The Global Ocean Observing System

GCOS

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Essential Ocean Variable Specification Sheet

Coral Cover and Composition

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EOV Specification Sheet curated by:

Biology and Ecosystems Panel

The Global Ocean Observing System

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

Background and justification

Corals span shallow tropical waters to deep-sea environments, forming biodiverse reefs of immense ecological and economic importance. As ecosystem engineers, hard corals (Scleractinia, Stylasteridae), soft corals (Octocorallia), and sponges create biogenic habitats that support 25% of marine species while sustaining fisheries worth 6.8 billion annually (Souster et al., 2021). These ecosystems provide coastal protection, novel pharmaceuticals, and contribute 375 billion yearly to the global economy, including 36 billion from reef tourism.

Despite their value, corals are exceptionally vulnerable due to slow growth rates and sensitivity to environmental changes. Climate change threatens 70-90% of shallow reefs with extinction by 2050 (IPCC), while degraded reefs could expose 63 million more people to annual flooding by 2100 (IPCC). Additional pressures include ocean acidification, pollution, and destructive practices like deep-sea mining, which risks irreversible damage to 4,000-year-old deep sea coral colonies (NOAA, 2021).

Monitoring these ecosystems requires specialized approaches: shallow-water corals (0-30m) are studied via SCUBA surveys assessing live cover, bleaching, and recruitment, while deep-sea corals (>200m) demand advanced technologies like ROVs, AUVs, and seabed mapping to evaluate Vulnerable Marine Ecosystems (VMEs). Ongoing research integrates these methods - combining eDNA analysis, high-resolution imaging, and terrain mapping - to develop comprehensive conservation strategies for coral communities worldwide.

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.

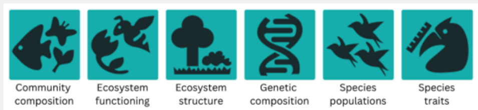
The Essential Biodiversity Variables (EBVs) defined and curated by the Group on Earth Observations Biodiversity Observation Network (GEO BON) complement the GOOS biological and ecosystem (BioEco) EOVs (Muller-Karger et al., 2018; Bax et al., 2019). The EOVs represent the basic observations of a particular 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 Coral Cover and Composition EOV contributes to both ECVs and EBVs, as well as to many indicators used for policy and assessment (Obura et al. 2019), providing critical data for understanding and managing marine ecosystems over short periods to climate time scales. 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

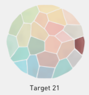
Diverse networks and communities are collecting observations of biology and ecosystems EOVs at different scales and in different regions. An initial baseline survey conducted in 2019/20 identified 203 active, long-term (>5 years) observing programs systematically sampling marine life. These programs 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:

EBV: 

ECV: 

CBD: 



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1. EOV information

ESSENTIAL OCEAN VARIABLE (EOV)	**Coral cover and composition**
DEFINITION	For the purpose of this EOV, corals encompass both warm-water species generally found in tropical regions and accessible by SCUBA (0–30 m), and cold-water species inhabiting mesophotic to deep-sea waters (>30 m) in tropical, temperate, and polar settings—where advanced monitoring methods (e.g., technical diving, ROVs, AUVs, towed camera systems, benthic landers, and crewed submersibles) become necessary (>200m). Corals are further subdivided into hard corals (Scleractinia, Stylasteridae) and soft corals (Octocorallia), accommodating their distinct morphologies and ecological functions.
EOV SUB-VARIABLES *bare minimum	**Coral condition and health** (e.g., bleaching, disease, mortality, disturbance) **Coral diversity** (at the most accurate resolution recorded in Darwin Core format: Family, Genera, Species, Morphotype) **Live coral cover and areal extent** (percentage of living coral on available substrate and the total spatial footprint) **Total habitable substrate** (structural complexity such as rugosity)
SUPPORTING VARIABLES	**Temperature** (sea surface temperature, subsurface temperature) **Salinity** (sea surface salinity, subsurface salinity) **Turbidity** (ocean colour, dissolved organic carbon, particulate matter) **pH** (oxygen) **Total alkalinity** (stable carbon isotopes) **Dissolved inorganic carbon (DIC)** (inorganic carbon, transient tracers) **Herbivory & reef EOVs** (macroalgal canopy cover & composition, fish abundance & distribution)
DERIVED PRODUCTS	Coral cover, areal extent and habitat mapping (GIS mapped layers/grid cells) **Coral health and condition inventory** (disease prevalence, overall condition) **Coral diversity and recruitment inventory** (taxonomic, size-class diversity etc.) **Coral reef habitat classification inventory** (e.g., patch, low relief, high relief, etc.) **Coral reef system health assessment** (inclusive of fish and macroalgae EOVs) **ESA and Red List species inventory** (focus on species of conservation concern) **Habitat risk mapping** (e.g. temp., pH, turbidity, areas at risk of eutrophication, etc.)

