Essential Biodiversity Variables Framework for Terrestrial Antarctic and Sub-Antarctic Ecosystems

WORKSHOP REPORT

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Abstract—This report presents outcomes from the international workshop "Essential Biodiversity Variables (EBV) Framework for Terrestrial Antarctic and Sub-Antarctic Ecosystems," held in Cambridge, UK, from 18–20 September 2024, with significant online contributions from a remote Oceania cohort. The workshop aimed to develop a standardized framework for identifying and monitoring terrestrial EBVs across these vulnerable and rapidly changing high-latitude environments. A preliminary set of EBVs was proposed, spanning multiple levels of biological organization, from genes to ecosystems, including metrics on species composition, population dynamics, functional traits, and ecosystem processes. These build on global frameworks while addressing the region's unique ecological and logistical challenges. Participants stressed the need for harmonized monitoring protocols, robust data standards, long-term continuity, and shared analytical workflows. The report underscores the importance of leveraging existing datasets, infrastructures, and open science practices to improve data integration and accessibility. Ensuring interoperability between National Antarctic Data Centres (NADCs) and international repositories will be key to enabling seamless data exchange and reuse across national and disciplinary boundaries. This report marks a foundational step toward implementing a terrestrial biodiversity observing system for the Antarctic and sub-Antarctic regions, grounded in the EBV framework. Realizing this vision will require sustained collaboration among researchers, data managers, and decision-makers. The preliminary list of terrestrial EBVs discussed during the workshop is provided in Table 1.

1. Introduction

1.1. The value of Antarctic and sub-Antarctic biodiversity: the need for monitoring.

The Antarctic and sub-Antarctic regions are home to ecosystems that are globally unique and often highly sensitive to environmental change (Convey and Peck 2019). These environments are experiencing increasing pressure due to climate change, human activity, and biological invasions. While our scientific understanding of these ecosystems is improving, substantial gaps remain, particularly in the consistency and taxonomic breadth of biodiversity data collection (Bonnet-Lebrun et al. 2023). This limits the ability to predict and manage ecological responses to change.

A systematic, standardized approach to biodiversity observation is urgently needed to enable long-term monitoring, improve data comparability, and inform conservation and policy strategies. EBVs, proposed by the Group on Earth Observations Biodiversity Observation Network (GEO BON) as a conceptual framework, offer a structured way to monitor core aspects of biodiversity, acting as a bridge between raw biodiversity data and high-level indicators used in reporting and decision-making.

1.2. The Essential Biodiversity Variables. EBVs represent a minimum set of harmonized measurements that capture key dimensions of biodiversity, such as genetic composition, species populations, community structure, and ecosystem functioning (Pereira et al. 2013; Navarro et al. 2017). They are designed to be scalable, policy-relevant, and scientifically robust. By providing standardized metrics across diverse regions and ecosystems, EBVs facilitate consistent tracking of biodiversity trends over time and space.

Similar in concept to Essential Climate Variables (ECVs) and Essential Ocean Variables (EOVs), EBVs are intended to support global observation systems and reporting mechanisms such as those required under the Convention on Biological Diversity (CBD) and the Sustainable Development Goals (SDGs). They integrate multiple data sources, from field surveys to remote sensing, and serve as a foundation for biodiversity assessments, forecasting, and management (Gonzalez et al. 2023).

1.3. Rationale for Antarctic and sub-Antarctic EBVs. The implementation of EBVs tailored to Antarctic and sub-Antarctic terrestrial ecosystems addresses both scientific and policy needs. These variables can inform national and international commitments, such as those under the Antarctic Treaty System (ATS), the Convention on Biological Diversity, and national biodiversity strategies (e.g., the Australian Antarctic Decadal Plan). Importantly, EBVs are designed to remain scientifically grounded and temporally consistent, even as policy priorities evolve.

Antarctic-specific EBVs can support multiple applications, including conservation planning, biosecurity, bioremediation, and environmental impact monitoring. They are particularly valuable for examining anthropogenic drivers such as climate change, pollution, establishment and spreading of non-native species. Developing such variables provides a critical opportunity to align scientific data collection with management and conservation imperatives.

1.4. Workshop objectives. The workshop, titled **"Essential Biodiversity Variables (EBVs) Framework for Terrestrial Antarctic and Sub-Antarctic Ecosystems"** (Cambridge-24 workshop), was convened to advance the development of an EBV-based monitoring system for high-latitude terrestrial ecosystems. The specific objectives were to:

1. Define a set of EBVs relevant to the region, aligned with global EBV frameworks but adapted to local ecological contexts.

2. Develop standard monitoring protocols to ensure data quality, consistency, and sustainability.

3. Establish analytical workflows for EBV calculation and validation.

4. Identify existing data sources and strategies for data sharing and integration.

5. Identify and create a roadmap for data management planning

6. Pinpoint knowledge gaps and prioritize areas for future research and capacity-building.

7. Create a roadmap for implementation, linking EBVs to management, reporting, and policy frameworks.

This workshop builds on the outcomes of the 2023 "Biodiversity.aq / SOOS / EG-ABI Essential Variables Workshop" held in Hobart, Australia, which focused on marine EBVs and was organized in collaboration with the Southern Ocean Observing System (SOOS). The Hobart meeting proposed marine-focused EVs and assessed existing infrastructure and data gaps. Results are documented in a public report and an associated GitHub repository. The workshop described in this report extended these efforts to terrestrial systems, helping to lay the groundwork for an integrated biodiversity observation framework encompassing both marine and terrestrial environments.

Arctic biodiversity monitoring programs, such as the Circumpolar Biodiversity Monitoring Program (CBMP), offer a longstanding and robust foundation. The EBV-based approach developed during the Cambridge-24 workshop complements these efforts by aligning from the outset with emerging global standards. This parallel development may offer opportunities for mutual learning and convergence between Arctic and Antarctic biodiversity monitoring frameworks.

2. Workshop methodology

2.1. Convening organizations. The workshop was organized by several key initiatives and research programs:

- **EG-ABI (Expert Group on Antarctic Biodiversity Informatics)**: A Scientific Committee on Antarctic Research (SCAR)-affiliated group chaired by Dr. Ben Raymond and co-chaired by Dr. Anton Van de Putte. EG-ABI promotes open, transparent, and reproducible science through the development of biodiversity informatics tools and data standards for Antarctic ecosystems.

- **Biodiversity.aq**: A SCAR-endorsed data platform funded by the Belgian Science Policy Office (BELSPO). Biodiversity.aq acts as a regional node for the Global Biodiversity Information Facility (GBIF) and the Ocean Biodiversity Information System (OBIS), with the goal of transforming biodiversity data into actionable outputs through its ADVANCE project.

- **Ant-ICON (Integrated Science to Inform Antarctic and Southern Ocean Conservation)**: A SCAR Scientific Research Programme that addresses conservation and management challenges in the region. Led in part by Kevin Hughes and Jasmine Lee, Ant-ICON's "R2" theme focuses on human impact mitigation and sustainability.

- **IDEA (Integrated Digital East Antarctica Program)**: A program initiated by the Australian Antarctic Division (AAD) and led by Aleks Terauds. IDEA facilitates and coordinates access to integrated interdisciplinary data, processing tools and syntheses, to support scientific and policy objectives.

The workshop welcomed a diverse group of participants, primarily mid-career researchers with strong representation from Australia, South America, and Western Europe. Senior experts also contributed, enriching discussions with strategic insights. However, limited participation from Asia, Africa and North America was noted, pointing to opportunities for broader geographic engagement in future activities.

