Chown, SL, **Brooks, CM.** 2019. The state and future of Antarctic environments in a global context. *Annual Review of Environment and Resources* **44**: 1–30. DOI: https://doi.org/10.1146/annurev-environ-101718-033236.

Cimoli, E, **Lucieer, V**, **Meiners, KM**, **Chennu, A**, **Castrisios, K**, **Ryan, KG**, **Lund-Hansen, LC**, **Martin, A**, **Kennedy, F**, **Lucieer, A.** 2020. Mapping the in situ microspatial distribution of ice algal biomass through hyperspectral imaging of sea-ice cores. *Scientific Reports* **10**(1): 21848. DOI: https://doi.org/10.1038/s41598-020-79084-6.

Cimoli, E, **Lucieer, A**, **Meiners, KM**, **Lund-Hansen, LC**, **Kennedy, F**, **Martin, A**, **McMinn, A**, **Lucieer, V.** 2017. Towards improved estimates of sea-ice algal biomass: Experimental assessment of hyperspectral imaging cameras for under-ice studies. *Annals of Glaciology* **58**(75pt1): 68–77. DOI: https://doi.org/10.1017/aog.2017.6.

Cimoli, E, **Meiners, KM**, **Lucieer, A**, **Lucieer, V**. 2019. An under-ice hyperspectral and RGB imaging system to capture fine-scale biophysical properties of sea ice. *Remote Sensing* **11**(23): 2860. DOI: https://doi.org/10.3390/rs11232860.

Clark, MR, **Althaus, F**, **Schlacher, TA**, **Williams, A**, **Bowden, DA**, **Rowden, AA.** 2015. The impacts of deep-sea fisheries on benthic communities: A review. *ICES Journal of Marine Science* **73**. DOI: https://doi.org/10.1093/icesjms/fsv123.

Claustre, H, **Legendre, L**, **Boyd, PW**, **Levy, M.** 2021. The oceans' biological carbon pumps: Framework for a research observational community approach. *Frontiers in Marine Science* **8**. DOI: https://doi.org/10.3389/fmars.2021.780052.

Constable, AJ, **Costa, DP**, **Schofield, O**, **Newman, L**, **Urban, ER**, **Fulton, EA**, **Melbourne-Thomas, J**, **Ballerini, T**, **Boyd, PW**, **Brandt, A**, **de la Mare, WB**, **Edwards, M**, **Eléaume, M**, **Emmerson, L**, **Fennel, K**, **Fielding, S**, **Griffiths, H**, **Gutt, J**, **Hindell, MA**, **Hofmann, EE**, **Jennings, S**, **La, HS**, **McCurdy, A**, **Mitchell, BG**, **Moltmann, T**, **Muelbert, M**, **Murphy, E**, **Press, AJ**, **Raymond, B**, **Reid, K**, **Reiss, C**, **Rice, J**, **Salter, I**, **Smith, DC**, **Song, S**, **Southwell, C**, **Swadling, KM**, **Van de Putte, A**, **Willis, Z.** 2016. Developing priority variables ("ecosystem Essential Ocean Variables"—eEOVS) for observing dynamics and change in Southern Ocean ecosystems. *Journal of Marine Systems* **161**. DOI: https://doi.org/10.1016/j.jmarsys.2016.05.003.

Constable, AJ, **Melbourne-Thomas, J**, **Corney, SP**, **Arrigo, KR**, **Barbraud, C**, **Barnes, DKA**, **Bindoff, NL**, **Boyd, PW**, **Brandt, A**, **Costa, DP**, **Davidson, AT**, **Ducklow, HW**, **Emmerson, L**, **Fukuchi, M**, **Gutt, J**, **Hindell, MA**, **Hofmann, EE**, **Hosie, GW**, **Iida, T**, **Jacob, S**, **Johnston, NM**, **Kawaguchi, S**, **Kokubun, N**, **Koubbi, P**, **Lea, M-A**, **Makhado, A**, **Massom, RA**, **Meiners, K**, **Meredith, MP**, **Murphy, EJ**, **Nicol, S**, **Reid, K**, **Richerson, K**, **Riddle, MJ**, **Rintoul, SR**, **Smith, WO Jr**, **Southwell, C**, **Stark, JS**, **Sumner, M**, **Swadling, KM**, **Takahashi, KT**, **Trathan, PN**, **Welsford, DC**, **Weimerskirch, H**, **Westwood, KJ**, **Wienecke, BC**, **Wolf-Gladrow, D**, **Wright, SW**, **Xavier, JC**, **Ziegler, P.** 2014. Climate change and Southern Ocean ecosystems I: How changes in physical habitats directly affect marine biota. *Global Change Biology* **20**(10): 3004–3025. DOI: https://doi.org/10.1111/gcb.12623.

Constable, AJ, **Melbourne-Thomas, J**, **Muelbert, MM**, **Hollowed, AB.** 2024. Marine Ecosystem Assessment for the Southern Ocean: Meeting the challenge for conserving Earth ecosystems in the long term. *Frontiers in Ecology and Evolution* **12**: 1507045.

Constable, AJ, **Melbourne-Thomas, J**, **Muelbert, MMC**, **McCormack, S**, **Brasier, M**, **Caccavo, JA**, **Cavanagh, RD**, **Grant, SM**, **Griffiths, HJ**, **Gutt, J**, **Henley, SF**, **Höfer, J**, **Hollowed, AB**, **Johnston, NM**, **Morley, SA**, **Murphy, EJ**, **Pinkerton, MH**, **Schloss, IR**, **Swadling, KM**, **Van de Putte, AP.** 2023. Marine ecosystem assessment for the Southern Ocean: Summary for policymakers. *Zenodo.* DOI: https://doi.org/10.5281/zenodo.8359585.

Convention on Biological Diversity (CBD). 2025. 2030 targets (with guidance notes). Available at https://www.cbd.int/gbf/targets. Accessed July 1, 2025.

Deppeler, SL, **Davidson, AT.** 2017. Southern Ocean phytoplankton in a changing climate. *Frontiers in Marine Science* **4**. DOI: https://doi.org/10.3389/fmars.2017.00040.

Dornan, T, **Fielding, S**, **Saunders, RA**, **Genner, MJ.** 2022. Large mesopelagic fish biomass in the Southern Ocean resolved by acoustic properties. *Proceedings of the Royal Society B: Biological Sciences* **289**(1967): 20211781. DOI: https://doi.org/10.1098/rspb.2021.1781.

Dowdeswell, JA, **Evans, J**, **Mugford, R**, **Griffiths, G**, **McPhail, S**, **Millard, N**, **Stevenson, P**, **Brandon, MA**, **Banks, C**, **Heywood, KJ**, **Price, MR**, **Dodd, PA**, **Jenkins, A**, **Nicholls, KW**, **Hayes, D**, **Abrahamsen, EP**, **Tyler, P**, **Bett, B**, **Jones, D**, **Wadhams, P**, **Wilkinson, JP**, **Stansfield, K**, **Ackley, S.** 2008. Autonomous underwater vehicles (AUVs) and investigations of the ice–ocean interface in Antarctic and Arctic waters. *Journal of Glaciology* **54**(187): 661–672. DOI: https://doi.org/10.3189/002214308786570773.