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) relevant to the phenomena are depicted as follows: **climate**, **ocean health** & **operational services**

PHENOMENA TO OBSERVE		Reef Status and Trends	Extreme events and mass mortality	Community recovery and regeneration
PHENOMENA EXTENT	HORIZONTAL	**Local**, **regional**, and **global** **Warm-water corals** (0–40 m, SCUBA-accessible, typically tropical) **Cold-water corals** (>40 m, from mesophotic to deep-sea, ROV/AUV accessible, tropical to polar)	**Local** to **regional**	**Local** to **regional**
	VERTICAL	**Upper** to **deep-ocean**, integrating shallow SCUBA surveys (0–40 m) and deep-sea imaging (>40 m) **Warm-water** (coastal reefs) **Cold-water** (continental shelves, slopes, seamounts, canyons)	**Upper** to **deep-ocean**	**Upper** to **deep-ocean**
	TEMPORAL	**Years** to **decades**	**Days to weeks** to **2-3 years** (dependent on whether short episodic events or larger scale, monitoring should be event-based)	**Weeks** to **months** (short-term recovery) to **months** to **years** (long-term recovery)

RESOLUTION TO OBSERVE PHENOMENA	HORIZONTAL	**Local** (1-20m, high-res SCUBA or ROV imaging) to **regional** (20-200m, remote sensing, sonar) to **global** (>200m, global synthesis)	**Local** (1-20m) to **regional** (20-100m)	**Local** (1-20m) to **regional** (20-100m)
	VERTICAL	**Upper-ocean** (1-30) **Mesophotic** (30-200) **Deep-ocean** (>200m)	**Upper-ocean** (1-30) **Mesophotic** (30-200) **Deep-ocean** (>200m)	**Upper-ocean** (1-30) **Mesophotic** (30-200) **Deep-ocean** (>200m)
	TEMPORAL	**Yearly** (for 10+ years)	**Quarterly** to **yearly**	**Yearly** (or depending on recovery trajectory)
SIGNAL TO CAPTURE		**1-2%** annual change	**>10%** change in coral coverage/composition	
SUB-VARIABLES NEEDED TO MEASURE		**1.** Coral condition and health **2.** Coral diversity **3.** Live coral cover and areal extent **4.** Total habitable substrate	**1.** Live coral cover and areal extent	**1.** Coral condition and health
SUPPORTING VARIABLES NEEDED TO MEASURE		**Temperature** (sea surface temperature, subsurface temperature), **turbidity** (ocean colour, dissolved organic carbon, particulate matter), **herbivory & reef EOVs** (macroalgal canopy cover and composition, fish abundance & distribution), **dissolved inorganic carbon (DIC)** (inorganic carbon)	**Temperature** (sea surface temperature, subsurface temperature), **salinity** (sea surface salinity, subsurface salinity), **turbidity** (ocean colour, particulate matter), **pH** (oxygen), **total alkalinity** (stable carbon isotopes), **herbivory & reef EOVs** (macroalgal canopy cover & composition, fish abundance & distribution)	**Temperature** (sea surface temperature, subsurface temperature), **salinity** (sea surface salinity, subsurface salinity), **pH** (oxygen), **total alkalinity** (stable carbon isotopes), **dissolved inorganic carbon (DIC)** (inorganic carbon), **herbivory & reef EOVs** (macroalgal canopy cover & composition, fish abundance & distribution)