2.2. Format and group discussions.

Held at the Scott Polar Research Institute in Cambridge, UK, the workshop used a hybrid format to accommodate both in-person and remote participants. Activities were structured over two days, including plenary sessions, breakout discussions, and participant presentations.
Following an introduction to the EV framework and existing EBV initiatives, attendees formed three breakout groups based on areas of expertise:

- **Group 1: Top/Meso-predators**
  Grant Humphries, Zuzana Zajková, Alvaro Soutullo, Anne Treasure, Jasmine Lee, Daniela Cajiao.

- **Group 2: Plants/Invertebrates**
  Eliana Lima da Fonseca, Claudia Colesie, Luis R. Pertierra, Tomás I. Marina, Aleks Terauds, Stef Bokhorst, Hanna Yevchun, Camila Neder, Peter Convey.

- **Group 3: Microorganisms**
  Annick Wilmotte, Paul Czechowski, Kevin A. Hughes, Victoria M. Quiroga, Valeria Casa.

Each group identified priority EBVs, assessed existing data availability, and highlighted data gaps. A common Google Sheets template, adapted from the EuropaBON EBV list, was used to guide the evaluation and documentation process. Technical experts were embedded in each group to support the design of data-centric approaches. Group outcomes were synthesized in plenary sessions to support consensus-building and refinement.

3. Results: Proposed Essential Biodiversity Variables

- *EBV framework thematic classes are outlined in Appendix A, Table 1.*

- *For a complete list of acronyms used throughout this document, see Appendix A, Table 2.*

- *To propose an additional candidate variable, refer to the EBV identification template in Appendix A, Table 3.*

- *Parallel discussions and additional points raised during the workshop are summarized in Appendix B.*

3.1. EBV framework and alignment with global efforts. The GEO BON EBV framework provides an internationally recognized structure for aligning local biodiversity observations in Antarctica with broader global monitoring efforts. By focusing on core aspects of biodiversity, EBVs facilitate data integration from diverse sampling programs, supporting both scientific understanding and policy development in the face of rapid environmental change (Schmeller, Weatherdon, et al. 2017). Given the reciprocal influence between Antarctic ecosystems and global environmental dynamics, participants in the Cambridge-24 workshop prioritized EBVs capable of supporting long-term biodiversity monitoring and conservation strategies across the Antarctic and sub-Antarctic terrestrial regions.
While acknowledging the complementary roles of ECVs and EOVs, the workshop emphasized EBVs for their specificity to biodiversity and ecosystem health. ECVs, typically based on satellite observations, provide large-scale, high-resolution data on environmental trends such as sea surface temperature or ice dynamics. In contrast, EBVs, especially those related to genetic diversity and ecosystem functioning, often require in-situ measurements, addressing ecological dimensions not easily captured through remote sensing (Miloslavich et al. 2018). The group also noted that Antarctica's unique environmental conditions may require adaptation of existing EBVs or the development of new variables tailored to regional specificities.
EBVs are defined through complementary perspectives and serve multiple, overlapping roles:

1. They enable standardized biodiversity surveillance across space, time, and biological organization (Schmeller, Mihoub, et al. 2017).

2. They act as a bridge between raw ecological data and biodiversity indicators, supporting change detection and informing policy (Langer et al. 2022).

Figure 1. *Antarctic coastal landscape, featuring areas of snow colonized by red algae, picture provided by Matthew P. Davey.*

3. They represent a minimum set of essential, complementary measurements that capture key biodiversity dimensions, as defined by GEO BON.

The EBV framework is organized into six thematic classes (1°Genetic Composition, 2°Species Populations, 3°Species Traits, 4°Community Composition, 5°Ecosystem Functioning, and 6°Ecosystem Structure) and spans three realms (1°Terrestrial, 2°Marine/Coastal, and 3°Freshwater). Each class comprises specific EBVs (e.g., "Species Abundances" under Species Populations, "Phenology" under Species Traits). A glossary of these variables is available online, thematic classes are outlined in *Appendix A, Table 1*.

3.1.1. EuropaBON as a model. EuropaBON (BON, Biodiversity Observation Network) exemplifies a structured and participatory approach to EBV development. In 2022, the initiative completed a year-long process combining rapid surveys, stakeholder workshops, standardized assessments, and interviews. This yielded a list of 84 EBVs that are feasible, policy-relevant, and precisely defined across all EBV classes and ecological realms. The finalized list, publicly reviewed for robustness, is hosted on GitHub.

At the Cambridge-24 workshop, the EuropaBON frame-

work was adapted to Antarctic- and sub-Antarctic-specific challenges. Participants adopted two main components of the approach:

1. Identifying priority EBVs across species and ecosystem indicators, based on the EuropaBON list of EBVs (report).

2. Developing workflows to harmonize and integrate observations into EBV datasets and indicators, drawing on existing tools (EuropaBON workflow templates, report).

Despite this promising start, broader community engagement will be necessary to refine and implement an Antarctic/sub-Antarctic-specific EBV framework. The EuropaBON templates and workflows, which are soon to be integrated into GEO BON EBV Data Portal, provide valuable operational guidance for future Antarctic efforts.

3.1.2. The Arctic perspective. In the Arctic, ecosystem monitoring is primarily coordinated by the Arctic Council's CAFF working group, which serves as the Arctic BON under GEO BON. Monitoring focuses on Focal Ecosystem Components (FECs), with ongoing efforts to

better align with the GEO BON framework. As momentum builds toward the next International Polar Year (IPY), there is increasing interest in standardizing biodiversity monitoring across polar regions. One example is the pan-Arctic Arctic Vegetation Archive (AVA), assembled using compositional data (e.g., Braun-Blanquet method) and a standardized species list. The AVA currently includes about 10,000 vegetation plots, covering vascular plants, mosses, and lichens, with harmonized data from Alaska and Russia, and ongoing efforts in Greenland and Canada. Data are managed in *Turboveg*, a tool for consistent species-level data entry that also underpins the global *sPlot* initiative, though the latter contains less environmental metadata. A 2025 workshop in Boulder brought together Arctic vegetation and biodiversity experts to coordinate future activities and plan IPY contributions. These efforts offer a valuable model—and potential for collaboration—for Antarctic data communities aiming to develop interoperable biodiversity monitoring across both poles. A key question remains whether a parallel Antarctic BON could be developed to ensure more balanced global representation.

3.2. Proposed terrestrial variables.

In identifying EBVs for terrestrial ecosystems in Antarctica, participants emphasized feasibility and impact. The goal was not to exclude lower-priority variables but to focus initial efforts on the most implementable and scientifically valuable EBVs over the next decade, given logistical constraints. *Table 1*, comprising 73 proposed variables and associated information, reflects significant progress toward identifying relevant variables and provides a solid foundation for EBV prioritization. *Figure 2* illustrates how these variables are distributed across the six defined EBV classes.