EuropaBON. 2025. Description of the 84 Essential Biodiversity Variables of EuropaBon—EuropaBon/EBV-Descriptions[. *GitHub*. Available at https://github.com/EuropaBON/EBV-Descriptions/wiki/generic-glossary. Accessed July 1, 2025.

Fraser, AD, **Wongpan, P**, **Langhorne, PJ**, **Klekociuk, AR**, **Kusahara, K**, **Lannuzel, D**, **Massom, RA**, **Meiners, KM**, **Swadling, KM**, **Atwater, DP**, **Brett, GM**, **Corkill, M**, **Dalman, LA**, **Fiddes, S**, **Granata, A**, **Guglielmo, L**, **Heil, P**, **Leonard, GH**, **Mahoney, AR**, **McMinn, A**, **van der Merwe, P**, **Weldrick, CK**, **Wienecke, B.** 2023. Antarctic landfast sea ice: A review of its physics, biogeochemistry and ecology. *Reviews of Geophysics* **61**(2): e2022RG000770. DOI: https://doi.org/10.1029/2022RG000770.

Freer, JJ, **Tarling, GA**, **Collins, MA**, **Partridge, JC**, **Genner, MJ.** 2020. Estimating circumpolar distributions of lanternfish using 2D and 3D ecological niche models. *Marine Ecology Progress Series* **647**: 179–193. DOI: https://doi.org/10.3354/meps13384.

Gaffey, CB, **Bax, N**, **Krauzig, N**, **Tougeron, K.** 2024. A call to strengthen international collaboration to assess climate change effects in polar regions. *PLOS Climate* **3**(10): e0000495. DOI: https://doi.org/10.1371/journal.pclm.0000495.

Geijzendorffer, IR, **Regan, EC**, **Pereira, HM**, **Brotons, L**, **Brummitt, N**, **Gavish, Y**, **Haase, P**, **Martin, CS**, **Mihoub, J-B**, **Secades, C**, **Schmeller, DS**, **Stoll, S**, **Wetzel, FT**, **Walters, M.** 2016. Bridging the gap between biodiversity data and policy reporting needs: An Essential Biodiversity Variables perspective. *Journal of Applied Ecology* **53**(5): 1341–1350. DOI: https://doi.org/10.1111/1365-2664.12417.

GEO BON. 2025. What are EBVS? *GEO BON website*. Available at https://geobon.org/ebvs/what-are-ebvs/. Accessed January 17, 2024.

Global Ocean Observing System. 2020. Essential Ocean Variables—Global Ocean Observing System. Available at https://goosocean.org/what-we-do/framework/essential-ocean-variables/. Accessed February 14, 2025.

Gordó-Vilaseca, C, **Costello, MJ**, **Coll, M**, **Jüterbock, A**, **Reiss, H**, **Stephenson, F.** 2024. Future trends of marine fish biomass distributions from the North Sea to the Barents Sea. *Nature Communications* **15**(1): 5637. DOI: https://doi.org/10.1038/s41467-024-49911-9.

Grant, SM, **Hill, SL**, **Trathan, PN**, **Murphy, EJ.** 2013. Ecosystem services of the Southern Ocean: Trade-offs in decision-making. *Antarctic Science* **25**(5): 603–617. DOI: https://doi.org/10.1017/S0954102013000308.

Griffiths, HJ. 2010. Antarctic marine biodiversity—What do we know about the distribution of life in the Southern Ocean? *PLOS One* **5**(8): e11683. DOI: https://doi.org/10.1371/journal.pone.0011683.

Griffiths, HJ, **Cummings, VJ**, **Van de Putte, A**, **Whittle, RJ**, **Waller, CL.** 2024. Antarctic benthic ecological change. *Nature Reviews Earth & Environment* **5**(9): 645–664. DOI: https://doi.org/10.1038/s43017-024-00583-5.

Haëntjens, N, **Della Penna, A**, **Briggs, N**, **Karp-Boss, L**, **Gaube, P**, **Claustre, H**, **Boss, E.** 2020. Detecting mesopelagic organisms using biogeochemical-Argo floats. *Geophysical Research Letters* **47**(6): e2019GL086088. DOI: https://doi.org/10.1029/2019GL086088.

Haris, K, **Kloser, RJ**, **Ryan, TE**, **Downie, RA**, **Keith, G**, **Nau, AW.** 2021. Sounding out life in the deep using acoustic data from ships of opportunity. *Scientific Data* **8**(1): 23. DOI: https://doi.org/10.1038/s41597-020-00785-8.

Hazen, EL, **Abrahms, B**, **Brodie, S**, **Carroll, G**, **Jacox, MG**, **Savoca, MS**, **Scales, KL**, **Sydeman, WJ**, **Bograd, SJ.** 2019. Marine top predators as climate and ecosystem sentinels. *Frontiers in Ecology and the Environment* **17**(10): 565–574. DOI: https://doi.org/10.1002/fee.2125.

Henley, SF, **Cavan, EL**, **Fawcett, SE**, **Kerr, R**, **Monteiro, T**, **Sherrell, RM**, **Bowie, AR**, **Boyd, PW**, **Barnes, DKA**, **Schloss, IR**, **Marshall, T**, **Flynn, R**, **Smith, S.** 2020. Changing biogeochemistry of the Southern Ocean and its ecosystem implications. *Frontiers in Marine Science* **7**. DOI: https://doi.org/10.3389/fmars.2020.00581.

Hill, SL, **Phillips, T**, **Atkinson, A**. 2013. Potential climate change effects on the habitat of Antarctic krill in the Weddell quadrant of the Southern Ocean. *PLOS One* **8**(8): e72246. DOI: https://doi.org/10.1371/journal.pone.0072246.

Hindell, MA, **Reisinger, RR**, **Ropert-Coudert, Y**, **Hückstädt, LA**, **Trathan, PN**, **Bornemann, H**, **Charrassin, J-B**, **Chown, SL**, **Costa, DP**, **Danis, B**, **Lea, M-A**, **Thompson, D**, **Torres, LG**, **Van de Putte, AP**, **Alderman, R**, **Andrews-Goff, V**, **Arthur, B**, **Ballard, G**, **Bengtson, J**, **Bester, MN**, **Blix, AS**, **Boehme, L**, **Bost, C-A**, **Boveng, P**, **Cleeland, J**, **Constantine, R**, **Corney, S**, **Crawford, RJM**, **Dalla Rosa, L**, **de Bruyn, PJN**, **Delord, K**, **Descamps, S**, **Double, M**, **Emmerson, L**, **Fedak, M**, **Friedlaender, A**, **Gales, N**, **Goebel, ME**, **Goetz, KT**, **Guinet, C**, **Goldsworthy, SD**, **Harcourt, R**, **Hinke, JT**, **Jerosch, K**, **Kato, A**, **Kerry, KR**, **Kirkwood, R**, **Kooyman, GL**, **Kovacs, KM**, **Lawton, K**, **Lowther, AD**, **Lydersen, C**, **Lyver, PO**, **Makhado, AB**, **Márquez, MEI**, **McDonald, BI**, **McMahon, CR**, **Muelbert, M**, **Nachtsheim, D**, **Nicholls, KW**, **Nordøy, ES**, **Olmastroni, S**, **Phillips, RA**, **Pistorius, P**, **Plötz, J**, **Pütz, K**, **Ratcliffe, N**, **Ryan, PG**, **Santos, M**, **Southwell, C**, **Staniland, I**, **Takahashi, A**, **Tarroux, A**, **Trivelpiece, W**, **Wakefield, E**, **Weimerskirch, H**, **Wienecke, B**, **Xavier, JC**, **Wotherspoon, S**, **Jonsen, ID**, **Raymond, B.** 2020. Tracking of marine predators to protect Southern Ocean ecosystems. *Nature* **580**(7801): 87–92. DOI: https://doi.org/10.1038/s41586-020-2126-y.