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	**Coral cover and composition**							
PHENOMENA	**Reef status and trends** (measured by all sub-variables) **Extreme events and mass mortality** (measured through live coral cover and areal extent) **Community recovery and regeneration** (measured by coral condition and health)							
EOV SUB-VARIABLES	**Coral condition and health**			**DEFINITION**		**Coral condition and health** describes the **current state** of coral colonies by measuring indicators such as [**%** tissue death, **%** mortality, **%** damage]. These provide insight on environmental/anthropocentric impacts on coral stress and resilience.		
	Resolution				**Uncertainty**		**Sampling approach**	**References**
	Spatial Horizontal	**Spatial Vertical**	**Temporal**	**Timeliness**	**Measurement**	**Stability**		
IDEAL SHALLOW	1-5m grid		Monthly or quarterly	Data or cruise metadata available within month of collection	**±5%**	**> 10** years, long-term monitoring	**1**. In-situ surveying (photo/video) **2.** Forecast modeling (ex. thermal stress prediction) **3.** Satellite SST observations (monitoring for thermal anomalies or diseases) **4.** Imaging w/ AUVs or sUAS **5.** Hi-res 3D photogrammetry or sonar	1. Towle et al. 2021 2. Maynard et al. 2010 3. Liu et al. 2014, NOAA Coral Reef Watch program 4. Levy et al. 2018; Grasmueck et al. 2006 5. Combs et al. 2021 6. Roach et al. 2021

							6. SfM software/photomosaics	
IDEAL DEEP/MESOPHOTIC	High-res imaging to meter resolution		Monthly or quarterly	Data or cruise metadata available within month of collection	**15±%**	**> 10** years, long-term monitoring	**1.** ROVs/AUVs w/ high-res imaging and/or sonar **2.** 3D photogrammetry over transects **3.** Genetic tools (eDNA, metabarcoding) for species ID and stress-markers **4.** Forecast modeling (monitoring for thermal anomalies or disease)	1. Aguzzi et al, 2024, (ex. ROV SuBastian (Schmidt Ocean Institute); HROV NUI (WHOI); AUV Sentry (WHOI)) 2. Combs et al, 2021. 3. 4. Maynard et al, 2010 NOAA Deep Sea Coral Program
DESIRABLE SHALLOW	10-20m grid		Annual	Data available within 6-12 months of collection	**±10%**	**5-10** years, med-term monitoring	**1.** Visual census methods or AUV surveying for larger scale assessments **2.** AUV surveying	1. Grasmueck et al, 2006 2.
DESIRABLE DEEP/MESOPHOTIC	Meter-scale (site-level)		Annual	Data available within 6-12 months of collection	**20±%**	**5-10** years, med-term monitoring	**1.** Imaging w/ ROVs/AUVs across fixed sites **2.** Drop-camera arrays	1. Grasmueck et al, 2006 2.
MINIMUM SHALLOW	>20m grid		Bi-annual	Data available within 1 year of collection	**15±%**	**< 5** years, short-term monitoring	**1.** Opportunistic in-situ (snorkel/SCUBA visual assessments) **2.** Local/volunteer-based coral reef monitoring	1. 2. Forrester et al, 2014
MINIMUM DEEP/MESOPHOTIC	Broad estimates from cruises & surveys		Opportunistic deep-water surveying via research cruises	Data available within 1 year of collection	**25±%**	**< 5** years, short-term monitoring	**1.** Drop cameras and/or other basic imaging techniques from research cruises	1. Aguzzi et al, 2024

