The Global Ocean Observing System

DRAFT

Version: 1.0 April 2025

Essential Ocean Variable Specification Sheet

Benthic invertebrate abundance and distribution

Global Ocean Observing System (2025). Essential Ocean Variable Specification Sheet: Benthic invertebrate abundance and distribution. GOOS Reference No; DOI: [to be assigned]

EOV Specification Sheet curated by:

Biology and Ecosystems Panel

DETAILED INFORMATION ON HOW TO READ THE SPECIFICATION SHEET CAN BE FOUND IN THIS GUIDE

DRAFT

Background and justification

Benthic invertebrates live on, near or beneath seafloors across the world, from polar seas to tropical reefs, and from intertidal mudflats to abyssal plains. They represent a huge number of taxa (27 phyla) and a large range of sizes (nanograms to kilograms).

Benthic invertebrates make up a significant proportion of global biodiversity across the ocean's most extreme gradients of temperature, oxygen availability, food supply, and pH. They play critical roles in ecosystem function, including food webs, carbon cycling, and habitat provision. Additionally, many species are of economic, social and cultural benefit, supporting food security, tourism, and indigenous values. Many taxa and habitats within this group are also protected under conservation frameworks.

Despite the importance of this group, collecting, integrating, and analyzing biological and ecosystem data for benthic invertebrates is challenging. Efforts are complicated by the lack of universally accepted size-range definitions and methodologies for quantifying benthic invertebrates, due to their wide size range and varied habitat conditions.

Advances in technology and methodology are significantly enhancing the availability of comparable and collatable benthic invertebrate data. Typical methods to quantify abundance and distribution include direct sampling methods and marine imagery, with newer techniques such as environmental DNA and drone imagery also proving useful. Broader adoption of best practices throughout the data lifecycle can revolutionize our understanding of benthic invertebrates by linking sampling and surveying techniques, body-size estimates, laboratory analysis, artificial intelligence and machine learning, metadata and taxonomic standards, integrative data management and cyberinfrastructure, modeling, and translational data and information products.

Integration with Global Observation Frameworks

The Global Climate Observing System (GCOS) developed the Essential Climate Variable (ECV) framework to define necessary observations for monitoring Earth's climate (Bojinski et al., 2014). Some EOVs, including ocean physics, biogeochemistry, and biology/ecosystems variables (GCOS, 2022a; GCOS, 2022b), are also ECVs.

The Essential Biodiversity Variables (EBVs) defined and curated by the Group on Earth Observations Biodiversity Observation Network (GEO BON) complement the GOOS biological and ecosystem (BioEco) EOVs (Muller-Karger et al., 2018; Bax et al., 2019). The EOVs represent the basic observations of a particular parameter or process. EBVs are time series of biodiversity observations across genes, species populations, communities, or ecosystems. Thus, EOVs may be seen as the building blocks for GEO BON EBVs. The EOVs can be used to synthesise the EBVs as time series of BioEco EOV sub-variables at one location, or as time series of gridded, mapped, or modelled EOVs (Jetz et al., 2019).

The GOOS Biology and Ecosystems Panel collaborates with the Physics and Climate and Biogeochemistry Panels to advance EOVs, advocating for the need for biological observations, information management, and applications. GOOS, MBON, GEO BON, and OBIS work together to standardise guidelines and data management for EOVs, EBVs, and ECVs.

Current observing networks and coordination

Diverse networks and communities are collecting observations of biology and ecosystems EOVs at different scales and in different regions. An initial baseline survey conducted in 2019/20 identified 203 active, long-term (>5 years) observing programs systematically sampling marine life. These programs spanned about 7% of the ocean surface area, mostly concentrated in coastal regions of the United States, Canada, Europe, and Australia (Satterthwaite et al 2021). This information can be found in the GOOS BioEco Metadata Portal, which is continually updated. To consult the latest information, please visit: https://bioeco.goosocean.org

Contributes to (please click on the symbol for more information):

Essential Biodiversity Variables, Marine Habitats, SDG 14 and CBD

1. EOV information

ESSENTIAL OCEAN VARIABLE (EOV)	Benthic invertebrate abundance and distribution
DEFINITION	The quantity and spatial distribution of non-vertebrate animals living near (bentho-pelagic or hyperbenthic), on (epifauna), or beneath (infauna), the seafloor.
EOV SUB-VARIABLES - key measurements that are used to estimate the EOV ***occurrence (presence only) is a minimum requirement, but not recommended**	Number of individuals per unit area Biomass per unit area % living cover *Presence / absence
SUPPORTING VARIABLES - other measurements that are useful to provide scale or context to the sub-variables of the EOV	**Environmental** Sea surface temperature Subsurface temperature (near bottom) Surface currents Subsurface currents Oxygen Particulate matter - e.g. Particulate Organic Carbon flux Ocean Bottom Pressure (depth) Bathymetric Position Index Substrate Type Microbe biomass and diversity (pilot GOOS EOV) **EOV related** Body size Functional traits Life stage Metabolic rates, including as proxy for activity (e.g. bioturbation, feeding)
DERIVED PRODUCTS - outputs calculated from the EOV and sub-variables, often in combination with the supporting variables	Benthic diversity indices Distribution maps Habitat type

DRAFT

2. Phenomena to observe - what we want to observe with this EOV

This section presents an example of 3 priority phenomena for GOOS that can be (partly) characterised by this EOV's sub-variables. This list is not exhaustive but serves to provide general guidance on how observation efforts can structure their planning and implementation.