Hobbs, WR, **Massom, R**, **Stammerjohn, S**, **Reid, P**, **Williams, G**, **Meier, W.** 2016. A review of recent changes in Southern Ocean sea ice, their drivers and forcings. *Global and Planetary Change* **143**: 228–250. DOI: https://doi.org/10.1016/j.gloplacha.2016.06.008.

Intergovernmental Oceanographic Commission. 2021. The United Nations Decade of Ocean Science for Sustainable Development (2021–2030): Implementation plan—UNESCO Digital Library. Available at https://unesdoc.unesco.org/ark:/48223/pf0000377082.locale=en. Accessed February 13, 2025.

Intergovernmental Panel On Climate Change (IPCC). 2022. *The ocean and cryosphere in a changing climate: Special report of the Intergovernmental Panel on Climate Change. 1st ed*. Cambridge, UK: Cambridge University Press. DOI: https://doi.org/10.1017/9781009157964.

Janssen, AR, **Badhe, R**, **Bransome, NC**, **Bricher, P**, **Cavanagh, R**, **de Bruin, T**, **Elshout, P**, **Grant, S**, **Griffin, E**, **Grilly, E**, **Henley, SF**, **Hofmann, EE**, **Johnston, NM**, **Karentz, D**, **Kent, R**, **Lynnes, A**, **Martin, T**, **Miloslavich, P**, **Murphy, E**, **Nolan, JE**, **Sikes, E**, **Sparrow, M**, **Tacoma, M**, **Williams, MJM**, **Arata, JA**, **Bowman, J**, **Corney, S**, **Lau, SCY**, **Manno, C**, **Mohan, R**, **Nielsen, H**, **van Leeuwe, MA**, **Waller, C**, **Xavier, JC**, **Van de Putte, AP.** 2022. Southern Ocean action plan (2021–2030) in support of the United Nations Decade of Ocean Science for Sustainable Development. *Zenodo*. DOI: https://doi.org/10.5281/zenodo.6412191.

Jetz, W, **McGeoch, MA**, **Guralnick, R**, **Ferrier, S**, **Beck, J**, **Costello, MJ**, **Fernandez, M**, **Geller, GN**, **Keil, P**, **Merow, C**, **Meyer, C**, **Muller-Karger, FE**, **Pereira, HM**, **Regan, EC**, **Schmeller, DS**, **Turak, E.** 2019. Essential biodiversity variables for mapping and monitoring species populations. *Nature Ecology & Evolution* **3**(4): 539–551. DOI: https://doi.org/10.1038/s41559-019-0826-1.

Johnston, NM, **Murphy, EJ**, **Atkinson, A**, **Constable, AJ**, **Cotté, C**, **Cox, M**, **Daly, KL**, **Driscoll, R**, **Flores, H**, **Halfter, S**, **Henschke, N**, **Hill, SL**, **Höfer, J**, **Hunt, BPV**, **Kawaguchi, S**, **Lindsay, D**, **Liszka, C**, **Loeb, V**, **Manno, C**, **Meyer, B**, **Pakhomov, EA**, **Pinkerton, MH**, **Reiss, CS**, **Richerson, K**, **Smith, WO Jr**, **Steinberg, DK**, **Swadling, KM**, **Tarling, GA**, **Thorpe, SE**, **Veytia, D**, **Ward, P**, **Weldrick, CK**, **Yang, G.** 2022. Status, change, and futures of zooplankton in the Southern Ocean. *Frontiers in Ecology and Evolution* **9**. DOI: https://doi.org/10.3389/fevo.2021.624692.

Katlein, C, **Schiller, M**, **Belter, HJ**, **Coppolaro, V**, **Wenslandt, D**, **Nicolaus, M.** 2017. A new remotely operated sensor platform for interdisciplinary observations under sea ice. *Frontiers in Marine Science* **4**. DOI: https://doi.org/10.3389/fmars.2017.00281.

Kawaguchi, S, **Atkinson, A**, **Bahlburg, D**, **Bernard, KS**, **Cavan, EL**, **Cox, MJ**, **Hill, SL**, **Meyer, B**, **Veytia, D.** 2024. Climate change impacts on Antarctic krill behaviour and population dynamics. *Nature Reviews Earth & Environment* **5**(1): 43–58. DOI: https://doi.org/10.1038/s43017-023-00504-y.

Krumhardt, KM, **Long, MC**, **Sylvester, ZT**, **Petrik, CM.** 2022. Climate drivers of Southern Ocean phytoplankton community composition and potential impacts on higher trophic levels. *Frontiers in Marine Science* **9**. DOI: https://doi.org/10.3389/fmars.2022.916140.

Kubiszewski, I, **Adams, VM**, **Baird, R**, **Boothroyd, A**, **Costanza, R**, **MacDonald, DH**, **Finau, G**, **Fulton, EA**, **King, CK**, **King, MA**, **Lannuzel, D**, **Leane, E**, **Melbourne-Thomas, J**, **Ooi, C-S**, **Raghavan, M**, **Senigaglia, V**, **Stoeckl, N**, **Tian, J**, **Yamazaki, S.** 2024. Cascading tipping points of Antarctica and the Southern Ocean. *Ambio* **54**(4): 642–659. DOI: https://doi.org/10.1007/s13280-024-02101-9.

Lancraft, TM, **Torres, JJ**, **Hopkins, TL.** 1989. Micronekton and macrozooplankton in the open waters near Antarctic ice edge zones (AMERIEZ 1983 and 1986). *Polar Biology* **9**(4): 225–233. DOI: https://doi.org/10.1007/BF00263770.

Langer, C, **Fernández, N**, **Quoß, L**, **Valdez, J**, **Fernandez, M**, **Pereira, HM.** 2022. Cataloging Essential Biodiversity Variables with the EBV Data Portal. *Biodiversity Information Science and Standards* **6**: e93593. DOI: https://doi.org/10.3897/biss.6.93593.