Table 1 awaits further input from domain experts to ensure completeness, consistency, and applicability across polar regions. While some variables identified by the three working groups could potentially be grouped under a common EBV, differences in measurement approaches or definitions led to their provisional separation. Note that a substantial number of proposed variables relate to marine birds and mammals. This likely reflects the legacy of long-standing monitoring efforts, such as those under the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) Ecosystem Monitoring Program (CEMP), which primarily focus on these species. While they are undeniably important components of Antarctic ecosystems, future developments may benefit from broadening the taxonomic and ecological scope of EBVs to ensure a more balanced representation.
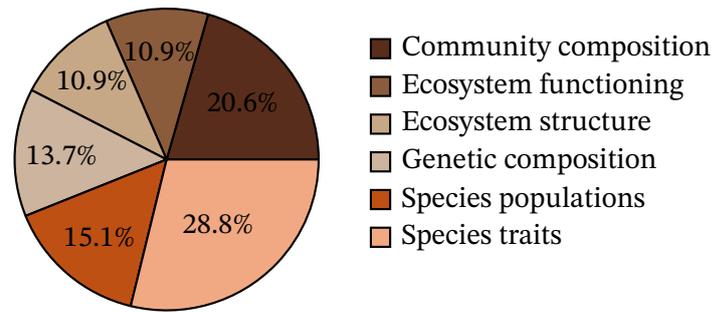

Figure 2. *Distribution of EBV classes among proposed variables*

3.3. Implementation strategy.

To support implementation, the workshop proposed a multi-step, adaptive strategy:

- Relevance index: Develop a unified method for ranking EBVs based on perceived importance (ideally co-developed through science-policy interfaces), data availability, connectivity with other variables, and expected variability over time.

- Workflow templates: Adapt EuropaBON workflow models to Antarctic contexts. These encompass data collection, integration, modeling, and result in spatially explicit EBV data products (Kissling, Walls, et al. 2018; Schmeller, Weatherdon, et al. 2017). Templates also assess maturity stages of workflows and support transparency and collaboration (Kissling and Lumbierres 2023).

- Integration with global initiatives: Align EBV development with international milestones like the future IPY, which will emphasize collaborative research on polar climate change. Consider building synergies with Arctic initiatives like Arctic BON/CAFF and the AVA.

- Policy engagement roadmap: Clearly communicate to policy-makers which EBVs are relatively easily implementable and which face greater challenges. The InSync project can serve as a model for accelerating decision-making.

- Infrastructure and tools: A variety of open source data and software are available, including the GEO BON Portal, GitHub, R/Python environments, Google Earth Engine, and Google Drive, to support sharing, processing, and classification. Careful coordination is necessary to ensure these tools collectively contribute to robust workflows.

- EBV refinement: Remove or consolidate variables that are similarly measured and/or referred to different organisms simultaneously, insufficiently defined, infeasible at the Antarctic scale, or derivable from others.

Table 1. *List of terrestrial variables and their respective spatial, temporal and taxonomic specifications, identified during the Cambridge-24 workshop. Cells marked as "to be completed" will be filled in during upcoming rounds of engagement and consultation.*

N°	EBV realm	EBV class	EBV name	EBV identified	EBV definition / description	Spatial resolution	Temporal resolution	Taxonomic focus	EV relevance	Data required	Possible data sources and resources
1	Terrestrial	Community composition	Community abundance	Parasite load of birds and marine mammals	The total parasite load of birds and mammals at breeding colonies, haul-outs or nursery sites	Same as host populations	Every few years	All birds and marine mammals	Measure of population health, prevalence may provide more informative insights than abundance in parasitology	Parasite counts	National programmes, microscopy, DNA (for qPCR)
2	Terrestrial	Community composition	Community abundance	Biomass of birds and marine mammals	The total abundance of any marine mammal species at a known persistent haul-out site	Entire Antarctica	To be completed	All birds and marine mammals	Measure of site importance	Drone surveys, satellite imagery	QuickBird (DigitalGlobe)
3	Terrestrial	Community composition	Community abundance	Disease occurence for birds and marine mammals	To be completed	Entire Antarctica	To be completed	All birds and marine mammals	Measure of population health	Blood/tissue samples	Engage with SCAR pathogen group
4	Terrestrial	Community composition	Taxonomic/phylogenetic diversity	Alpha diversity for macro/micro invertebrates	To be completed	To be completed	To be completed	All macro/micro invertebrates (link to all microorganisms)	To be completed	Occurence data, taxonomic identity	To be completed
5	Terrestrial	Community composition	Trait diversity	Functional traits for plants, micro/macro invertebrates, and lichens	Heritable characteristics of organisms and how they affect the structure and function of ecosystems	To be completed	To be completed	All photosynthetic organisms (excluding non-lichen cyanobacteria and microalgae)	Measurement of acclimation status, potential for local adaption and movement of sp./commu. if diveristy and limits of functional traits allow	Operational traits, morphometrics (e.g., SLA, leaf area/volume, photosynthetic rates, metabolic composition)	Laboratory data, IRGA, PAM
6	Terrestrial	Community composition	Taxonomic/phylogenetic diversity	Alpha diversity for photosynthetic organisms (vascular plants, mosses, liverworts and lichens)	To be completed	To be completed	Repeated measurements over several years	All photosynthetic organisms (link to all microorganisms)	To be completed	Occurence data	To be completed
7	Terrestrial	Community composition	Taxonomic/phylogenetic diversity	Community composition of vegetation, macro and micro invertebrates (regional occurrences, alpha diversity)	Number and types of species that make up the biological community, and how they are arranged	To be completed	To be completed	All plants, micro/macro invertebrates, and lichens	Community composition provides possibility for exploring diversity and ecosystem modelling	Occurence data, taxonomic identity, abundances	National programmes
8	Terrestrial	Community composition	Taxonomic/phylogenetic diversity	Regional species inventories for plants, micro/macro invertebrates, and lichens	A list of all taxa occuring in a defined area (region)	To be completed	To be completed	All plants, micro/macro invertebrates, and lichens	To be completed	Occurence data, taxonomic identity	To be completed
9	Terrestrial	Community composition	Taxonomic/phylogenetic diversity	Beta diversity of plants, micro/macro invertebrates, and lichens	Species turnover, succession, changes in species composition across spatial and temporal scales	To be completed	Repeated measurements over several years	All plants, micro/macro invertebrates, and lichens	To be completed	Community composition, repeated measures, genetic diversity (richness), DNA read counts, % composition data	To be completed
10	Terrestrial	Community composition	Interaction diversity	Biotic interactions of all plants, micro/macro invertebrates, and lichens	Relationships between organisms in a ecosystem: competition, facilitation, neutral	To be completed	To be completed	All plants, micro/macro invertebrates, and lichens	To be completed	Community composition, trait diversity	To be completed