EOV SUB-VARIABLE	Coral diversity			DEFINITION	**Coral diversity** is the variety/abundance of corals at **different taxonomic levels** (species, genera and functional type; alpha, beta or gamma) within a classified reef-area: **species/area** (m2)		
	Resolution							
	Spatial Horizontal	Spatial Vertical	Temporal	Timeliness	Uncertainty Measurement	Stability	Sampling approach	References
IDEAL SHALLOW	1-5m grid		Monthly or quarterly	Data or cruise metadata available within month of collection	**±5%**	**> 10** years, long-term monitoring	**1.** Hi-res imaging; 3D photogrammetry over transects or SfM software/photomosaics **2.** In-situ surveying using photo/videographic methods over transects **3.** Genetic tools (eDNA, metabarcoding) for accurate taxonomic classification **4.** Taxonomic verification through physical sampling, specimen collection to support imaging/genetic methods	1. Nocerino et al, 2020 2. Towle et al. 2021 3. Alexander et al. 2020 (Scleractinia); Levy et al, 2023; Satoh et al. 2024
IDEAL DEEP/MESOPHOTIC	High-res imaging to meter resolution		Monthly or quarterly	Data or cruise metadata available within month of collection	**15±%**	**> 10** years, long-term monitoring	**1.** ROV-based hi-res imaging; 3D photogrammetry over transects or SfM software/photomosaics **2.** Direct observations of ROV/submersible (imaging, physical sampling) **3.** Genetic tools (eDNA, metabarcoding) for accurate taxonomic classification	1. Price et al. 2019

							4. Taxonomic verification through physical sampling, specimen collection to support imaging/genetic methods	
DESIRABLE SHALLOW	10-20m grid		Annual	Data available within 6-12 months of collection	**±10%**	**5-10** years, med-term monitoring	**1.** Visual census methods and/or AUVs **2.** Occasional genetic sampling	1. Grasmueck et al, 2006
DESIRABLE DEEP/MESOPHOTIC			Annual	Data available within 6-12 months of collection	**20±%**	**5-10** years, med-term monitoring	**1.** Hi-res (photogrammetry over transects), in-situ **2.** Occasional genetic sampling	
MINIMUM SHALLOW	>20m grid		Bi-annual	Data available within 1 year of collection	**15±%**	**< 5** years, short-term monitoring	**1.** Ad-hoc in-situ sampling and photographic documentation for basic taxonomic estimates **2.** Local/volunteer-based coral reef monitoring	1. Forrester et al, 2014
MINIMUM DEEP/MESOPHOTIC	Broad estimates from cruises & surveys		Opportunistic deep-water surveying via research cruises	Data available within 1 year of collection	**25±%**	**< 5** years, short-term monitoring	**1.** Ad-hoc surveying with drop cameras and/or other basic imaging techniques from research cruises for basic taxonomic estimates	

EOV SUB-VARIABLE	**Live coral cover and areal extent**				**DEFINITION**		**Live coral cover is the % area** covered by living coral and **areal extent is the % total geographic area** occupied by reefs. These provide monitoring of reef health and spatial distributions (m).	
	Resolution							
	Spatial Horizontal	**Spatial Vertical**	**Temporal**	**Timeliness**	**Uncertainty Measurement**	**Stability**	**Sampling approach**	**References**
IDEAL SHALLOW	1-5m grid		Monthly or quarterly	Data or cruise metadata available within month of collection	**±5%**	**> 10** years, long-term monitoring	**1.** Hi-resolution (satellite data) remote sensing (i.e. 3D mapping w/ satellite stereo-imagery and/or underwater video) **2.** In-situ measurements for coral cover, areal extent **3.** Satellite observations (monitoring for thermal stress via sea surface temperature/forecasts) **4.** eDNA measurements for rapid assessment of coral distribution	1.Collin et al. 2021 (WorldView-3); Pierce et al. 2021 2. Live-coral surveying in-situ; Towle et al. 2021 3. Liu et al. 2014, NOAA Coral Reef Watch program 4. Kutti et al. 2020
IDEAL DEEP/MESOPHOTIC	High-res imaging to meter resolution		Monthly or quarterly	Data or cruise metadata available within month of collection	**15±%**	**> 10** years, long-term monitoring	**1.** Hi-resolution imaging (ROV/AUV) of coral cover over large areas (multi-beam, photogrammetry, etc.) to meter resolution **2.** 3D mapping/modelling using LIDAR/sonar for spatial distribution **3.** eDNA measurements for rapid assessment of coral distribution	1. Maynard et al. 2010; Grasmueck et al. 2006; Price et al. 2019 2. NOAA Deep Sea Coral Program 3. Kutti et al. 2020