Lavergne, T, **Kern, S**, **Aaboe, S**, **Derby, L**, **Dybkjaer, G**, **Garric, G**, **Heil, P**, **Hendricks, S**, **Holfort, J**, **Howell, S**, **Key, J**, **Lieser, JL**, **Maksym, T**, **Maslowski, W**, **Meier, W**, **Muñoz-Sabater, J**, **Nicolas, J**, **Özsoy, B**, **Rabe, B**, **Rack, W**, **Raphael, M**, **de Rosnay, P**, **Smolyanitsky, V**, **Tietsche, S**, **Ukita, J**, **Vichi, M**, **Wagner, P**, **Willmes, S**, **Zhao, X.** 2022. A new structure for the sea ice essential climate variables of the global climate observing system. *Bulletin of the American Meteorological Society* **103**(6): E1502–E1521. DOI: https://doi.org/10.1175/BAMS-D-21-0227.1.

Le Quéré, C, **Andrew, RM**, **Friedlingstein, P**, **Sitch, S**, **Hauck, J**, **Pongratz, J**, **Pickers, PA**, **Korsbakken, JI**, **Peters, GP**, **Canadell, JG**, **Arneth, A**, **Arora, VK**, **Barbero, L**, **Bastos, A**, **Bopp, L**, **Chevallier, F**, **Chini, LP**, **Ciais, P**, **Doney, SC**, **Gkritzalis, T**, **Goll, DS**, **Harris, I**, **Haverd, V**, **Hoffman, FM**, **Hoppema, M**, **Houghton, RA**, **Hurtt, G**, **Ilyina, T**, **Jain, AK**, **Johannessen, T**, **Jones, CD**, **Kato, E**, **Keeling, RF**, **Goldewijk, KK**, **Landschützer, P**, **Lefèvre, N**, **Lienert, S**, **Liu, Z**, **Lombardozzi, D**, **Metzl, N**, **Munro, DR**, **Nabel, JEMS**, **Nakaoka, S**, **Neill, C**, **Olsen, A**, **Ono, T**, **Patra, P**, **Peregon, A**, **Peters, W**, **Peylin, P**, **Pfeil, B**, **Pierrot, D**, **Poulter, B**, **Rehder, G**, **Resplandy, L**, **Robertson, E**, **Rocher, M**, **Rödenbeck, C**, **Schuster, U**, **Schwinger, J**, **Séférian, R**, **Skjelvan, I**, **Steinhoff, T**, **Sutton, A**, **Tans, PP**, **Tian, H**, **Tilbrook, B**, **Tubiello, FN**, **van der Laan-Luijkx, IT**, **van der Werf, GR**, **Viovy, N**, **Walker, AP**, **Wiltshire, AJ**, **Wright, R**, **Zaehle, S**, **Zheng, B.** 2018. Global Carbon Budget 2018. *Earth System Science Data* **10**(4): 2141–2194. DOI: https://doi.org/10.5194/essd-10-2141-2018.

Lenton, TM, **Held, H**, **Kriegler, E**, **Hall, JW**, **Lucht, W**, **Rahmstorf, S**, **Schellnhuber, HJ.** 2008. Tipping elements in the Earth's climate system. *Proceedings of the National Academy of Sciences* **105**(6): 1786–1793. DOI: https://doi.org/10.1073/pnas.0705414105.

Lindstrom, E, **Gunn, J**, **Fischer, A**, **McCurdy, A**, **Glover, LK.** 2012. A framework for ocean observing. (No. IOC/INF-1284). UNESCO Intergovernmental Oceanographic Commission (IOC). Available at https://unesdoc.unesco.org/ark:/48223/pf0000211260. Accessed July 07, 2025.

Ljungström, G, **Langbehn, TJ**, **Jørgensen, C.** 2021. Light and energetics at seasonal extremes limit poleward range shifts. *Nature Climate Change* **11**(6): 530–536. DOI: https://doi.org/10.1038/s41558-021-01045-2.

Marina, TI, **Saravia, LA**, **Kortsch, S.** 2024. New insights into the Weddell Sea ecosystem applying a quantitative network approach. *Ocean Science* **20**(1): 141–153. DOI: https://doi.org/10.5194/os-20-141-2024.

Maroni, PJ, **Wilson, NG.** 2022. Multiple *Doris "kerguelenensis"* (Nudibranchia) species span the Antarctic Polar Front. *Ecology and Evolution* **12**. DOI: https://doi.org/10.1002/ece3.9333.

Matsuoka, K, **Skoglund, A**, **Roth, G**, **de Pomereu, J**, **Griffiths, H**, **Headland, R**, **Herried, B**, **Katsumata, K, Le Brocq, A, Licht, K, Morgan, F, Neff, P, Ritz, C, Scheinert, M, Tamura, T, Van de Putte, A, van den Broeke, M, von Deschwanden, A, Deschamps-Berger, C, Van Liefferinge, B, Tronstad, S, Melvær, Y**. 2018. Quantarctica [Dataset]. Norwegian Polar Institute. DOI: https://doi.org/10.21334/NPOLAR.2018.8516E961

McBride, MM, **Schram Stokke, O**, **Renner, AHH**, **Krafft, BA**, **Bergstad, OA**, **Biuw, M**, **Lowther, AD**, **Stiansen, JE.** 2021. Antarctic krill *Euphausia superba*: Spatial distribution, abundance, and management of fisheries in a changing climate. *Marine Ecology Progress Series* **668**: 185–214. DOI: https://doi.org/10.3354/meps13705.

McCormack, SA, **Melbourne-Thomas, J**, **Trebilco, R**, **Blanchard, JL**, **Constable, A.** 2020. Alternative energy pathways in Southern Ocean food webs: Insights from a balanced model of Prydz Bay, Antarctica. *Deep Sea Research Part II: Topical Studies in Oceanography* **174**: 104613. DOI: https://doi.org/10.1016/j.dsr2.2019.07.001.

McMahon, C, **Roquet, F**, **Guinet, C**, **Hindell, MA**, **Harcourt, R**, **Charrassin, J-B**, **Labrousse, S**, **Jonsen, I**, **Picard, B**, **Bestley, S**, **Doriot, V**, **Fedak, M.** 2025. An enduring, 20-year, multidisciplinary seal-borne ocean sensor research collaboration in the Southern Ocean. *Elementa: Science of the Anthropocene* **13**. DOI: https://doi.org/10.1525/elementa.2024.00071.

McMahon, CR, **Hindell, MA**, **Charrassin, J-B**, **Corney, S**, **Guinet, C**, **Harcourt, R**, **Jonsen, I**, **Trebilco, R**, **Williams, G**, **Bestley, S.** 2019. Finding mesopelagic prey in a changing Southern Ocean. *Scientific Reports* **9**(1): 19013. DOI: https://doi.org/10.1038/s41598-019-55152-4.

McMahon, CR, **Roquet, F**, **Baudel, S**, **Belbeoch, M**, **Bestley, S**, **Blight, C**, **Boehme, L**, **Carse, F**, **Costa, DP**, **Fedak, MA**, **Guinet, C**, **Harcourt, R**, **Heslop, E**, **Hindell, MA**, **Hoenner, X**, **Holland, K**, **Holland, M**, **Jaine, FRA**, **Jeanniard du Dot, T**, **Jonsen, I**, **Keates, TR**, **Kovacs, KM**, **Labrousse, S**, **Lovell, P**, **Lydersen, C**, **March, D**, **Mazloff, M**, **McKinzie, MK**, **Muelbert, MMC**, **O'Brien, K**, **Phillips, L**, **Portela, E**, **Pye, J**, **Rintoul, S**, **Sato, K**, **Sequeira, AMM**, **Simmons, SE**, **Tsontos, VM**, **Turpin, V**, **van Wijk, E**, **Vo, D**, **Wege, M**, **Whoriskey, FG**, **Wilson, K**, **Woodward, B.** 2021. Animal borne ocean sensors—AniBOS—An essential component of the Global Ocean Observing System. *Frontiers in Marine Science* **8**: 751840. DOI: https://doi.org/10.3389/fmars.2021.751840.