The GOOS application area(s) the phenomena are relevant for are depicted as follows: Climate , ocean health , operational services

PHENOMENA TO OBSERVE		Community or population abundance status and trends	Changes in marine life distribution	Changes in biodiversity
PHENOMENA EXTENT	HORIZONTAL	Local, regional and global	Local, regional and global	Local, regional and global
	VERTICAL	On, near (+ 2 m), and beneath (-0.2 m) the seafloor (all depths)	On, near (+ 2 m), and beneath (-0.2 m) the seafloor (all depths)	On, near (+ 2 m), and beneath (-0.2 m) the seafloor (all depths)
	TEMPORAL	Seasonal (particularly shallow environments) to decadal (particularly deep sea)	Annual (regional species extinction) to decadal (changes in species range extension due to climate change)	Annual (resulting from stochastic events) to decadal (resulting from long-term environmental chance)
RESOLUTION TO OBSERVE PHENOMENA	HORIZONTAL	Local: <100 kms Regional: 100-1000 km Global: 0.5° or 1° grid cells	Local: <100 kms Regional: 100-1000 km Global: 0.5° or 1° grid cells	Local: <100 kms Regional: 100-1000 km Global: 0.5° or 1° grid cells
	VERTICAL	Organism dependent, ~1 m above seafloor, ~5 cm below seafloor (meiofauna) - greater for larger infauna organisms	Organism dependent, ~1 m above seafloor, ~5 cm below seafloor (meiofauna) - greater for larger infauna organisms	Organism dependent, ~1 m above seafloor, ~5 cm below seafloor (meiofauna) - greater for larger infauna organisms
	TEMPORAL	Seasonal to decadal	Annual to decadal	Annual to decadal
SIGNAL TO CAPTURE		Change in IUCN category	Statistically significant changes in species occurrence observations outside their known natural range	Statistically significant changes in alpha, beta or gamma diversity

	Statistically significant change in abundance per taxa	Species lost or gained	
SUB-VARIABLES NEEDED TO MEASURE	Taxonomic/functional group/size-specific: • Individuals per unit area and/or • Biomass per unit area • Presence/absence • Occurrence	Taxonomic/functional group/size-specific: • Individuals per unit area and/or • Biomass per unit area • Presence/absence • Occurrence	Taxonomic/functional group/size-specific: • Individuals per unit area and/or • Biomass per unit area • Presence/absence • Occurrence
SUPPORTING VARIABLES NEEDED	• Sea surface temperature • Subsurface temperature (near bottom) • Subsurface salinity • Surface currents • Subsurface currents • Oxygen • Particulate matter • Depth • Bathymetric Position Index • Substrate Type • Microbe biomass and diversity (*pilot)	• Sea surface temperature • Subsurface temperature (near bottom) • Subsurface salinity • Surface currents • Subsurface currents • Oxygen • Particulate matter • Depth • Bathymetric Position Index • Substrate Type • Microbe biomass and diversity (*pilot)	• Sea surface temperature • Subsurface temperature (near bottom) • Subsurface salinity • Surface currents • Subsurface currents • Oxygen • Particulate matter • Depth • Bathymetric Position Index • Substrate Type • Microbe biomass and diversity (*pilot)

DRAFT

3. GOOS Observing Specifications or Requirements

This section outlines ideal measurements for an optimal observing system for this Essential Ocean Variable (EOV). It offers guidance on creating a long-term system to observe key phenomena related to the EOV. These values are not mandatory, and no single system is expected to meet all requirements. Instead, the combined efforts of various observing systems should aim to meet these goals. Observations at different scales are also valuable contributions to global ocean observation if shared openly.

EOV	Benthic Invertebrate abundance and distribution

PHENOMENA	Community or population status and trends Changes in marine life distribution Changes in biodiversity		
EOV SUB-VARIABLE	Individuals per unit area	**DEFINITION**	Total number of individuals within a taxon, functional group, or size class identified from a quantified spatial area in the sample or imagery.

	Resolution			**Timeliness**	**Uncertainty Measure-ment**	**Stability**	**Sampling approach**	**References**
	Spatial Horizontal	**Spatial Vertical**	**Temporal**					
IDEAL	Number of replicate sample informed by power analysis	-n/a	Number of replicate sample informed by power analysis	-n/a	within 95% confidence limits for imagery, quantify observer bias	-n/a	Underwater imagery (towed, remote, autonomous) for epifauna Samples (trawl, grab, box corer) or proxy imagery (e.g. sediment	General: Eleftheriou 2013, Soucek et al 2023 Imagery: Benoist et al 2019, de Mendonça and Metaxas 202, Durden et al 2016a Sediment sampling: Danavaro 2010, Rumohr 2009, Gray and Elliott 2009, Rogers et al 2008

DESIRABLE	0.5 ° grid cells / 10-20 replicate samples per spatial unit*	-n/a	seasonal to annual / 10-20 replicate samples per temporal unit	-n/a	within 95% confidence limits for imagery, quantify observer bias	-n/a	traces) for infauna Combining techniques	Meiofauna: Somerfield and Warwick 2013 Sediment traces: Przeslawski et al 2012 Observer bias in imaging: Durden et al 2016b AI bias/machine learning: Bravo et al 2021 Spatial autocorrelation: Legendre 1993 Deep Sea: Clark et al 2016
MINIMUM	1° grid cells / 3-10 replicate samples per spatial unit*	-n/a	Once (e.g. deep-sea)	-n/a	within 95% confidence limits	-n/a		

EOV SUB-VARIABLE	Biomass per unit area				**DEFINITION**		Total mass of individuals within a taxon, functional group, or size class identified from a quantified spatial area in the sample or imagery. For imagery: require density of individuals for groups or categories of fauna, as well as individual size/mass information to allow extrapolation.	
	Resolution							
	Spatial Horizontal	**Spatial Vertical**	**Temporal**	**Timeliness**	**Uncertainty Measure-ment**	**Stability**	**Sampling approach**	**References**
IDEAL	Variable with body size and application	-n/a	Number of replicate sample	-n/a	Scale calibration (imagery),	-n/a	For imagery: estimation of individual body	General: Eleftheriou 2013, Soucek et al 2023