DESIRABLE SHALLOW	10-20m grid		Annual	Data available within 6-12 months of collection	**±10%**	**5-10** years, med-term monitoring	**1.** Regular/annual remote sensing, annual in-situ. **2.** Drone-based RGB imagery & deep learning	1. Giles et al, 2023
DESIRABLE DEEP/MESOPHOTIC			Annual	Data available within 6-12 months of collection	**20±%**	**5-10** years, med-term monitoring	**1.** ROV/AUV imaging of coral cover along fixed quadrants **2.** Permanent markers at fixed monitoring sites	1. Grasmueck et al, 2006
MINIMUM SHALLOW	>20m grid		Bi-annual	Data available within 1 year of collection	**15±%**	**< 5** years, short-term monitoring	**1.** Opportunistic/periodic remote sensing and in-situ (SCUBA, etc.) **2.** Local/volunteer-based coral reef monitoring	1.Forrester et al, 2014
MINIMUM DEEP/MESOPHOTIC	Broad estimates from cruises & surveys		Opportunistic deep-water surveying via research cruises	Data available within 1 year of collection	**25±%**	**< 5** years, short-term monitoring	**1.** Drop cameras (weighted frame/sled) from research vessels **2.** Sonar mapping from research vessels for broad estimates of coral extent	1. Aguzzi et al, 2024

EOV SUB-VARIABLE	**Total habitable substrate**			**DEFINITION**	**Total habitable substrate** is the **%** area suitable for coral settlement, inclusive of both abiotic and biotic substrates.			
	Resolution							
	Spatial Horizontal	**Spatial Vertical**	**Temporal**	**Timeliness**	**Uncertainty Measurement**	**Stability**	**Sampling approach**	**References**
IDEAL SHALLOW	1-5m grid		Monthly or quarterly	Data or cruise metadata available within month of collection	**±5%**	**> 10** years, long-term monitoring	**1.**Remote-sensing/mapping and imaging for 3D/4D modelling (LiDAR, satellite stereo-imagery, drone photogrammetry) **2.** Fixed point (diver surveys w/ photogrammetry & transects)	1. Collin et al. 2021 (WorldView-3) 2. Nocerino et al. 2020; AIM Procedure (EcoRRAP) for Field Photogrammetry in 4D
IDEAL DEEP/MESOPHOTIC	High-res imaging to meter resolution		Monthly or quarterly	Data or cruise metadata available within month of collection	**15±%**	**> 10** years, long-term monitoring	**1.** Remote-sensing (acoustic: multibeam sonar) **2.** Subsurface vehicles (ROV/AUVs w/ sonar & imaging)	1.Price et al. 2019
DESIRABLE SHALLOW	10-20m grid		Annual	Data available within 6-12 months of collection	**±10%**	**5-10** years, med-term monitoring	**1.** Drone-based remote sensing (RGB, multispectral) **2.** Periodic fixed point diver surveys **3.** Satellite bathymetry (lower-res)	
DESIRABLE DEEP/MESOPHOTIC			Annual	Data available within 6-12 months of collection	**20±%**	**5-10** years, med-term monitoring	**1.** Remote-sensing (acoustic: multibeam sonar) **2.** Regional seabed mapping	

							3. Subsurface vehicles (ROV/AUVs w/ sonar & imaging)	
MINIMUM SHALLOW	>20m grid		Bi-annual	Data available within 1 year of collection	**15±%**	**< 5** years, short-term monitoring	**1.** Remote-sensing (coarser-resolution) **2.** Fixed point (diver surveys w/ quadrats/ transects)	
MINIMUM DEEP/MESOPHOTIC	Broad estimates from cruises & surveys		Opportunistic deep-water surveying via research cruises	Data available within 1 year of collection	**25±%**	**< 5** years, short-term monitoring	**1.** Opportunistic deep-water surveying (drop-cameras) **2.** Single-beam sonar or coarse multibeam	1. Aguzzi et al, 2024