McNeil, BI, **Matear, RJ.** 2008. Southern Ocean acidification: A tipping point at 450-ppm atmospheric CO_2. *Proceedings of the National Academy of Sciences* **105**(48): 18860–18864. DOI: https://doi.org/10.1073/pnas.0806318105.

Meiners, KM, **Vancoppenolle, M**, **Thanassekos, S**, **Dieckmann, GS**, **Thomas, DN**, **Tison, J-L**, **Arrigo, KR**, **Garrison, DL**, **McMinn, A**, **Lannuzel, D**, **van der Merwe, P**, **Swadling, KM**, **Smith, WO Jr**, **Melnikov, I**, **Raymond, B.** 2012. Chlorophyll *a* in Antarctic sea ice from historical ice core data. *Geophysical Research Letters* **39**(21). DOI: https://doi.org/10.1029/2012GL053478.

Miloslavich, P, **Bax, NJ**, **Simmons, SE**, **Klein, E**, **Appeltans, W**, **Aburto-Oropeza, O**, **Andersen Garcia, M**, **Batten, SD**, **Benedetti-Cecchi, L**, **Checkley, DM**, **Chiba, S**, **Duffy, JE**, **Dunn, DC**, **Fischer, A**, **Gunn, J**, **Kudela, R**, **Marsac, F**, **Muller-Karger, FE**, **Obura, D**, **Shin, Y-J.** 2018. Essential ocean variables for global sustained observations of biodiversity and ecosystem changes. *Global Change Biology* **24**(6): 2416–2433. DOI: https://doi.org/10.1111/gcb.14108.

Muller-Karger, FE, **Miloslavich, P**, **Bax, NJ**, **Simmons, S**, **Costello, MJ**, **Sousa Pinto, I**, **Canonico, G**, **Turner, W**, **Gill, M**, **Montes, E**, **Best, BD**, **Pearlman, J**, **Halpin, P**, **Dunn, D**, **Benson, A**, **Martin, CS**, **Weatherdon, LV**, **Appeltans, W**, **Provoost, P**, **Klein, E**, **Kelble, CR**, **Miller, RJ**, **Chavez, FP**, **Iken, K**, **Chiba, S**, **Obura, D**, **Navarro, LM**, **Pereira, HM**, **Allain, V**, **Batten, S**, **Benedetti-Checchi, L**, **Duffy, JE**, **Kudela, RM**, **Rebelo, L-M**, **Shin, Y**, **Geller, G.** 2018. Advancing marine biological observations and data requirements of the complementary Essential Ocean Variables (EOVs) and Essential Biodiversity Variables (EBVs) frameworks. *Frontiers in Marine Science* **5**: 211.

Murphy, EJ, **Cavanagh, RD**, **Hofmann, EE**, **Hill, SL**, **Constable, AJ**, **Costa, DP**, **Pinkerton, MH**, **Johnston, NM**, **Trathan, PN**, **Klinck, JM**, **Wolf-Gladrow, DA**, **Daly, KL**, **Maury, O**, **Doney, SC.** 2012. Developing integrated models of Southern Ocean food webs:

Including ecological complexity, accounting for uncertainty and the importance of scale. *Progress in Oceanography* **102**: 74–92. DOI: https://doi.org/10.1016/j.pocean.2012.03.006.

Murphy, EJ, **Johnston, NM**, **Hofmann, EE**, **Phillips, RA**, **Jackson, JA**, **Constable, AJ**, **Henley, SF**, **Melbourne-Thomas, J**, **Trebilco, R**, **Cavanagh, RD**, **Tarling, GA**, **Saunders, RA**, **Barnes, DKA**, **Costa, DP**, **Corney, SP**, **Fraser, CI**, **Höfer, J**, **Hughes, KA**, **Sands, CJ**, **Thorpe, SE**, **Trathan, PN**, **Xavier, JC.** 2021. Global connectivity of Southern Ocean ecosystems. *Frontiers in Ecology and Evolution* **9**: 624451.

Murphy, EJ, **Watkins, JL**, **Trathan, PN**, **Reid, K**, **Meredith, MP**, **Thorpe, SE**, **Johnston, NM**, **Clarke, A**, **Tarling, GA**, **Collins, MA**, **Forcada, J**, **Shreeve, RS**, **Atkinson, A**, **Korb, R**, **Whitehouse, MJ**, **Ward, P**, **Rodhouse, PG**, **Enderlein, P**, **Hirst, AG**, **Martin, AR**, **Hill, SL**, **Staniland, IJ**, **Pond, DW**, **Briggs, DR**, **Cunningham, NJ**, **Fleming, AH.** 2007. Spatial and temporal operation of the Scotia Sea ecosystem: A review of large-scale links in a krill centred food web. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* **362**(1477): 113–148. DOI: https://doi.org/10.1098/rstb.2006.1957.

Navarro, LM, **Fernández, N**, **Guerra, C**, **Guralnick, R**, **Kissling, WD**, **Londoño, MC**, **Muller-Karger, F**, **Turak, E**, **Balvanera, P**, **Costello, MJ**, **Delavaud, A**, **El Serafy, G**, **Ferrier, S**, **Geijzendorffer, I**, **Geller, GN**, **Jetz, W**, **Kim, E-S**, **Kim, H**, **Martin, CS**, **McGeoch, MA**, **Mwampamba, TH**, **Nel, JL**, **Nicholson, E**, **Pettorelli, N**, **Schaepman, ME**, **Skidmore, A**, **Sousa Pinto, I**, **Vergara, S**, **Vihervaara, P**, **Xu, H**, **Yahara, T**, **Gill, M**, **Pereira, HM.** 2017. Monitoring biodiversity change through effective global coordination. *Current Opinion in Environmental Sustainability* **29**: 158–169. DOI: https://doi.org/10.1016/j.cosust.2018.02.005.

Newman, L, **Heil, P**, **Trebilco, R**, **Katsumata, K**, **Constable, A**, **van Wijk, E**, **Assmann, K**, **Beja, J**, **Bricher, P**, **Coleman, R**, **Costa, D**, **Diggs, S**, **Farneti, R**, **Fawcett, S**, **Gille, ST**, **Hendry, KR**, **Henley, S**, **Hofmann, E**, **Maksym, T**, **Mazloff, M**, **Meijers, A**, **Meredith, MM**, **Moreau, S**, **Ozsoy, B**, **Robertson, R**, **Schloss, I**, **Schofield, O**, **Shi, J**, **Sikes, E**, **Smith, IJ**, **Swart, S**, **Wahlin, A**, **Williams, G**, **Williams, MJM**, **Herraiz-Borreguero, L**, **Kern, S**, **Lieser, J**, **Massom, RA**, **Melbourne-Thomas, J**, **Miloslavich, P**, **Spreen, G.** 2019. Delivering sustained, coordinated, and integrated observations of the Southern Ocean for global impact. *Frontiers in Marine Science* **6**: 433.