DRAFT

	(e.g. meiofauna can be sampled with several cm^2 vs. megafauna requiring much larger areas Number of replicate samples informed by power analysis and collected within the spatial decorrelation scale of the data		informed by power analysis		wet weight conversion within 95% confidence limits		size by linear measurement with conversion to wet weight biomass and/or carbon biomass For sediment samples: wet weight/dry weight/ ash-free dry weight of all individuals per sample	Autocorrelation: Legendre 1993 Biomass estimation with imagery: Ärje et al 2020 Observer bias in imaging: Durden et al 2016b Weight-to-weight conversion factors: Gogina et al 2022
DESIRABLE	0.5 ° grid cells / 10-20 replicate samples per spatial unit*	-n/a	seasonal to annual / 10-20 replicate samples per temporal unit	-n/a	within 95% confidence limits	-n/a		
MINIMUM	1° grid cells / 3-10 replicate samples per spatial unit*	-n/a	Once (e.g. deep-sea)	-n/a	within 95% confidence limits	-n/a		

EOV SUB-VARIABLE	% Living cover				**DEFINITION**		The percent of cover of living invertebrates (total or from a particular taxon) identified from a quantified spatial area in imagery or visual census	
	Resolution			**Timeliness**	**Uncertainty Measure-ment**	**Stability**	**Sampling approach**	**References**
	Spatial Horizontal	**Spatial Vertical**	**Temporal**					
IDEAL	<1 m	-n/a	Seasonal	-n/a	<10%cover	-n/a	Underwater imagery (towed, remote, autonomous) for epifauna Measurements in quadrats or images, defined areas desirable	General: Eleftheriou 2013, Soucek et al 2023 Visual census: Mello et al 2023 Observer bias/imaging: Durden et al 2016b
DESIRABLE	<1 m	-n/a	Annual	-n/a	10-20% cover	-n/a		
MINIMUM	<5 m	-n/a	Decadal	-n/a	10 - 40% cover	-n/a		

EOV SUB-VARIABLE	Presence/absence				**DEFINITION**		The presence or absence of a taxon, functional group, or size class identified from samples or imagery from a known location.	
	Resolution			**Timeliness**	**Uncertainty Measurement**	**Stability**	**Sampling approach**	**References**
	Spatial Horizontal	**Spatial Vertical**	**Temporal**					
IDEAL	Number of replicate sample informed by power analysis and collected	-n/a	Number of replicate sample informed by power analysis	-	within 95% confidence limits for imagery, quantify observer bias	-	Underwater imagery (towed, remote, autonomous) for epifauna Samples (trawl, grab, box corer)	General: Eleftheriou 2013, Soucek et al 2023 Imagery, including classification scheme: Untiedt et al 2021

	within the spatial decorrelation scale of the data						or proxy imagery (e.g. sediment traces) for infauna Combining techniques eDNA metabarcoding of bottom water samples or sediment samples	eDNA: de Brauwer et al 2023, Kopp et al 2023 Imagery: Buhl-Mortensen and Buhl Mortensen 2014 Trawl and imagery: Mendonça and Metaxas 2021 Sediment sampling: Danavaro 2010, Rumohr 2009, Gray and Elliott 2009, Rogers et al 2008 Meiofauna: Somerfield and Warwick 2013 Sediment traces: Przeslawski et al 2012 Observer bias in imaging: Durden et al 2016 AI bias/machine learning: Bravo et al 2021 Spatial autocorrelation: Legendre 1993 Deep Sea: Clark et al 2016
DESIRABLE	0.5 ° grid cells / 10-20 replicate samples per spatial unit*	-n/a	seasonal to annual / 10-20 replicate samples per temporal unit	-	within 95% confidence limits for imagery, quantify observer bias	-		
MINIMUM	1° grid cells / 3-10 replicate samples per spatial unit*	-n/a	Once (e.g. deep sea)	-	within 95% confidence limits	-		

* Observing benthic invertebrates in a quantitatively robust way requires observing a sufficient number of individuals to estimate density, biomass or diversity, which can take increasingly large numbers depending on the variance of a given community or assemblage (e.g. 100 + individuals per sample). And areas with less density can require observing larger areas to reach sufficient numbers of individuals for quantitative descriptions, where smaller fauna are in higher densities than larger fauna in line with the relationships described by the Metabolic Theory of Ecology (Brown et al 2004).

4. Observing approach, platforms and technologies

This table provides examples of approaches and technologies used to collect this EOV to help observe priority phenomena

APPROACH / PLATFORM	Underwater imagery & visual census	Sediment/infaunal sampling	Epibenthos sampling
EOV SUB-VARIABLE(S) MEASURED	Individuals per unit area Biomass per unit area % Living cover Presence/absence	Individuals per unit area Biomass per unit area Presence/absence	Individuals per unit area Biomass per unit area Presence/absence
TECHNIQUE / SENSOR TYPE	Camera (video/stills) Baited videos (BRUVs) Sediment Profile Imaging Time-lapse imaging	Box corers, grabs	Benthic sleds, trawls
SUGGESTED METHODS AND BEST PRACTICES	General: Bowden et al 2020 Photogrammetry: Reviewed in Durden et al. 2016a Observer bias quantification: Durden et al 2016b Standardised nomenclature (e.g. CATAMI): Althaus et al, Horton et al 2021) BRUVs (Langlois et al 2024) ROVs: (Monk et al 2024a) Towed Camera: (Carroll et al 2024) AUVs: (Monk et al 2024b) Visual census: Edgar et al 2020	Przeslawski et al 2024a	Przeslawski et al 2024b
SUPPORTING VARIABLES MEASURED			