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 SHALLOW	Remote-sensing (satellite-derived)	Remote-sensing (acoustic)	Remote-sensing (other): (optical/laser-based sensors & visual systems)
EOV SUB-VARIABLE(S) MEASURED	**Coral condition and health** **Live coral cover and areal extent**	**Live coral cover and areal extent**	**Live coral cover and areal extent** **Total habitable substrate**
TECHNIQUE / SENSOR TYPE	1. **Near real-time satellite products** (ex. NOAA CRW) for monitoring 2. **Habitat-level mapping** w/ hi-res satellite data (ex. WorldView3) or **image-mosaics from satellite data** (ex. PlanetScope mosaic from Dove satellites) for mapping coral areal extent	1. **Sonar mapping** from research vessels for broad estimates of coral extent and macroalgal/fish abundance and distribution 2. **ADCP** (Acoustic Doppler Current Profilers) possibly able to assess subsurface temperature, salinity, turbidity	1. **LiDAR** (light detection and ranging) for topography mapping **2. MiDAR** (multispectral LiDAR) for more 3. **Hi-resolution imaging and video** - Drone-based (RGB, multispectral, etc.) - **Photogrammetry**, **structure-from-motion (SfM)** for 3D modelling of seafloor topography or reef structures
SUGGESTED METHODS AND BEST PRACTICES	- **Satellite observations** (monitoring for potential thermal stress via sea surface temperature) (ex. NOAA CRW); with machine-learning (ML) methods (ex. Nguyen et al, 2021) - **Probabilistic modelling** from satellite data/space-borne remote sensing (Candela et al, 2021) **References:** 1. Liu et al, 2014 2. Lyons et al, 2024	- **Multibeam echo sounders** (MBES) for mapping seafloor topography/reef structures - **Backscatter analysis** for habitat mapping - **ADCP** measurements via AUV **References:** 1. Feldens et al, 2023; Neves et al, 2014 2. Linton-Izquierdo et al, 2024	- **Drop cameras** (weighted frame) from research vessels for point-sampling, repeat drops could mimic ground-truthing for larger spatial benthic area similar to STAVIRO protocol (Pelletier et al, 2021) **References:** 1. Collin et al, 2018 2. Chirayath & Li, 2019 3. Price et al, 2019; Nocerino et al, 2020
SUPPORTING VARIABLES MEASURED	Temperature (sea surface temperature), salinity (sea surface salinity), turbidity (ocean colour, dissolved organic carbon, particulate matter)	Temperature (sea surface temperature), salinity (sea surface salinity)	Temperature (sea surface temperature), salinity (sea surface salinity)