Nunes Vaz, RA, **Lennon, GW**. 1996. Physical oceanography of the Prydz Bay region of Antarctic waters. *Deep Sea Research Part I: Oceanographic Research Papers* **43**(5): 603–641. DOI: https://doi.org/10.1016/0967-0637(96)00028-3.

OceanExpert. 2025. Process to adopt new GOOS Essential Ocean Variables (EOVs). Available at https://oceanexpert.org/document/35429. Accessed July 1, 2025.

Ohman, MD, **Davis, RE**, **Sherman, JT**, **Grindley, KR**, **Whitmore, BM**, **Nickels, CF**, **Ellen, JS.** 2019. *Zooglider*: An autonomous vehicle for optical and acoustic sensing of zooplankton. *Limnology and Oceanography: Methods* **17**(1): 69–86. DOI: https://doi.org/10.1002/lom3.10301.

Pereira, HM, **Ferrier, S**, **Walters, M**, **Geller, GN**, **Jongman, RHG**, **Scholes, RJ**, **Bruford, MW**, **Brummitt, N**, **Butchart, SHM**, **Cardoso, AC**, **Coops, NC**, **Dulloo, E**, **Faith, DP**, **Freyhof, J**, **Gregory, RD**, **Heip, C**, **Höft, R**, **Hurtt, G**, **Jetz, W**, **Karp, DS**, **McGeoch, MA**, **Obura, D**, **Onoda, Y**, **Pettorelli, N**, **Reyers, B**, **Sayre, R**, **Scharlemann, JPW**, **Stuart, SN**, **Turak, E**, **Walpole, M**, **Wegmann, M.** 2013. Essential Biodiversity Variables. *Science* **339**: 277–278. DOI: https://doi.org/10.1126/science.1229931.

Pinkerton, MH, **Boyd, PW**, **Deppeler, S**, **Hayward, A**, **Höfer, J**, **Moreau, S.** 2021. Evidence for the impact of climate change on primary producers in the Southern Ocean. *Frontiers in Ecology and Evolution* **9**: 592027. DOI: https://doi.org/10.3389/fevo.2021.592027.

Plasman, C, **Hancock, A**, **Raymond, B**, **Fierro Arcos, D**, **Evans, K**, **Swadling, K**, **Henley, S**, **Halfter, S**, **Brokensha, L**, **Meiners, K**, **Jansen, J**, **ten Hoopen, P**, **Williams, J**, **Eriksen, R**, **Corney, I**, **Meijers, A**, **MacDonald, A**, **Walters, A**, **Henderson, A**, **Link, H**, **Schloss, I**, **Tattersall, K**, **Hill, N**, **Friscourt, N**, **Corney, S**, **Volzke, S**, **Gan, Y-M**, **Van de Putte, A.** 2024. Designing Southern Ocean E(B)V workflows, from data collection to data products. *Zenodo*. DOI: https://doi.org/10.5281/zenodo.11060582.

Plasman, C, **Terauds, A**, **Raymond, B**, **Lee, J**, **Hughes, K**, **Treasure, A**, **Neder, C**, **Colesie, C**, **Cajiao, D**, **Schaepman-Strub, G**, **Tołkacz, K**, **Pertierra, L**, **Quiroga, MV**, **Davey, MP**, **Miloslavich, P**, **Czechowski, P**, **Convey, P**, **Robinson, S**, **Bokhorst, S**, **Halfter, S**, **Marina, TI**, **Zajková, Z**, **Soutullo, A**, **MacDonald, A**, **Wilmotte, A**, **Verhey, C**, **Patterson, C**, **Clarke, D**, **Fonseca, E**, **Peña Chávez, E**, **Humphries, G**, **Yevchun, H**, **Hernan, S**, **Wasley, J**, **da Silva, J**, **Stark, JS**, **Maria, O**, **Lea, M-A**, **McGeoch, M**, **Da Costa, P**, **Xie, Q**, **Leeger, R**, **Casa, V**, **Van de Putte, A.** 2025. Essential Biodiversity Variables Framework for terrestrial Antarctic and sub-Antarctic ecosystems. *Zenodo*. DOI: https://doi.org/10.5281/zenodo.15799169.

Press, AJ. 2021. Science and policy interactions in assessing and managing marine ecosystems in the Southern Ocean. *Frontiers in Ecology and Evolution* **9**: 576047. DOI: https://doi.org/10.3389/fevo.2021.576047.

Quang, RGT, **Kourantidou, M**, **Jin, D.** 2024. Assessing the potential economic effects of mesopelagic fisheries as a novel source of fishmeal. *Natural Resource Modeling* **37**(3): e12398. DOI: https://doi.org/10.1111/nrm.12398.

Queirós, JP, **Borras-Chavez, R**, **Friscourt, N**, **Groß, J**, **Lewis, CB**, **Mergard, G**, **O'Brien, K.** 2024. Southern Ocean food-webs and climate change: A short review and future directions. *PLOS Climate* **3**(3): e0000358. DOI: https://doi.org/10.1371/journal.pclm.0000358.

Ratnarajah, L, **Abu-Alhaija, R**, **Atkinson, A**, **Batten, S**, **Bax, NJ**, **Bernard, KS**, **Canonico, G**, **Cornils, A**, **Everett, JD**, **Grigoratou, M**, **Ishak, NHA**, **Johns, D**, **Lombard, F**, **Muxagata, E**, **Ostle, C**, **Pitois, S**, **Richardson, AJ**, **Schmidt, K**, **Stemmann, L**, **Swadling, KM**, **Yang, G**, **Yebra, L.** 2023. Monitoring and modelling marine zooplankton in a changing climate. *Nature Communications* **14**(1): 564. DOI: https://doi.org/10.1038/s41467-023-36241-5.

Reisinger, RR, **Corney, S**, **Raymond, B**, **Lombard, AT**, **Bester, MN**, **Crawford, RJM**, **Davies, D**, **de Bruyn, PJN**, **Dilley, BJ**, **Kirkman, SP**, **Makhado, AB**, **Ryan, PG**, **Schoombie, S**, **Stevens, KL**, **Tosh, CA**, **Wege, M**, **Whitehead, TO**, **Sumner, MD**, **Wotherspoon, S**, **Friedlaender, AS**, **Cotté, C**, **Hindell, MA**, **Ropert-Coudert, Y**, **Pistorius, PA.** 2022. Habitat model forecasts suggest potential redistribution of marine predators in the southern Indian Ocean. *Diversity and Distributions* **28**(1): 142–159. DOI: https://doi.org/10.1111/ddi.13447.

Rintoul, SR, **Chown, SL**, **DeConto, RM**, **England, MH**, **Fricker, HA**, **Masson-Delmotte, V**, **Naish, TR**, **Siegert, MJ**, **Xavier, JC.** 2018. Choosing the future of Antarctica. *Nature* **558**(7709): 233–241. DOI: https://doi.org/10.1038/s41586-018-0173-4.