APPROACH / PLATFORM	eDNA	Acoustics	Aerial Imagery
EOV SUB-VARIABLE(S) MEASURED	Presence/absence	% Living cover Presence/absence	% Living cover Presence/absence
TECHNIQUE / SENSOR TYPE	Water or sediment samples	Multibeam, sidescan, acoustic camera	Drone imagery, manned aircraft imagery, satellite imagery
SUGGESTED METHODS AND BEST PRACTICES	De Brauwer et al 2023, Pawlowski et al 2022	Conway et al 2005, Picard et al 2022	Drone imagery: Clarkson and Pollack 2022, Monteiro et al 2021 Satellite imagery: Sagar et al 2020, Espriella and Lecours 2023
SUPPORTING VARIABLES MEASURED			

5. Data and information management

Access to data and information is at the core of an ocean observing system. This section provides essential information on how to contribute data to the GOOS

GOOS approach to data management is aligned with open data and FAIR (Findable, Accessible, Interoperable, Reusable)[1] practices. All EOV data and information is valuable, thus effective data management practices are essential to ensure it remains accessible and (re)usable for future generations.

In this section you will be directed to resources that explain how you can contribute data to global ocean observing and ensure your data and information is accessible, interoperable and sustained. This resource has instructions for different scenarios: an individual submitting data, or existing data centres connecting to the system.

Please follow these practices carefully, as BioEco EOV data FAIRness relies on compliance with these guidelines.

Before proceeding, please note these important points:

1. As a **minimum**, you must ensure information describing your EOV data (i.e. metadata) are visible in the Ocean Data and Information System (ODIS)[2]. Regardless of where the actual data is stored, evidence of its existence must be findable within ODIS.
2. BioEco EOV data is successfully managed if it is discoverable in the **GOOS BioEco Portal**. The BioEco Portal is the central point of access and coordination of BioEco EOV observing programmes. Data visible in ODIS will automatically be visible in the BioEco Portal and vice versa.
3. If data is published to OBIS[3], it will also be visible in ODIS and the BioEco Portal. You do not need to also add it elsewhere, unless there is extra information you would like to include.

The main data management steps are as follow:

1. Become discoverable: ensure the data producers (e.g., organisation, programme, project, etc.) and datasets are visible in ODIS
2. Prepare the required metadata about the data producer and the datasets
3. Publish EOV data (e.g. OBIS)
4. Verify discoverability in ODIS

[1] Wilkinson et al. 2016 https://doi.org/10.1038/sdata.2016.18
[2] ODIS, part of IOC-UNESCO's International Oceanographic Data and Information Exchange (IODE), is a global federation of data systems sharing interoperable (meta)data about holdings, services, and other resources to enhance cross-domain data accessibility.
[3] OBIS is a global biodiversity database and IOC-UNESCO IODE component, connecting +30 nodes, +1000 institutions, and 99 countries, interoperating with other major biodiversity hubs like GBIF and makes data visible in ODIS as an ODIS node.

Not all steps may be relevant for you, but **Step 1 is the minimum required** to ensure your data contributes to EOVs. .

TO CONTRIBUTE DATA AND METADATA TO THE GLOBAL OBSERVING SYSTEM, PLEASE GO TO: https://iobis.github.io/eov-data-management/

Figure 2. Map of OBIS Nodes. See https://obis.org/contact/ for a complete list.

Contact the OBIS Secretariat (helpdesk@obis.org) for help setting up your data workflows. To publish BioEco EOV data from systems like NCEI or ERDDAP to OBIS, consider becoming an OBIS node or collaborating with one. The OBIS Secretariat can help guide you through the process of becoming a Node, or connect you with an appropriate OBIS node (Figure 2).

Help Resources

- EOV Metadata Submission tool: https://eovmetadata.obis.org/

ODIS

- General help https://book.odis.org/index.html
- Connecting to ODIS https://book.odis.org/gettingStarted.html
- ODIS Catalogue of Sources: https://catalogue.odis.org/
- Ocean Info Hub: https://oceaninfohub.org/
- Schema.org framework https://schema.org/

OBIS

- OBIS Manual: https://manual.obis.org/
- OBIS YouTube data formatting and publishing videos: https://www.youtube.com/playlist?list=PLlgUwSvpCFS4TS7ZN0fhByj_3EBZ5IXbF
- Darwin Core term reference list: https://dwc.tdwg.org/terms/
- WoRMS taxonomy: https://www.marinespecies.org/
- Spreadsheet template generator https://www.nordatanet.no/aen/template-generator/config%3DDarwin%20Core
- BioData Guide with example code for transforming datasets to DwC: https://ioos.github.io/bio_data_guide/

GOOS BioEco Portal

- Documentation https://iobis.github.io/bioeco-docs/
- Access https://bioeco.goosocean.org/

—-------------

Data on benthic invertebrate abundance and distribution can be obtained from whole biological specimens, imagery, or genetic samples, and this determines the most appropriate data management workflow (Durden et al 2024). Traditionally, data related to biological specimens have been delivered as presence-only taxonomic identifications, thus reducing the applicability of such databases for monitoring purposes. Data are often managed by individual museum scientists or curators and subsequently harvested by online platforms. Some of these platforms (e.g. Atlas of Living Australia) do not yet include absences or information related to sampling effort.

The primary global repository for all BioEco EOV data is the Ocean Biodiversity Management System which often cross- posts data with the Global Biodiversity Information Facility. The OBIS Manual describes example data schema for invertebrate abundance and distribution data, sub variables, and data products collected by various sampling and imagery platforms. Taxonomic identity ontology and tracking uses tools of the World Register of Marine Species (WoRMS, https://www.marinespecies.org/) These ontologies include numeric identifiers that allow for reclassification as taxonomic knowledge improves. Importantly, OBIS is now able to store absence records and sampling effort, as well as to link species data to other related information (e.g. environmental data, images, sampling effort) using the OBIS ENV-DATA approach (De Pooter et al. 2017).