#	Realm	Class	EBV	Description	Detail	Spatial scale	Temporal scale	Taxonomic scope	Rationale	Data	Methods / Repositories
11	Terrestrial	Community composition	Community abundance	Genetic diversity of selected microorganisms taxa	Number of individuals of a species or genetic sequence reads in a given area or volume	Local (1x1 m)	At least once / one year	All prokaryotic and eukaryotic microorganisms	Measure of habitable zones (e.g., availability of free water)	DNA sequences, cell counts, optical density, morphology	(e)DNA, culture collection deposits (CCAP), EOV/Microbe Biomass and Diversity
12	Terrestrial	Community composition	Interaction diversity	Biotic interactions for all microorganisms	Requirement of chemical ecology for ecosystem function and growth	Local (1x1 m)	At least once / one year	All prokaryotic and eukaryotic microorganisms	To be completed	DNA/RNA sequences, metabolites, microscopy or photographic images of samples or sampling sites, cell morphology	(e)DNA, metabolomics, repositories of biotic interactions (e.g., GloBI, www.globalbioticinteractions.org)
13	Terrestrial	Community composition	Taxonomic diversity	Taxonomic diversity of selected microorganisms taxa	To be completed	Local (1x1 m)	At least once / one year	All prokaryotic and eukaryotic microorganisms	To be completed	DNA sequences	(e)DNA, EOV/Microbe Biomass and Diversity
14	Terrestrial	Community composition	Trait diversity	Trait diversity of selected microorganisms taxa	To be completed	Local (1x1 m)	At least once / one year	All prokaryotic and eukaryotic microorganisms	Measure of plasticity, acclimation in the ecosystem and signatures of physiological stress or disease	DNA sequences, biochemical assays, photosynthetic rates	(e)DNA, metabolite assays, enzyme profiles, IRGA, PAM
15	Terrestrial	Ecosystem functioning	Ecosystem disturbance	Degree of soundscape disturbance (anthropogenic)	The NVSI or acoustic index (e.g., proportion of anthropogenic noise in the sound scape) at a location	To be completed	To be completed	All birds and marine mammals	Measure of disturbance at a site	Acoustic monitors	Tourist vessels
16	Terrestrial	Ecosystem functioning	Primary productivity	Primary productivity of all plants, micro/macro invertebrates, and lichens	The rate at which organic compounds are created from carbon dioxide	To be completed	To be completed	All plants, micro/macro invertebrates, and lichens	To be completed	Biomass, abiotic drivers, physiological traits, vegetation cover	Remote sensing methods
17	Terrestrial	Ecosystem functioning	Ecosystem disturbances	Ecosystem state (all plants, micro/macro invertebrates, and lichens)	Ecological condition of a system measured as physical, chemical, and biological characteristics, as well as the processes and interactions that connect them	To be completed	To be completed	All plants, micro/macro invertebrates, and lichens, Birds and Marine Mammals	Human impact, glacial retreat, temperature changes, succession, water availability	Community composition, abiotic, biotic and antropogenic drivers, beta diversity, dispersal capabilities	Satellite / drone imagery: SWIR (water availability), and RGB/multi-/hyper-spectral imagery (plant stress: chlorophyll/pigments)
18	Terrestrial	Ecosystem functioning	Ecosystem disturbances	Microbial ecosystem disturbance and stress response	To be completed	Local (1x1 m)	At least once / one year, or reactive when an event happen (e.g., chemical spill, heatwave)	All prokaryotic and eukaryotic microorganisms	To be completed	Images, DNA sequences, stress assays (PAM for photosynthesis)	Photography, (e)DNA, IRGA, PAM
19	Terrestrial	Ecosystem functioning	Ecosystem phenology	Ecosystem phenology for all microorganisms	Change in species or community life cycle over time	Local (1x1 m)	At least once a year (ideally 3-4 sample sessions for a phenology project)	All prokaryotic and eukaryotic microorganisms	Baseline knowledge enables detection of disruptions to normal life cycle or phenology by external factors	Images, DNA sequence, records of aerial coverage	Photography, (e)DNA
20	Terrestrial	Ecosystem functioning	Primary productivity	Primary productivity of all microorganisms	To be completed	Local (1x1 m)	At least once / one year	All prokaryotic and eukaryotic microorganisms	To be completed	Images, DNA sequences, pigment measurements, Chl-a, oxygen production, dry weight, total C/N, DOC, DIC, gas exchange (IRGA or O_2 electrode), SIF, PAM	Photography, (e)DNA, IRGA, DOC, DIC, PAM, total C/N, isotopes

#	Realm	Category	EBV	Description	Definition	Spatial scale	Temporal scale	Taxa	Rationale	Metrics	Data sources
21	Terrestrial	Ecosystem functioning	Ecosystem disturbance	Human disturbance pressure on birds, marine mammals and plants	The number of humans visiting a site for either tourism or research purposes	To be completed	To be completed	Birds and Marine Mammals, All plants	Measure of disturbance at a site and proxy for impacts on marine mammals/birds and plants (e.g., moss bed impact)	Counts or activity description	IAATO, National programs
22	Terrestrial	Ecosystem structure	Live cover fraction	Vegetation cover (all plants and lichens)	Vegetation per unit area (fundamental proxy for understanding vegetation distribution)	1-10 m	1-5 year	All plants, micro/macro invertebrates, and lichens	Proxy for understanding vegetation distribution	Spatial cover	Remote-sensed maps vegetation (Plantarctica vegetation map)
23	Terrestrial	Ecosystem structure	Ecosystem vertical profile	Ecosystem trophic function of all plants, micro/macro invertebrates, and lichens	Trophic profiling and how energy is moving through the system, foodweb description, nutrient cycling, feeding relationships, energy and nutrient flow	To be completed	To be completed	All plants, micro/macro invertebrates, and lichens	To be completed	Regional species inventories, biotic interactions, primary productivity	To be completed
24	Terrestrial	Ecosystem structure	Ecosystem distribution	Ecosystem distribution (all plants, micro/macro invertebrates, and lichens, Birds and Marine Mammals)	The pattern and arrangement of ecological systems influenced by factors such as climate and landscape	To be completed	To be completed	All plants, micro/macro invertebrates, and lichens, Birds and Marine Mammals	Habitat knowledge for potential early identification in shifts	Abiotic drivers, biotic interactions, sp. traits, regional sp. inventories, physio. envelope	To be completed
25	Terrestrial	Ecosystem structure	Ecosystem distribution	Ecosystem structure for all microorganisms	To be completed	Local (1x1 m) except remote sensing, where it is larger	At least once / one year	All prokaryotic and eukaryotic microorganisms	To be completed	Images (ground truth in field)	Photography, drones, satellite imagery
26	Terrestrial	Ecosystem structure	Ecosystem vertical profile	To be completed	To be completed	Local (1x1 m)	At least once / one year	All prokaryotic and eukaryotic microorganisms	To be completed	Images, coring and drilling	Photography (section of ice, sediment, rock cores) / association with vegetation distribution along terrain elevation
27	Terrestrial	Ecosystem structure	Live cover structure	To be completed	To be completed	Local (1x1 m) except remote sensing, where it is larger	At least once / one year	All prokaryotic and eukaryotic microorganisms	If snow algae, then measure of active primary production	Images, field data, accounts for snow algae and microbial distributions beneath snowpack or cloud cover	Photography
28	Terrestrial	Ecosystem structure	Ecosystem distribution	Nutrient loads from guano, etc	The total amount of organic carbon or nitrogen from bird or marine mammal guano in soil, or seasonal terrestrial snow and ice and meltwater run off	To be completed	To be completed	Birds and Marine Mammals	Guano is an important variable driving plant and invertebrate communites, proxy of habitat suitabilitiy	Satellite/drone imagery, ground truth	To be completed
29	Terrestrial	Ecosystem structure	Ecosystem distribution	Total ice free area	Total potential area available for nesting (could be species specific) and plant establishment not covered in ice	To be completed	To be completed	Birds and Marine Mammals, All plants, micro/macro invertebrates, and lichens	Measure of available habitat which is likely to change with climate change and habitat lost (e.g., seasonal snow cover)	Satellite / drone imagery, ground truth	Antarctic Digital Database
30	Terrestrial	Genetic composition	Genetic diversity	Genetic diversity (richness) of plants, lichen, macro and micro invertebrates	The total number of genetic characteristics in a community (Community level, eDNA, evolutionary history, extant diversity)	To be completed	Yearly	All plants, micro/macro invertebrates, and lichens	Measure of communitiy composition shifts/local adaptations	Multiple sequence data	GBIF, GenBank