Roach, CJ, **Speer, K.** 2019. Exchange of water between the Ross Gyre and ACC assessed by Lagrangian particle tracking. *Journal of Geophysical Research: Oceans* **124**: 4631–4643. DOI: https://doi.org/10.1029/2018JC014845.

Rogers, AD, **Frinault, BA**, **Barnes, DKA**, **Bindoff, NL**, **Downie, R**, **Ducklow, HW**, **Friedlaender, AS**, **Hart, T**, **Hill, SL**, **Hofmann, EE**, **Linse, K**, **McMahon, CR**, **Murphy, EJ**, **Pakhomov, EA**, **Reygondeau, G**, **Staniland, IJ**, **Wolf-Gladrow, DA**, **Wright, RM.** 2020. Antarctic futures: An assessment of climate-driven changes in ecosystem structure, function, and service provisioning in the Southern Ocean. *Annual Review of Marine Science* **12**: 87–120. DOI: https://doi.org/10.1146/annurev-marine-010419-011028.

Roquet, F, **Williams, G**, **Hindell, MA**, **Harcourt, R**, **McMahon, C**, **Guinet, C**, **Charrassin, J-B**, **Reverdin, G**, **Boehme, L**, **Lovell, P**, **Fedak, M.** 2014. A southern Indian Ocean database of hydrographic profiles obtained with instrumented elephant seals. *Scientific Data* **1**(1): 140028. DOI: https://doi.org/10.1038/sdata.2014.28.

Roquet, F, **Wunsch, C**, **Forget, G**, **Heimbach, P**, **Guinet, C**, **Reverdin, G**, **Charrassin, J-B**, **Bailleul, F**, **Costa, DP**, **Huckstadt, LA**, **Goetz, KT**, **Kovacs, KM**, **Lydersen, C**, **Biuw, M**, **Nøst, OA**, **Bornemann, H**, **Ploetz, J**, **Bester, MN**, **McIntyre, T**, **Muelbert, MC**, **Hindell, MA**, **McMahon, CR**, **Williams, G**, **Harcourt, R**, **Field, IC**, **Chafik, L**, **Nicholls, KW**, **Boehme, L**, **Fedak, MA.** 2013. Estimates of the Southern Ocean general circulation improved by animal-borne instruments. *Geophysical Research Letters* **40**(23): 6176–6180. DOI: https://doi.org/10.1002/2013GL058304.

Ruhl, HA, **Bett, BJ**, **Ingels, J**, **Martin, A**, **Gates, AR**, **Yool, A**, **Benoist, NMA**, **Appeltans, W**, **Howell, KL**, **Danovaro, R.** 2023. Integrating ocean observations across body-size classes to deliver benthic invertebrate abundance and distribution information. *Limnology and Oceanography Letters* **8**(5): 692–706. DOI: https://doi.org/10.1002/lol2.10332.

Saunders, RA, **Hill, SL**, **Tarling, GA**, **Murphy, EJ.** 2019. Myctophid fish (family Myctophidae) are central consumers in the food web of the Scotia Sea (Southern Ocean). *Frontiers in Marine Science* **6**: 530. DOI: https://doi.org/10.3389/fmars.2019.00530.

SCARFISH. 2025. SCARFISH Action Group webpage. *SCAR*. Available at https://scar.org/science/life/scarfish. Accessed March 11, 2025.

Schmeller, DS, **Mihoub, J-B**, **Bowser, A**, **Arvanitidis, C**, **Costello, MJ**, **Fernández, M**, **Geller, GN**, **Hobern, D**, **Kissling, WD**, **Regan, E**, **Saarenmaa, H**, **Turak, E**, **Isaac, NJB.** 2017. An operational definition of essential biodiversity variables. *Biodiversity and Conservation* **26**: 1–6. DOI: https://doi.org/10.1007/s10531-017-1386-9.

Smetacek, V, **Nicol, S.** 2005. Polar ocean ecosystems in a changing world. *Nature* **437**(7057): 362–368. DOI: https://doi.org/10.1038/nature04161.

St. John, MA, **Borja, A**, **Chust, G**, **Heath, M**, **Grigorov, I**, **Mariani, P**, **Martin, AP**, **Santos, RS.** 2016. A dark hole in our understanding of marine ecosystems and their services: Perspectives from the mesopelagic community. *Frontiers in Marine Science* **3**: 31. DOI: https://doi.org/10.3389/fmars.2016.00031.

Steiner, NS, **Bowman, J**, **Campbell, K**, **Chierici, M**, **Eronen-Rasimus, E**, **Falardeau, M**, **Flores, H**, **Fransson, A**, **Herr, H**, **Insley, SJ**, **Kauko, HM**, **Lannuzel, D**, **Loseto, L**, **Lynnes, A**, **Majewski, A**, **Meiners, KM**, **Miller, LA**, **Michel, LN**, **Moreau, S**, **Nacke, M**, **Nomura, D**, **Tedesco, L**, **van Franeker, JA**, **van Leeuwe, MA**, **Wongpan, P.** 2021. Climate change impacts on sea-ice ecosystems and associated ecosystem services. *Elementa: Science of the Anthropocene* **9**(1): 00007. DOI: https://doi.org/10.1525/elementa.2021.00007.

Swadling, KM, **Constable, AJ**, **Fraser, AD**, **Massom, RA**, **Borup, MD**, **Ghigliotti, L**, **Granata, A**, **Guglielmo, L**, **Johnston, NM**, **Kawaguchi, S**, **Kennedy, F**, **Kiko, R**, **Koubbi, P**, **Makabe, R**, **Martin, A**, **McMinn, A**, **Moteki, M**, **Pakhomov, EA**, **Peeken, I**, **Reimer, J**, **Reid, P**, **Ryan, KG**, **Vacchi, M**, **Virtue, P**, **Weldrick, CK**, **Wongpan, P**, **Wotherspoon, SJ.** 2023. Biological responses to change in Antarctic sea ice habitats. *Frontiers in Ecology and Evolution* **10**: 1073823.

Tanhua, T, **Pouliquen, S**, **Hausman, J**, **O'Brien, K**, **Bricher, P**, **de Bruin, T**, **Buck, JJH**, **Burger, EF**, **Carval, T**, **Casey, KS**, **Diggs, S**, **Giorgetti, A**, **Glaves, H**,

Harscoat, V, Kinkade, D, Muelbert, JH, Novellino, A, Pfeil, B, Pulsifer, PL, Van de Putte, A, Robinson, E, Schaap, D, Smirnov, A, Smith, N, Snowden, D, Spears, T, Stall, S, Tacoma, M, Thijsse, P, Tronstad, S, Vandenberghe, T, Wengren, M, Wyborn, L, Zhao, Z. 2019. Ocean FAIR data services. *Frontiers in Marine Science* **6**: 440. DOI: https://doi.org/10.3389/fmars.2019.00440.