The OBIS ENV-DATA approach can also be used to capture body size to mass conversion information with the Extended Measurement or Fact extension (eMoF), linking multiple biometric measurements (weight, biomass) to a particular occurrence record or (sub)sample. In addition, eMoF can also capture processing details (e.g. automated versus human identification of invertebrates).

For image data, international tools and repositories are developing such as FathomNet (https://fathomnet.org) which is a global, open-source image and machine learning model repository. FathomNet partners with National Centers for Environmental Information (NCEI, https://www.ncei.noaa.gov) to offer long-term, web accessible image archiving, which allows for transfer learning and other artificial intelligence approaches to train models on novel combinations of training images and classification systems. Other international and national systems with long-term or ongoing support include Squidle+ (www.squidle.org) and Reef Cloud (https://reefcloud.ai).

In a global context, there are several initiatives that use benthic invertebrate data for research, observing, and statutory monitoring including the following:

- GEO BON,
- International Seabed Authority (ISA) for observing and model data to understand baseline and impact assessment for its Reserved Areas for prospective seafloor mining (Stratmann et al. 2018),
- Intergovernmental Panel on Climate Change (IPCC, Peck et al. 2018, Yool et al. 2017, Cooley et al. 2022),
- Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES),
- Convention on Biodiversity,
- Coastal and Estuarine Research Federation (CERF),
- OSPAR Commission,
- International Council for the Exploration of the Sea (ICES),
- Deep Ocean Stewardship Initiative (DOSI), and those implementing the Deep Ocean Observing Strategy (DOOS, Levin et al. 2019).

Many national and regional initiatives also evaluate the status and trends in marine invertebrate variables (e.g. European Marine Strategy Framework Directive, US National Marine Sanctuaries Act, Australian State of the Environment reporting). While each has differing combinations of observing needs, size-specific information on benthic invertebrate biomass, including via a gridded time variant format, can address needs across these groups.

References

Background information

Bax, N. et al. 2019. A response to scientific and societal needs for marine biological observations. Frontiers in Marine Science.

Benoist NMA, Morris KJ, Bett BJ, Durden JM, Huvenne VAI, Le Bas TP, Wynn RB, Ware SJ, Ruhl HA. 2019. Monitoring mosaic biotopes in a marine conservation zone by autonomous underwater vehicle. Conservation Biology, 33(5):1174-1186.

Bojinski, S. et al. 2014. The concept of essential climate variables in support of climate research, applications, and policy. Bull. Amer. Meteor. Soc., 95, 1431–1443, doi:https://doi.org/10.1175/BAMS-D-13-00047.1.

Bravo G, Moity N, Londoño-Cruz E, Muller-Karger F, Bigatti G, Klein E, Choi F, Parmalee L, Helmuth B and Montes E (2021) Robots Versus Humans: Automated Annotation Accurately Quantifies Essential Ocean Variables of Rocky Intertidal Functional Groups and Habitat State. Front. Mar. Sci. 8:691313

Brown, J.H., Gillooly, J.F., Allen, A.P., Savage, V.M. and West, G.B. 2004. Toward a metabolic theory of ecology. Ecology, 85: 1771-1789.

Buhl-Mortensen, P., & Buhl-Mortensen, L. (2013). Diverse and vulnerable deep-water biotopes in the Hardangerfjord. Marine Biology Research, 10(3), 253–267.

Burnett, T.H. B.R., H. Thiel, "The nanobenthos" in Introduction to the study of meiofauna, T. H. Higgins R.P., Ed. (Smithsonian Institution Press, Washington D.C., 1988), pp. 488.

Butenschön, M., J. Clark, J. Aldridge, N., J. I. Allen, Y. Artioli, et al., ERSEM 15.06: a generic model for marine biogeochemistry and the ecosystem dynamics of the lower trophic levels. Geoscientific Model Development 9, 1293-1339 (2016).

Cooley, S., D. Schoeman, L. Bopp, P. Boyd, S. Donner, et al. 2022: Ocean and Coastal Ecosystems and their Services. In: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press.

Durden, J. M., et al. (2024). "Defining the target population to make marine image-based biological data FAIR." Ecological Informatics 80: 102526.

GCOS, 2022a. The 2022 GCOS Implementation Plan (GCOS-244). World Meteorological Organization, Geneva. https://library.wmo.int/records/item/58104-the-2022-gcos-implementation-plan-gcos-244.

GCOS, 2022b. The 2022 GCOS ECVs Requirements (GCOS 245). World Meteorological Organization, Geneva. https://library.wmo.int/records/item/58111-the-2022-gcos-ecvs-requirements-gcos-245

Higgins, R.P., H. Thiel, Introduction to the study of meiofauna (Smithsonian Institution Press, 1988).

Jetz, W. et al. 2019. Essential biodiversity variables for mapping and monitoring species populations. Nature Ecology & Evolution. 3, p. 539–551. Doi: 10.1038/s41559-019-0826-1.

Kopp, D., et al. (2023). "Assessing without harvesting: Pros and cons of environmental DNA sampling and image analysis for marine biodiversity evaluation." Marine Environmental Research 188: 106004.

Levin, L. A., B. J. Bett, A. R. Gates, P. Heimbach, B. M Howe et al., Global Observing Needs in the Deep Ocean. Front. Mar. Sci. 6, 241 (2019).

Mello, T. J., et al. (2023). "Drivers of temporal variation in benthic cover and coral health of an oceanic intertidal reef in Southwestern Atlantic." Regional Studies in Marine Science 60: 102874.

de Mendonça, SN, Metazas, A. 2021. Comparing the Performance of a Remotely Operated Vehicle, a Drop Camera, and a Trawl in Capturing Deep-Sea Epifaunal Abundance and Diversity. Front. Mar. Sci 8:631354.