#	Realm	EBV class	EBV					Taxon			
31	Terrestrial	Genetic composition	Genetic diversity	Genetic diversity (heterozygosity) of all plants, lichen, macro and micro invertebrates	Variability of the plasticity (individual level)	To be completed	To be completed	All plants, micro/macro invertebrates, and lichens	To be completed	Multiple sequence data	To be completed
32	Terrestrial	Genetic composition	Effective population size	To be completed	Size of an ideal population that loses genetic variation at the same rate as the focal population	To be completed	To be completed	Birds and Marine Mammals	Proxy of population health	Blood/tissue samples	To be completed
33	Terrestrial	Genetic composition	Genetic differentiation	Differentiation between units (Birds and Marine Mammals)	Degree of genetic differentiation among populations or units	To be completed	To be completed	Birds and Marine Mammals	Proxy for adaptive capacity of species	Blood/tissue samples	To be completed
34	Terrestrial	Genetic composition	Inbreeding	Inbreeding of top-predators	Degree of relatedness between pairs of individuals, mating among relatives, or identity by descent	To be completed	To be completed	Birds and Marine Mammals	Proxy of population health and adaptive capacity	Blood/tissue samples	To be completed
35	Terrestrial	Genetic composition	Genetic diversity	Intraspecific genetic richness of top-predators	The number of alleles in a population	To be completed	To be completed	Birds and Marine Mammals	Proxy for adaptive capacity of species	Blood/tissue samples	To be completed
36	Terrestrial	Genetic composition	Genetic diversity	Intraspecific genetic evenness of top-predators	Expected number of heterozygotes in a population	To be completed	To be completed	Birds and Marine Mammals	Proxy for adaptive capacity of species	Blood/tissue samples	To be completed
37	Terrestrial	Genetic composition	Genetic diversity	Number of genetic units	The number of genetic lineages	To be completed	To be completed	Birds and Marine Mammals, Plants	Proxy for adaptive capacity of species	Blood/tissue samples	To be completed
38	Terrestrial	Genetic composition	Effective population size	To be completed	To be completed	Local (1x1 m)	At least once / one year	Microeucaryotes	Bloom defined by cell density; threshold not yet standardized	DNA sequences (mitochondrial markers)	SNP panel, whole genome sequencing
39	Terrestrial	Genetic composition	Genetic differentiation	To be completed	To be completed	Local (1x1 m)	At least once / one year	Microeucaryotes	To be completed	DNA sequences (rapidly evolving markers, incl. SNPs, microsatelites, spacers)	(e)DNA
40	Terrestrial	Genetic composition	Genetic diversity	Genetic diversity for all microorganisms	To be completed	Local (1x1 m)	At least once / one year	Microeucaryotes	To be completed	DNA sequences (specific PCR primers)	EOV/Microbe Biomass and Diversity

#	Realm	EBV Class	EBV	Title	Description	Spatial scale	Temporal	Taxa	Rationale	Product	Data source
41	Terrestrial	Species populations	Species abundances	Abundance/relative abundance of all plants, micro/macro invertebrates, and lichens	Relative abundances of species (across year comparisons)	To be completed	To be completed	All plants, micro/macro invertebrates, and lichens	To be completed	Vegetation cover, community composition	To be completed
42	Terrestrial	Species populations	Species distributions	Species distribution of all plants, micro/macro invertebrates, and lichens	Biogeographic range, realised ranges (occurrence data), dispersal capabilities, species interactions (includ. SDMs)	Local (10x10 km) to Global (entire Antarctica)	At least once in 5 years	All plants, micro/macro invertebrates, and lichens	State of present distribution for identifying potential changes in habitat and community structure	Community composition, abiotic, biotic and antropogenic drivers, georeferenced locations	Biodiversity.aq, GBIF, Chelsa
43	Terrestrial	Species populations	Species abundances	Species abundances for all microorganisms	To be completed	Local (1x1 m)	At least once / one year	All prokaryotic and eukaryotic microorganisms	To be completed	Cell counts (e.g. via Utermöhl method), OTUs from eDNA, microscopy identifications	qPCR, eDNA, microscopy
44	Terrestrial	Species populations	Species distributions	Species distributions for all microorganisms	To be completed	Local (1x1 m)	At least once / one year	All prokaryotic and eukaryotic microorganisms	To be completed	Cell counts (e.g. via Utermöhl method), OTUs from eDNA, microscopy identifications	qPCR, eDNA, microscopy
45	Terrestrial	Species populations	Species distributions	Distribution of marine bird breeding sites	The location of marine bird breeding colonies or nesting sites	To be completed	To be completed	Birds	Meas. of suitable breeding sites (pop. health). Can indicate changes in accessibility, food avail., and competition.	Georeferenced locations	Antarctic Site Inventory; biodiversity.aq portal
46	Terrestrial	Species populations	Species distributions	Distribution of marine bird staging or moulting sites	The locations of sites used by marine birds for staging or moulting during the migratory and/or breeding seasons	To be completed	To be completed	Birds	Important measure of non-breeding proportion of population and important sites for rest.	Georeferenced locations	Antarctic Site Inventory; biodiversity.aq portal
47	Terrestrial	Species populations	Species abundance	Annual survival and recruitment for all birds and marine mammals	Annual survival rates as categorized by age-class and population level recruitment	To be completed	To be completed	Birds and Marine Mammals	Measure of population health	Mark-recapture	CEMP
48	Terrestrial	Species populations	Species abundances	Population size / Abundance for Birds and Marine Mammals	The breeding population size (e.g., number of breeding sites)	To be completed	To be completed	Birds and Marine Mammals	Measure of population health and site importance	Satellite imagery	Antarctic Site Inventory, MAPPPD, CEMP
49	Terrestrial	Species populations	Species distributions	Connectivity/meta pop dynamics	To be completed	To be completed	To be completed	Birds and Marine Mammals	To be completed	Genetic information (blood/tissue samples), observation surveys	To be completed
50	Terrestrial	Species populations	Species abundances	Abundance of marine mammals at haul-outs	The total abundance of any marine mammal species at a known persistent haul-out site	To be completed	To be completed	Marine Mammals	Measure of site import. for m. mammals. Changes in abund. at haul-outs could indicate changes in prey/food avail. or habitat.	Counts	To be completed