Tejedo, P, Benayas, J, Cajiao, D, Leung, Y-F, De filippo, D, Liggett, D. 2022. What are the real environmental impacts of Antarctic tourism? Unveiling their importance through a comprehensive meta-analysis. *Journal of Environmental Management* **308**: 114634. DOI: https://doi.org/10.1016/j.jenvman.2022.114634.

Thomalla, SJ, Nicholson, S-A, Ryan-Keogh, TJ, Smith, ME. 2023. Widespread changes in Southern Ocean phytoplankton blooms linked to climate drivers. *Nature Climate Change* **13**(9): 975–984. DOI: https://doi.org/10.1038/s41558-023-01768-4.

Thomas, DN. 2017. *Sea ice. 3rd ed.* Hoboken, NJ: John Wiley & Sons. Available at https://books.google.be/books?hl=fr&lr=&id=bC94EQAAQBAJ&oi=fnd&pg=PR13&dq=Thomas,+DN.+2017.+Sea+ice,+3rd+ed.+John+Wiley+%26+Sons&ots=xBcxo94fcj&sig=Fzrh2z-BT2RoK0MIlVd0zylheco#v=onepage&q=Thomas%2C%20DN.%202017.%20Sea%20ice%2C%203rd%20ed.%20John%20Wiley%20%26%20Sons&f=false.

Turner, J, Barrand, NE, Bracegirdle, TJ, Convey, P, Hodgson, DA, Jarvis, M, Jenkins, A, Marshall, G, Meredith, MP, Roscoe, H, Shanklin, J, French, J, Goosse, H, Guglielmin, M, Gutt, J, Jacobs, S, Kennicutt, MC, Masson-Delmotte, V, Mayewski, P, Navarro, F, Robinson, S, Scambos, T, Sparrow, M, Summerhayes, C, Speer, K, Klepikov, A. 2014. Antarctic climate change and the environment: An update. *Polar Record* **50**(3): 237–259. DOI: https://doi.org/10.1017/S0032247413000296.

Turner, J, Guarino, MV, Arnatt, J, Jena, B, Marshall, GJ, Phillips, T, Bajish, CC, Clem, K, Wang, Z, Andersson, T, Murphy, EJ, Cavanagh, R. 2020. Recent decrease of summer sea ice in the Weddell Sea, Antarctica. *Geophysical Research Letters* **47**(11): e2020GL087127. DOI: https://doi.org/10.1029/2020GL087127.

UNESCO IOC GOOS. 2025a. EOV specification sheet: Zooplankton biomass and diversity. Available at https://goosocean.org/document/17509. Accessed July 1, 2025.

UNESCO IOC GOOS. 2025b. EOV specification sheet: Phytoplankton biomass and diversity. Available at https://goosocean.org/document/17507. Accessed July 1, 2025.

Van de Putte, AP, Griffiths, HJ, Brooks, C, Bricher, P, Sweetlove, M, Halfter, S, Raymond, B. 2021. From data to marine ecosystem assessments of the Southern Ocean: Achievements, challenges, and lessons for the future. *Frontiers in Marine Science* **8**: 637063.

Vernet, M, Geibert, W, Hoppema, M, Brown, PJ, Haas, C, Hellmer, HH, Jokat, W, Jullion, L, Mazloff, M, Bakker, DCE, Brearley, JA, Croot, P, Hattermann, T, Hauck, J, Hillenbrand, C-D, Hoppe, CJM, Huhn, O, Koch, BP, Lechtenfeld, OJ, Meredith, MP, Naveira Garabato, AC, Nöthig, E-M, Peeken, I, Rutgers van der Loeff, MM, Schmidtko, S, Schröder, M, Strass, VH, Torres-Valdés, S, Verdy, A 2019. The Weddell Gyre, Southern Ocean: Present knowledge and future challenges. *Reviews of Geophysics* **57**: 623–708. DOI: https://doi.org/10.1029/2018RG000604.

Williams, GD, Herraiz-Borreguero, L, Roquet, F, Tamura, T, Ohshima, KI, Fukamachi, Y, Fraser, AD, Gao, L, Chen, H, McMahon, CR, Harcourt, R, Hindell, M. 2016. The suppression of Antarctic bottom water formation by melting ice shelves in Prydz Bay. *Nature Communications* **7**: 12577. DOI: https://doi.org/10.1038/ncomms12577.

Woods, BL. 2022. Understanding the energy pathways through Southern Ocean mesopelagic communities [Ph.D. thesis]. Hobart, Australia: University of Tasmania. DOI: https://doi.org/10.25959/23246798.v1.

Woods, BL, Van de Putte, AP, Hindell, MA, Raymond, B, Saunders, RA, Walters, A, Trebilco, R. 2023. Species distribution models describe spatial variability in mesopelagic fish abundance in the Southern Ocean. *Frontiers in Marine Science* **9**: 981434.

Yang, J, Zhang, X. 2020. eDNA metabarcoding in zooplankton improves the ecological status assessment of aquatic ecosystems. *Environment International* **134**: 105230. DOI: https://doi.org/10.1016/j.envint.2019.105230.

Young, JW, Hunt, BPV, Cook, TR, Llopiz, JK, Hazen, EL, Pethybridge, HR, Ceccarelli, D, Lorrain, A, Olson, RJ, Allain, V, Menkes, C, Patterson, T, Nicol, S, Lehodey, P, Kloser, RJ, Arrizabalaga, H, Choy, CA. 2015. The trophodynamics of marine top predators: Current knowledge, recent advances and challenges. *Deep Sea Research Part II Topical Studies in Oceanography* **113**: 170–187. DOI: https://doi.org/10.1016/j.dsr2.2014.05.015.

Zhang, Z, Bao, Y, Fang, X, Ruan, Y, Rong, Y, Yang, G. 2024. A circumpolar study of surface zooplankton biodiversity of the Southern Ocean based on eDNA metabarcoding. *Environmental Research* **255**: 119183. DOI: https://doi.org/10.1016/j.envres.2024.119183

How to cite this article: Plasman, C, Hancock, AM, Raymond, B, Bax, N, Fierro-Arcos, D, Henley, SF, Benson, A, Corney, S, Evans, K, Friscourt, N, Eriksen, RS, Henderson, AF, Halfter, S, Jansen, J, McMahon, CR, Meijers, A, Miloslavich, P, Hoopen, PT, Corney, I, Walters, A, Swadling, K, Gan, Y-M, Van de Putte, A. 2026. Developing Essential Biodiversity Variables for the Southern Ocean: From data gaps to valuable insights. *Elementa: Science of the Anthropocene* 14(1).
DOI: https://doi.org/10.1525/elementa.2025.00038

Domain Editor-in-Chief: Jody W. Deming, University of Washington, Seattle, WA, USA

Guest Editor: Luciano Pezzi, National Institute for Space Research, Brazil

Knowledge Domain: Ocean Science

Part of an Elementa Special Feature: Understanding the Trajectory and Implication of a Changing Southern Ocean: The Need for an Integrated Observing System

Published: February 06, 2026 **Accepted:** September 22, 2025 **Submitted:** March 11, 2025

ELEMENTA Science of the Anthropocene

Elem Sci Anth is a peer-reviewed open access journal published by University of California Press.

OPEN ACCESS