Miloslavich, P et al. 2018. Essential Ocean Variables for sustained observations of marine biodiversity and ecosystems. Global Change Biology. Volume 24, Issue 6. Pages 2416-2433. http://dx.doi.org/10.1111/gcb.14108.

Muller-Karger, F. 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. https://doi.org/10.3389/fmars.2018.00211.

Peck, M. A., C. Arvanitidis, M. Butenschön, D. MelakuCanu, E. Chatzinikolaou et al., Projecting changes in the distribution and productivity of living marine resources: A critical review of the suite of modelling approaches used in the large European project VECTORS. Estuar. Coast. Shelf Sci. 201, 40-55 (2018).

Priede, I. G., F. E. Muller-Karger, T. Niedzielski, A. V. Gebruk , D. O. B. Jones, A. Colaço (2022) Drivers of Biomass and Biodiversity of Non-Chemosynthetic Benthic Fauna of the Mid-Atlantic Ridge in the North Atlantic. Front. Mar. Sci. 9:866654. doi: 10.3389/fmars.2022.866654

Ruhl, H. A., J. A. Ellena, K. L. Smith Jr, Connections between climate, food limitation, and carbon cycling in abyssal sediment communities. Proceedings of the National Academy of Sciences 105, 17006-17011 (2008).

Ruhl, H.A., Bett, B.J., Ingels, J., Martin, A., Gates, A.R., Yool, A., Benoist, N.M.A., Appeltans, W., Howell, K.L. and Danovaro, R. (2023), Integrating ocean observations across body-size classes to deliver benthic invertebrate abundance and distribution information. Limnology and Oceanography Letters, 8: 692-706.

Satterthwaite et al. 2021. Establishing the Foundation for the Global Observing System for Marine Life. *Front. Mar. Sci. 8.*

Snelgrove, P. V. R., K. Soetaert, M. Solan, S. Thrush, C. L. Wei, et al. Global Carbon Cycling on a Heterogeneous Seafloor. Trends Ecol Evol 33(2): 96-105.D. (2018).

Stratmann, T., L. Lins, A. Purse, Y. Marcon, C. F. Rodrigues, A. Ravara, et al. Abyssal plain faunal carbon flows remain depressed 26 years after a simulated deep-sea mining disturbance. Biogeosciences 15, 4131-4145 (2018).

Untiedt CB, Williams A, Althaus F, Alderslade P and Clark MR (2021). Identifying Black Corals and Octocorals From Deep-Sea Imagery for Ecological Assessments: Trade-Offs Between Morphology and Taxonomy. Front. Mar. Sci. 8:722839.

Yool, A., A. P. Martin, T. R. Anderson, B. J. Bett, D. O. B. Jones, et al., Big in the benthos: Future change of seafloor community biomass in a global, body size-resolved model. Glob Chang Biol. 23, 3554-3566 (2017).

Woodall, L.C., D.A. Andradi-Brown, A.S. Brierley, M.R. Clark, D. Connelly, R.A. Hall, K.L. Howell, V.A.I. Huvenne, K. Linse, R.E. Ross, P. Snelgrove, P.V. Stefanoudis, T.T. Sutton, M. Taylor, T.F. Thornton, and A.D. Rogers. 2018. A multidisciplinary approach for generating globally consistent data on mesophotic, deep-pelagic, and bathyal biological communities. Oceanography 31(3):76–89

Guides, best practices and methods

Althaus F, Hill N, Ferrari R, Edwards L, Przeslawski R, Schönberg CHL, et al. (2015) A Standardised Vocabulary for Identifying Benthic Biota and Substrata from Underwater Imagery: The CATAMI Classification Scheme. PLoS ONE 10(10): e0141039. https://doi.org/10.1371/journal.pone.0141039

Ärje J, Melvad C, Jeppesen MR, et al. Automatic image-based identification and biomass estimation of invertebrates. Methods Ecol Evol. 2020; 11: 922–931. https://doi.org/10.1111/2041-210X.13428

Bowden, D.A., Rowden, A.A., Chin, C., Hempel, S., Wood, B., Hart, A. and Clark, M.R. (2020) Best practice in seabed image analysis for determining taxa, habitat, or substrata distributions. Wellington, N.Z., Ministry of Primary Industries, 61pp. (New Zealand Aquatic Environment and Biodiversity Report No. 239).

Carroll A, Althaus F, Beaman R, Friedman A, Ierodiaconou D, Ingleton T, Jordan A, Linklater M, Monk J, Post A, Przeslawski R, Smith J, Stowar M, Tran M, Tyndall A. 2024. Marine sampling field manual for towed underwater camera systems. In Field Manuals for Marine Sampling to Monitor Australian Waters, Version 3. Przeslawski R, Foster S (Eds). National Environmental Science Programme (NESP).

Clark M, Consalvey M, Rowden AA (Eds). 2016. *Biological Sampling in the Deep Sea.* John Wiley & Sons:

Clarkson E, Beseres Pollack J (2022) Cost-effective use of aerial imagery to quantify faunal-habitat associations across multiple spatial scales. Mar Ecol Prog Ser 684:37-56.

Conway, K.W., Barrie, J.V. & Krautter, M. 2005.Geomorphology of unique reefs on the western Canadian shelf: sponge reefs mapped by multibeam bathymetry. Geo-Marine Letters 25, 205–213.

Danavaro, R. (ed.) (2010). Methods for the study of deep-sea sediments, their functioning and biodiversity. Boca Raton, FL: CRC Press.