51	Terrestrial	Species populations	Species distributions	Distribution of marine mammal haul-outs	The locations or presence of persistent marine mammal haul-out sites	To be completed	To be completed	Marine Mammals	Measure of non-breeding prop. of pop. and important sites for rest. Changes in distrib. could indicate changes in prey/food avail. or habitat.	Georeferenced locations	Antarctic Site Inventory; LaRue et al. 2021 (Weddell seals)
52	Terrestrial	Species traits	Phenology	Duration of incubation for all birds	Duration of the first incubation shift upon laying eggs (CEMP)	To be completed	Every year in breeding sites	All birds	Proxy of food availability and distance required for obtaining adequate food	Observation surveys	CEMP
53	Terrestrial	Species traits	Phenology	System-scale phenology of all plants, micro/macro invertebrates, and lichens	Seasonal and climate variations affecting life cycles (community-level focus: snow melt (liquid water availability), activity patterns, reproductive effort)	To be completed	To be completed	All plants, micro/macro invertebrates, and lichens	To be completed	Abiotic drivers	To be completed
54	Terrestrial	Species traits	Movement	Dispersal capabilities of all plants, micro/macro invertebrates, and lichens	Propagule pressure, the capacity of a species to move away from its birth area and establish itself in new areas	To be completed	To be completed	All plants, micro/macro invertebrates, and lichens	To be completed	Effective dispersal distances, eDNA, physiological envelope, transfer route data (+survey data), Connectivity	To be completed
55	Terrestrial	Species traits	Phenology	Life traits (timings of major live events) of all plants, micro/macro invertebrates, and lichens	Species-scale phenology, changes of traits including growth, survival, and reproduction (strategy) over time	To be completed	To be completed	All plants, micro/macro invertebrates, and lichens	To be completed	Continous measurements, repeated measures, phenology (system scale)	To be completed
56	Terrestrial	Species traits	Physiology	Ecological niche of all plants, micro/macro invertebrates, and lichens	Description of the realised niche, fundamental niche description (ecophysiology), the role and position of a species in its environment	To be completed	To be completed	All plants, micro/macro invertebrates, and lichens	To be completed	Biological tolerance data, traits, abiotic drivers	To be completed
57	Terrestrial	Species traits	Reproduction	Reproductive strategy of all plants, micro/macro invertebrates, and lichens	Description of reproduction strategies (asexual to sexual, annual, biannual), fitness	To be completed	To be completed	All plants, micro/macro invertebrates, and lichens	To be completed	Mode, descriptive measure, repeated measure	To be completed
58	Terrestrial	Species traits	Morphology	Morphometrics of all plants, micro/macro invertebrates, and lichens, birds and mammals	Characterisation of the bodysize of organisms (external shape and dimensions)	At least once/one year (ideally, once per year)	To be completed	All plants, micro/macro invertebrates, and lichens, Birds and Marine Mammals	To be completed	Morphometric measurements	To be completed
59	Terrestrial	Species traits	Physiology	Physiological functions of all microorganisms	To be completed	Local (1x1 m)	At least once/one year	All prokaryotic and eukaryotic microorganisms	To be completed	Respiration, carbon fixation, nutrient upake, nitrogen fixation	(e)DNA, physiological measurements
60	Terrestrial	Species traits	Morphology	Chick weight for all birds	The weight of chicks upon fledging	To be completed	To be completed	Birds	Proxy for food availability and likelihood of survival into adulthood, and therefore population health	Individual weight	CEMP

61	Terrestrial	Species traits	Physiology	Chick diet for all birds	The diet composition of chicks	To be completed	To be completed	Birds	Proxy of prey availability and quality, and therefore population health	Diet samples	CEMP
62	Terrestrial	Species traits	Morphology	Adult weight for all birds and marine mammals	Weight of adults on arrival at the breeding colony (CEMP)	To be completed	To be completed	Birds and Marine Mammals	Measure of health	Individual weight	CEMP
63	Terrestrial	Species traits	Phenology	Foraging duration for all birds and marine mammals	Duration of foraging trips	To be completed	To be completed	Birds and Marine Mammals	Proxy for distance to suitable foraging areas (indicating food availability and energetic costs of foraging)	Tracking data	CEMP
64	Terrestrial	Species traits	Phenology	Breeding window duration for all birds and marine mammals	The chronology of the breeding cycle from arrival at the colony to departure	To be completed	To be completed	Birds and Marine Mammals	Measure of time available for breeding, likely to be impacted by climate change	Time-lapse cameras	PenguinWatch, CEMP
65	Terrestrial	Species traits	Physiology	Adult diet for all birds and marine mammals	Presence/absence or quantity of specific prey items in diet of adults	To be completed	To be completed	Birds and Marine Mammals	Proxy of prey availability and quality, and therefore population health	Diet samples	CEMP
66	Terrestrial	Species traits	Reproduction	Breeding success for all birds and marine mammals	Annual survival rates as categorized by age-class and population level recruitment	To be completed	To be completed	Birds and Marine Mammals	Measure of population health	Observation surveys	CEMP
67	Terrestrial	Species traits	Morphology	Pup growth for all marine mammals	Growth rates of pups	To be completed	To be completed	Marine Mammals	Proxy for food availability and likelihood of survival into adulthood, and therefore population health	Individual weight	CEMP
68	Terrestrial	Species traits	Physiology	Foraging attendance duration for all marine mammals	Duration of attendance at nursery sites	To be completed	To be completed	Marine Mammals	Proxy of foraging duration, therefore providing information on food availability and energetic costs of foraging	Observation surveys	CEMP
69	Terrestrial	Species traits	Morphology	Morphological characteristics of all microeukaryotes	To be completed	Local (1x1 m) except remote sensing, where it is larger	At least once / one year	Microeukaryotes	To be completed	Image (cell meas., morpho. types, shapes, colours, structures, diatoms after removal of organic matter, fixation/stain for some taxa)	Microscopy (light, epifluorescence, SEM), culture collection/biobank deposits
70	Terrestrial	Species traits	Movement	Motility patterns of all microeukaryotes	To be completed	Local (1x1 m)	At least once / one year	Microeukaryotes	To be completed	Video footage (small distances, motility by flagella, gliding)	Microscopy, photography
71	Terrestrial	Species traits	Phenology	Phenological characteristics of all microeukaryotes	To be completed	Local (1x1 m)	At least once / one year	Microeukaryotes	To be completed	Photography (frozen/active), growth patterns, repro.cycles, responses to seas. varia. and envi. conditions	Photography, field observations
72	Terrestrial	Species traits	Physiology	Physiological characteristics of all microeukaryotes	To be completed	Local (1x1 m)	At least once / one year	Microeukaryotes	To be completed	Metabolic assays (Biolog system, API galleries), metabolomics, RNASeq, gas exchange, PAM	Microscopy, enzyme assays
73	Terrestrial	Species traits	Physiology	Snow petrel diet	To be completed	To be completed	To be completed	Snow petrels	Proxy of food availability and quality, and therefore population health	Midden cores	ANTSIE: https://antsie.webspace.durham.ac.uk/

- Sampling strategies:

  1. Design integrated modular sampling protocols to capture multiple EBVs at shared locations across national programs.
  2. Offer flexibility to omit specific modules (e.g., Remotely Piloted Aircraft System (RPAS) surveys) based on local resources and feasibility.
  3. Prioritize low-cost and and non-invasive sampling, scalable EBVs (e.g., remotely sensed vegetation cover) to initiate systematic community monitoring (noting, however, that such indicators still require the development of robust and validated methodologies, as recent literature has revealed significant challenges and potential for error).

  For example, Arctic vegetation monitoring has relied on a curated species list for vascular plants, mosses, liverworts, and lichens (now aging) which highlights the importance of maintaining taxonomic baselines. Establishing permanent plots along environmental gradients will also support repeatable in-situ observations that complement remote data).

- Standardization and interoperability:

  1. Apply consistent protocols with minimum metadata requirements to align EBV collection with individual research goals.
  2. Promote interoperability between global polar data centres and NADCs. Infrastructure could still be developed to support countries without NADCs, with researchers encouraged to deposit their data in existing national systems where appropriate.
  3. Leverage tools like Humboldt Extension to combine data from heterogeneous survey methods.

- Core EBV set: Narrow the EBV list to a prioritized subset of variables for co-design and cost-estimation. Consider grouping organism-independent EBVs into broader categories:

  - Taxonomy and diversity
  - Disease (pathogens and parasites)
  - Biotic interactions (microorganisms, plants, invertebrates, birds, mammals)

- Stakeholder input: Replicate EuropaBON's approach of linking EBVs to relevant policy domains and questions-tailored this time to Antarctic environmental governance.

- Community curation: Encourage continued engagement and disciplinary diversity. Broader representation, such as increased involvement of ge-

neticists, microbiologists, and taxonomists, may reshape prioritization and contribute to a more balanced, ecosystem-wide perspective. In parallel, efforts should not only focus on data curation but also consider the preservation of biological material through live culture collections, biobanking, and cryopreservation, particularly for understudied groups like microbes and algae.

3.4. Opportunities and challenges.

3.4.1. Opportunities. The development of EBVs for Antarctica offers several significant opportunities:

- Data cube and infrastructure development: The creation of a data cube workflow would provide a robust framework for handling large-scale biodiversity data in Antarctica. This infrastructure would prove valuable for Antarctic research, extending beyond just the development of specific EBVs, by enabling efficient data integration and management across different studies.

- Standardized data collection protocols: There is an opportunity to improve and harmonize protocols for standardized data collection across various research programs, facilitating the integration of data from different sources. This approach would also help incorporate contributions from citizen scientists, increasing the volume and diversity of data collected. The CASP-ICE initiative for snow and ice algae sampling is a current example of how protocol harmonization can be applied in practice to coordinate efforts across teams and environments.

- Enhanced information standards: By focusing on improving data standards in Antarctic/sub-Antarctic biodiversity research, the community can foster better comparability, reproducibility, and transparency in scientific findings. This would elevate the overall quality of the data used for monitoring and policy-making.

3.4.2. Challenges. While there are significant opportunities, there are also considerable challenges in developing EBVs for Antarctica:

- Modelling in ice-free areas: Modelling biodiversity in Antarctica's ice-free areas presents unique challenges due to their limited extent, spatial fragmentation, and scattered distribution across the continent. These conditions often require high-resolution data and may constrain modelling efforts to local scales, limiting broader generalizability. However, these

Figure 3. *Southern Giant Petrel (Macronectes giganteus) and chick on a nest among rocks, featuring lichens colonizing the rock surfaces, picture provided by Katarzyna Tołkacz*

areas are also where most research stations and human activities are concentrated, making them comparatively well studied and better documented than the ice-covered interior. This provides a valuable empirical foundation, although translating local data into broader-scale models remains a significant hurdle.

- Limited citizen science involvement beyond the Antarctic Peninsula: While the Antarctic Peninsula sees growing citizen science activity, particularly through tourism-related initiatives, most of the continent remains largely inaccessible to non-specialists. As a result, citizen scientists face significant logistical and environmental barriers to contributing to long-term biodiversity monitoring elsewhere in Antarctica, limiting temporal coverage and geographic representation.

- Climate variables for modelling: The scarcity of climate variables suitable for modelling in Antarctica poses another challenge. In particular, there is a lack of reliable environmental data that can be used to track long-term climatic changes and their impacts on biodiversity (Beugnon et al. 2025, Lembrechts, Aalto, et al. 2020, Lembrechts, Hoogen, et al. 2022, Lembrechts et al. 2025)

- Baseline year selection: Determining the appropriate baseline year for each EBV is a key challenge. Different EBVs may require different reference points in time, making it difficult to establish consistent and comparable datasets across variables and regions.

4. Future direction

In planning for the future development and application of Antarctic/sub-Antarctic-specific EBVs, it is crucial to identify the key stakeholders and their needs. Potential users of these variables include:

- Scientists: Researchers who will use the variables to track changes in biodiversity and ecosystem health over time. EBVs provide a standardized approach to data collection that will aid in generating consistent and comparable results.

- Policymakers: Decision-makers who will rely on EBVs to inform policies on conservation, resource management, and climate adaptation strategies for the Antarctic ecosystems.

- Conservation organizations: These groups can utilize EBVs to assess the effectiveness of conservation initiatives, monitor biodiversity, and ensure that conservation efforts are aligned with changing environmental conditions.

  By understanding the needs of these audiences, we can tailor the development of Antarctic/sub-Antarctic-specific EBVs to be more relevant and impactful. Key questions to address include:

  - Relevance of EBVs for Antarctic observations: Are the proposed EBVs adequate to capture the unique dynamics of the Antarctic and its ecosystems?
  - Additional variables for the Antarctic: What other variables, beyond the existing EBVs, might be necessary to fully capture the ecological complexity of the Antarctic?

  In moving forward, we should focus on the following actions:

- Prioritization of EBVs: Rank the EBVs based on their relevance to the Antarctic, considering the criteria of feasibility, ecological importance, and policy relevance.

- Alignment with management and policy objectives: Ensure that each EBV is linked to specific management goals and policy frameworks, clarifying their purpose and utility in decision-making processes.

- Collaboration with GEO BON: Engage with the GEO BON community to explore the potential for establishing an Antarctic Biodiversity Observation Network that would enable more coordinated and comprehensive monitoring across the region.

Acknowledgments

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5. Appendices

5.1. Appendix A: Tables.

Table 1. *EBV class structure, borrowed from EuropaBON report (Junker et al. 2023); EBVs that track the variability of specific attributes within species, such as genetic diversity (Genetic Composition EBVs), species distribution and abundance (Species Populations EBVs), and trait diversity within species (Species Traits EBVs), are categorized as "species-focused EBVs." On the other hand, EBVs that assess collective attributes of entire ecosystems at defined geographical locations-such as structural and functional characteristics of the ecosystem (Ecosystem Structure and Ecosystem Functioning EBVs), as well as community-level abundance and the various dimensions of compositional diversity (e.g., taxonomic, phylogenetic, and functional diversity)-are classified as "ecosystem-focused EBVs".*

Entity measured	EBV Class	Attributes measured
Species (Species-focused EBVs)	Genetic Composition	Genetic diversity
		Genetic differentiation
		Effective population size
		Inbreeding
	Species Populations	Species distributions
		Species abundances
	Species Traits	Morphology
		Physiology
		Phenology
		Movement
Ecosystem (Ecosystem-focused EBVs)	Ecosystem Structure	Live cover fraction
		Ecosystem distribution
		Ecosystem vertical profile
	Ecosystem Functioning	Primary productivity
		Ecosystem phenology
		Ecosystem disturbances
	Community Composition	Community abundance
		Taxonomic/phylogenetic diversity
		Trait diversity
		Interaction diversity

Table 2. *List of acronyms*

Acronym	Full Name / Description
Global observation frameworks	
EV	Essential Variable
ECV	Essential Climate Variable
EOV	Essential Ocean Variable
eEOV	ecosystem Essential Ocean Variable
EBV	Essential Biodiversity Variable
GEO BON	Group on Earth Observations Biodiversity Observation Network
BON	Biodiversity Observation Network
EuropaBON	Europa Biodiversity Observation Network
GCOS	Global Climate Observing System
GOOS	Global Ocean Observing System
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
CBD	Convention on Biological Diversity
SDG	Sustainable Development Goal
Polar monitoring and observation	
IPY	International Polar Year
SOOS	Southern Ocean Observing System
CBMP	Circumpolar Biodiversity Monitoring Program
CAFF	Arctic Council's Conservation of Arctic Flora and Fauna
Arctic BON	Arctic Biodiversity Observation Network
AVA	Arctic Vegetation Archive
FECs	Focal Ecosystem Components
CEMP	CCAMLR Ecosystem Monitoring Program
CEMM	CCAMLR Ecosystem Monitoring and Management
CCP	CCAMLR Conservation Planning
CASP-ICE	Cryospheric Algal Sampling Protocols – International Collaboration and Exchange
Cambridge-24 workshop	Essential Biodiversity Variables (EBVs) Framework for Terrestrial Antarctic and Sub-Antarctic Ecosystems
Antarctic institutions and frameworks	
SCAR	Scientific Committee on Antarctic Research
Ant-ICON	Integrated Science to Inform Antarctic and Southern Ocean Conservation
ANTOS	Antarctic Nearshore and Terrestrial Observing System
EG-ABI	Expert Group on Antarctic Biodiversity Informatics
IDEA	Integrated Digital East Antarctica Program
NADC	National Antarctic Data Centre
ATS	Antarctic Treaty System
ATCM	Antarctic Treaty Consultative Meeting
MEASO	Marine Ecosystem Assessment for the Southern Ocean
AAD	Australian Antarctic Division
CCAMLR	Conservation of Antarctic Marine Living Resources
ASPA	Antarctic Specially Protected Area
Biodiversity data infrastructure	
GBIF	Global Biodiversity Information Facility
OBIS	Ocean Biodiversity Information System
FAIR	Findable, Accessible, Interoperable, and Reusable
Technologies and tools	
RPAS	Remotely Piloted Aircraft System
AWS	Automatic Weather Stations