De Brauwer, M., Clarke, L. J., Chariton, A., Cooper, M. K., de Bruyn, M., Furlan, E., MacDonald, A. J., Rourke, M. L., Sherman, C. D. H., Suter, L., Villacorta-Rath, C., Zaiko, A., & Trujillo-González, A. (2023). Best practice guidelines for environmental DNA biomonitoring in Australia and New Zealand. Environmental DNA, 5, 417–423. https://doi.org/10.1002/edn3.395

De Pooter D, Appeltans W, Bailly N, et al. 2017. Toward a new data standard for combined marine biological and environmental datasets - expanding OBIS beyond species occurrences. Biodiversity Data Journal 5:e10989. doi: 10.3897/BDJ.5.e10989.

Durden JM, Schoening T, Althaus F et al (2016a) Perspectives in visual imaging for marine biology and ecology: from acquisition to understanding. Oceanography and Marine Biology, 54: 1-72.

Durden JM, Bett BJ, Schoening T, Morris KJ, Nattkemper TW, Ruhl HA (2016b) Comparison of image annotation data generated by multiple investigators for benthic ecology. Mar Ecol Prog Ser 552:61-70.

Edgar, G. J., et al. (2020). Establishing the ecological basis for conservation of shallow marine life using Reef Life Survey. Biological Conservation 252: 108855.

Eleftheriou, A. (ed.) (2013). Methods for the study of marine benthos (4th edn). Oxford: Wiley Blackwell.

Espriella, M. and V. Lecours. 2023. Using drone imagery to map intertidal oyster reefs along Florida’s Gulf of Mexico coast. Gulf and Caribbean Research 34 (1): 89-96.

Gogina, M., Zettler, A., Zettler, M. 2022, Weight-to-weight conversion factors for benthic macrofauna: recent measurements from the Baltic and the North seas. Earth System Science Data, 14: 1-4,

Gray, JS, Elliott, M, 2009, The Soft-Sediment Benthos in the Ecosystem, Ecology of Marine Sediments: From Science to Management, Oxford

Horton, T.; Marsh, L.; Bett, B.J.; Gates, A.R.; Jones, D.O.B.; Benoist, N.M.A.; Pfeifer, S.; Simon-Lledó, E.; Durden, J.M.; Vandepitte, L. and Appeltans, W. (2021) Recommendations for the Standardisation of OpenTaxonomic Nomenclature for Image-Based Identifications. Frontiers in Marine Science, 8:620702, 13pp.

Langlois, T, Goetze, J, Bond, T, et al. 2020. A field and video annotation guide for baited remote underwater stereo-video surveys of demersal fish assemblages. Methods Ecol Evol.; 11: 1401– 1409.

Legendre, P. 1993. Spatial autocorrelation: trouble or new paradigm? Ecology, 74: 1659-1673

Monk J, Barrett N, Bond T, Fowler A, McLean D, Partridge J, Perkins N, Przeslawski R, Thomson P.G, Williams J. 2024a. Field manual for imagery based surveys using remotely operated vehicles (ROVs). In Field Manuals for Marine Sampling to Monitor Australian Waters, Version 3. Przeslawski R, Foster S (Eds). National Environmental Science Programme (NESP).

Monk J, Barrett N, Bridge T, Carroll A, Friedman A, Ierodiaconou D, Jordan A, Kendrick G, Lucieer V. 2024b. Marine sampling field manual for autonomous underwater vehicles (AUVs). In Field Manuals for Marine Sampling to Monitor Australian Waters, Version 3. Przeslawski R, Foster S (Eds). National Environmental Science Program (NESP).

Monteiro, J.G., Jiménez, J.L., Gizzi, F. et al. Novel approach to enhance coastal habitat and biotope mapping with drone aerial imagery analysis. Sci Rep 11, 574 (2021). https://doi.org/10.1038/s41598-020-80612-7

Picard, K., Austine, K., Bergersen, N., Cullen, R., Dando, N., Donohue, D., Edwards, S., Ingleton, T., Jordan, A., Lucieer, V., Parnum, I., Siwabessy, J., Spinoccia, M., Talbot-Smith, R., Waterson, C., Barrett, N., Beaman, R., Bergersen, D., Boyd, M., Brace, B., Brooke, B., Cantrill, O., Case, M., Daniell, J., Dunne, S., Fellows, M., Harris, U., Ierodiaconou, D., Johnstone, E., Kennedy, P., Leplastrier, A., Lewis, A., Lytton, S., Mackay, K., McLennan, S., Mitchell, C., Monk, J., Nichol, S., Post, A., Price, A., Przeslawski, R., Pugsley, L., Quadros, N., Smith, J., Stewart, W., Sullivan J., Tran, M., Whiteway, T., 2022. Australian Multibeam Guidelines, Version 2. Record 2018/19. Geoscience Australia, Canberra. http://dx.doi.org/10.11636/Record.2018.019

Pawlowski J, Bruce K, Panksep K, et al, 2022, Environmental DNA metabarcoding for benthic monitoring: A review of sediment sampling and DNA extraction methods, Science of The Total Environment, 818, 151783.

Przeslawski R, Berents P, Clark M, Dittmann S, Edgar G, Frid C, Hooper G, Hughes L, Ingleton T, Kennedy D, Nichol S, Smith J. 2024a. Marine sampling field manual for grabs and box corers. In Field Manuals for Marine Sampling to Monitor Australian Waters, Version 3. Przeslawski R, Foster S (Eds). National Environmental Science Programme (NESP).

Przeslawski R, Althaus F, Atkinson L, Clark M, Colquhoun J, Gledhill D, Flukes E, Foster S, O'Hara T. 2024b. Marine sampling field manual for benthic sleds and bottom trawls. In Field Manuals for Marine Sampling to Monitor Australian Waters, Version 3. Przeslawski R, Foster S (Eds). National Environmental Science Program (NESP).

Przeslawski, R., et al. (2023). Developing an ocean best practice: A case study of marine sampling practices from Australia. Frontiers in Marine Science 10.