Table 3. *EBV identification template*

Field	Description
Essential Variable name (EV)	Proposed name for the Essential Variable
Realm	Choose between Cryosphere, Freshwater, Marine, or Terrestrial
EV definition	Define the proposed EV
EV relevance	Explain why this needs to be an EV
Taxonomic/ecosystem focus group	Define the focus group
Data required	What kind of data or observations are required to calculate this EV
Spatial resolution	Required spatial resolution
Spatial coverage	Required spatial coverage
Temporal resolution	Required temporal resolution
Temporal coverage	Required temporal coverage
Possible data sources and resources	Indicate existing data sources and relevant resources for this EV (specify data requirements)
Feasibility	What is the feasibility of collecting the required data or observations?
Existing Framework	Are there existing frameworks this EV would fit into?
ECV	Link to Essential Climate Variables
EOV	Link to Essential Ocean Variables
EBV	Link to Essential Biodiversity Variables
EBV class	Classification within the EBV framework
EESV	Link to Essential Ecosystem Service Variables

5.2. Appendix B: Additional discussion points from workshop.

5.2.1. *What happens in Antarctica does not stay in Antarctica.* It was emphasized that even though Antarctica is geographically remote, the effects of its ecosystem are global. The acceleration of climate change in the region has widespread consequences, particularly in terms of rising sea levels. This issue is not just about the persistence of Antarctic ecosystems but also about the well-being of human populations around the world. The recognition of the Antarctic ecosystem's importance should prompt societal actions toward conservation. Protecting Antarctica and the Southern Ocean is crucial for mitigating climate change, and cutting global greenhouse gas emissions is necessary to slow the melting of ice, which is occurring at a rate three times faster than in previous decades. In 2023 alone, over 1.5 million square kilometers of ice were lost, contributing to rising sea levels that will directly affect coastal communities worldwide. Additionally, the warming of the Antarctic region is disrupting global circulation patterns, further impacting ecosystems around the planet.

5.2.2. *Cyclical architecture.* A comprehensive and adaptive system for marine and terrestrial biological observations is essential for understanding the Southern Ocean's and Antarctica's ecosystems and assessing the impact of climate change. Initiatives like the Marine Ecosystem Assessment for the Southern Ocean (MEASO) rely on integrated frameworks that link monitoring efforts with policy decisions. This cyclical approach, as described by Benson et al. 2018, underscores the interdependence between policy and monitoring, where data-driven insights inform policy, and in turn, policies guide the focus of monitoring efforts.

At the core of this system are EBVs, EOVs, and ecological counterparts (eEOVs). Standardizing the measurement and estimation of these variables is vital for unifying scientific efforts and enabling policymakers to translate complex data into actionable insights for conservation and management.

To ensure the success of this approach, data management must adhere to international standards like the Darwin Core and the FAIR principles (Findable, Accessible, Interoperable, and Reusable), ensuring transparency, traceability, and scalability. Open-access platforms, such as the Ocean Biodiversity Information System and the Global Biodiversity Information Facility, enable the integration of global datasets, enhancing collaboration within the scientific community. Data must be made accessible in compliance with the Antarctic Treaty, particularly Article III, Section 1.c, which emphasizes the need for open-access scientific data.

This flexible, dynamic system must evolve with emerging methodologies and ideas, prioritizing the urgent ecological challenges through a transdisciplinary approach. Open-access technologies and rapid feedback loops between data collection and policy-making will ensure timely responses to environmental changes.

5.2.3. *CEMP (CCAMLR Ecosystem Monitoring Program).* The CEMP, established in 1989, was recognized as a valuable framework for biodiversity monitoring. This program focuses on specific "indicator species" that are sensitive to changes in the availability of harvested species. CEMP monitors predator-prey-environment interactions across designated Integrated Study Regions (ISDRs), assessing changes at the ecosystem level.

CEMP has successfully identified key parameters for each species and developed practical guidelines for data collection, which continue to be relevant for modern biodiversity monitoring. The workshop participants, particularly those from the top-predator breakout group, drew on these parameters to inform their selection of Essential Variables.

5.2.4. *ANTOS.*

- The Antarctic Nearshore and Terrestrial Observing System (ANTOS) is advancing a coordinated network of long-term platforms across terrestrial and nearshore environments. These platforms aim to co-locate environmental and biodiversity measurements, an essential step toward operationalizing EBVs in Antarctica. Although funding remains a key constraint, the growing network of Automatic Weather Stations (AWS) on the Antarctic Peninsula presents an opportunity to incorporate standardized biodiversity monitoring. ANTOS is exploring ways to leverage this infrastructure for integrated observations.

- At the national level, ANTOS members are working with environmental managers and programs in countries such as New Zealand, Australia, and Belgium to support ASPA (Antarctic Specially Protected Area) management and design monitoring platforms. In parallel, the network is developing technical protocols to promote standardization across sites and programs.

- Two forthcoming publications will synthesize ANTOS's efforts and support broader biodiversity monitoring discussions:

  - Borgmeier et al. (2025), *Gaps and Advances in Long-Term Monitoring of Antarctic Near-Shore and Terrestrial Ecosystems*, submitted to *Conservation Biology* (preprint);
  - Jones et al. (2025), *Research Bias in Antarctic Long-Term Biodiversity Monitoring*, submitted to *Global Change Biology*.

  Although not selected for Antarctic Treaty Consultative Meeting (ATCM) 2025, these papers are expected to be resubmitted following peer review and will provide key insights on monitoring priorities and current practices.

- ANTOS could benefit from alignment with CCAMLR's Conservation Planning (CP) subgroup, which emphasizes environmental management. Such collaboration would help bridge science and policy, supporting the implementation of robust monitoring practices.

- ANTOS may also help translate complex scientific outputs into actionable guidance for policymakers. For instance, it could contribute to establishing best practices for post-collection sample handling, an area identified in a 2022 publication advocating for biobanking. A coordinated system, inspired by developments within GBIF/OBIS, could enhance long-term archiving and data harmonization.

- Given the diversity of Antarctic ecosystems, harmonization is essential, though full standardization may not always be feasible. Context-specific strategies are therefore needed to ensure comparability while maintaining relevance across distinct environments.

- National operators, with their extensive access to regularly visited sites, are key to scaling up ANTOS efforts. Their involvement can strengthen broader initiatives to build a continent-wide understanding of biodiversity, a long-term endeavour that will require sustained commitment.

- Further collaboration with CCAMLR's Ecosystem Monitoring and Management (EMM) subgroup, which produces technical outputs, could also support the translation of scientific data into operational guidelines. ANTOS thus plays a vital role in ensuring that biodiversity science informs effective policy and conservation action.