Przeslawski, R, Dundas, K., Radke, L, Anderson, T.J. 2012.Deep-sea Lebensspuren of the Australian continental margins. Deep Sea Research Part I. 65: 26-35.

Rogers SI, Somerfield PJ, Schratzberger M, Warwick R, Maxwell TAD, Ellis JR, 2008, Sampling strategies to evaluate the status of offshore soft sediment assemblages, Marine Pollution Bulletin 56, 880-894

Rumohr, H, 2009, Soft‐bottom macrofauna: collection, treatment, and quality assurance of samples. ICES Techniques in Marine Environmental Sciences, No. 43, 20pp.

Sagar, S., Falkner, I., Dekker, A., Huang, Z., Blondeau-Patissier, D., Phillips, C., Przeslawski, R. (2020). Earth Observation for monitoring of Australian Marine Parks and other off-shore Marine Protected Areas. Report to the National Environmental Science Program, Marine Biodiversity Hub. Geoscience Australia.

Somerfield, P.J. and Warwick, R.M. (2013). Meiofauna Techniques. In Methods for the Study of Marine Benthos, A. Eleftheriou (Ed.).

Soucek, D.J., Farag, A.M., Besser, J.M., and Steevens, J.A., 2023, Guide for benthic invertebrate studies in support of Natural Resource Damage Assessment and Restoration: U.S. Geological Survey Open-File Report 2022–1110, 11 p., https://doi.org/10.3133/ofr20221110

Standards and reference materials

Nil

Integrated EOV products and visualisations

Nil

Contributors

Leading authors	Henry Ruhl, Rachel Przeslawski, Monika Kędra, Marta Szczepanek
Contributing authors	Elizabeth Lawrence, Ward Appeltans, Pier Luigi Buttigieg, Ana Lara-Lopez

Acronyms and Abbreviations

CBD: Convention on Biological Diversity

EBV: Essential Biodiversity Variables

ECV: Essential Climate Variables

EOV: Essential Ocean Variables

GCOS: Global Climate Observing System

GEO BON: Group on Earth Observations Biodiversity Observation Network

GOOS: Global Ocean Observing System

IOCCP: International Ocean Carbon Coordination Project

MBON: Marine Biodiversity Observation Network

OBIS: Ocean Biodiversity Information System

ODIS: Ocean Data Information System

OCG: Observation Coordination Group

OOPC:Ocean Observations Physics and Climate Panel

SDG: Sustainable Development Goals

Glossary of terms

Bathymetric Position Index: a measure of where a georeferenced location with a defined depth, is relative to the neighbouring locations. BPI plays a significant role in characterizing benthic terrain for modelling and classification.

Benthic invertebrates: Animals without vertebrae that are associated with the seabed. This includes animals that live or extend up to 2 m above the seabed (e.g. habitat formers, demersal invertebrates) and those that live beneath the seabed generally no more than 0.5 m deep (e.g. infauna).

Derived products: outputs calculated from the EOV and sub-variables, often in combination with the supporting variables, that contribute to evaluating change in phenomena. For example, evaporation can be determined from sea surface temperature measurements; air-sea fluxes of CO2 can be derived from inorganic carbon EOV; fish stock productivity can be determined from fish abundance.

Distribution maps: Maps showing recorded or predicted species occurrence, abundance, biomass, cover, habitat, or other sub-variables.

Diversity indices: Various metrics to assess biodiversity, e.g. richness, Shannon H; evenness

Functional group: Classification based on a particular ecosystem function or characteristic, which could include trophic level, habitat, size or other.

Indicators: An indicator can be defined as a ‘measure based on verifiable data that conveys information about more than just itself’. This means that indicators are purpose dependent - the interpretation or meaning given to the data depends on the purpose or issue of concern.

Measurement Uncertainty: the parameter, associated with the result of a measurement, that characterises the dispersion of the values that could reasonably be attributed to the measurand. It includes all contributions to the uncertainty, expressed in units of 2 standard deviations, unless stated otherwise

Ontogeny: the developmental process of an organism. For benthic marine invertebrates, life stages can often be very different, including non-benthic periods (e.g. free-swimming larvae).

Phenomena: properties (e.g., of a species such as distribution), processes (e.g., of the ocean such as surface ocean heat flux), or events (e.g., such as algal blooms) that have distinct spatial and temporal scales, and when observed, inform evaluations of ocean state and ocean change

Stability: The change in bias over time. Stability is quoted per decade.

Substrate Type: The physical characteristics of the surface of the seafloor, including sediment or rock type and sometimes combined with relief, slope and bedforms.

Supporting variables: other measurements that are useful to provide scale or context to the sub-variables of the EOV (e.g., pressure measurements to provide information on the depth at which subsurface currents are estimated, sea temperature to understand dissolved inorganic carbon, water turbidity to support estimations of hard coral cover).

Sub-variables: key measurements that are used to estimate the EOV (e.g., counts of individuals to provide an estimate of species abundance (such as fish, mammals, seabirds or turtles), partial pressure of carbon dioxide (pCO_2) to estimate ocean inorganic carbon, or wave height to estimate sea state).

Timeliness: The time expectation for availability of data measured from the data acquisition time.

Appendix - Additional information

A1. Applications

This table provides examples of applications of this EOV, including GOOS applications, contribution to other essential variable frameworks and contribution to indicators

EOV		
CORRESPONDING ESSENTIAL VARIABLES	ECV	
	EBV	
GLOBAL INDICATORS EOV CAN CONTRIBUTE	**SDG**	
	CBD	
	CLIMATE	
	OTHER	
GOOS APPLICATIONS		

DRAFT

A2. Additional supporting material and literature

Suggested literature

Other material

A3. Readiness level assessment

Essential Ocean Variable Specification Sheet

Sponsored by:

WMO

unesco
Intergovernmental Oceanographic Commission

UN environment programme

International Science Council