APPROACH / PLATFORM SHALLOW	Fixed point (diver surveys)	Autonomous: surface vehicles	Autonomous: subsurface vehicles
EOV SUB-VARIABLE(S) MEASURED	**Coral condition and health** **Coral diversity** **Live coral cover and areal extent** **Total habitable substrate**	**Live coral cover and areal extent** **Total habitable substrate**	**Live coral cover and areal extent** **Total habitable substrate**
TECHNIQUE / SENSOR TYPE	1. **In-situ photogrammetry** (overlapping hi-res reef images for 3D/4D imaging or mosaics) 2. **Transect/quadrat** surveying**, line-point intercept (LPI)** - ex. NCRMP Benthic Community Assessments 3. **Coral health index surveying** (visual or sensor assessments using health charts, imaging or PAM fluorometry) 4. **Additional sampling w/ portable sensors** or collection for post-dive laboratory analyses	1. **Gliders/USVs** (unmanned surface vehicles): ex. Saildrone (used in NOAA DSCRTP), ReefGlider (novel buoyant AUV), AutoNaut (wave-propelled USV) 2. **Lower cost sUSV** (small unmanned surface vehicle) for imaging/SfM modeling for shallow environments 3. **sUAS** (small unmanned aerial systems)	**1. AUVs** (autonomous underwater vehicles): ex. REMUS from WHOI
SUGGESTED METHODS AND BEST PRACTICES	- **Diver-surveying** including habitat type, community health (disease, mortality), LPI (substratum, coral cover, etc.), topography (rugosity), etc. **References:** 1. AIM Procedure (EcoRRAP) for Field Photogrammetry in 4D; Nocerino et al. 2020 2. NCRMP Assessment Survey Field Protocols for U.S. Atlantic; AGGRA Coral Survey Protocol 3. Coral Disease Handbook (CRTR) 4. CDHC Coral Heath Field and Laboratory Protocols	- **ASVs** able to map reef topography & monitor other stress indicators. Ideally equipped with: - hi-res multibeam or side-scan sonar for mapping structures - cameras for visual surveying - sensors for monitoring water quality/direct analysis **References:** 1. 2. Raber & Schill, 2019 3. Levy et al. 2018	- **AUVs** able to map reef topography & monitor other stress indicators. Ideally equipped with: - hi-res multibeam or side-scan sonar for mapping structures - cameras for visual surveying - sensors for monitoring water quality/direct analysis **References:** 1. Cardenas et al. 2024; Grasmueck et al. 2006
APPROACH / PLATFORM DEEP	Remote-sensing (acoustic)	Remote-sensing (other):	Fixed-point (mooring)

EOV SUB-VARIABLE(S) MEASURED	**Live coral cover and areal extent** **Total habitable substrate**	**Live coral cover and areal extent** **Total habitable substrate**	**Coral condition and health** **Total habitable substrate**
TECHNIQUE / SENSOR TYPE	1. **Multibeam mapping** 2. **Backscatter analysis**	1. **LIDAR** (for <200m depth) 2. **Airborne LIDAR** for upper mesophotic 3. **Drop-cameras** (weighted frame/sled) from research vessels for point-sampling and seabed observations	1. **Benthic landers** (ex. ALBEX & BOBO from NIOZ, "Little MonSta" from MMMonKey_Pro program)
SUGGESTED METHODS AND BEST PRACTICES	**ROV/AUV-mounted systems** **References:** 1. Conti et al. 2019 2. Foster et al. 2009	**References:** 1. 2. 3. MESH operating guidelines for underwater video/photographing techniques	**Weighted, moored benthic landers** able to collect long-term data at regular intervals. Ideally also equipped with: - settling plates for monitoring larval coral recruitment. - time lapse cameras for recording seafloor. **References:** 1. Wheeler et al. 2021
APPROACH / PLATFORM **DEEP**	**Autonomous: profiling floats**	**Autonomous: subsurface vehicles**	**Autonomous (other): deep-water sensor networks**
EOV SUB-VARIABLE(S) MEASURED	**Supporting variables only**	**Coral diversity** **Coral condition and health** **Live coral cover and areal extent** **Total habitable substrate**	**Coral condition and health** **Supporting variables**
TECHNIQUE / SENSOR TYPE	1. **Argo floats** with **deep profiles** (Deep Argo) or **biogeochemical floats** (BioGeoChemical Argo) with sensors deployed in coral habitat regions	1. **ROVs** with manipulators and imaging 2. **AUVs** with photogrammetry	1. **Cabled observatories** 2. **Acoustic sensors**
SUGGESTED METHODS AND BEST PRACTICES	- **High-resolution vertical profiles** for temperature, salinity, oxygen, pH, DIC, etc. **References:** 1. Bittig et al. 2019 (BGC-Argo guide)	- **Photomosaics** with scaling lasers - **eDNA** water sampling **References:** 1. Casoli et al. 2021 (hi-res photo mosaics for coral monitoring)	- **Continuous video** monitoring - **Passive acoustic** monitoring for indicators of broad ecosystem health (ex. SoundTraps, etc.) **References:**

		2. Satoh et al, 2025 (use of mini-ROV for eDNA survey)	1. Flagg et al, 2020 (monitoring using ONC underwater platforms); Howe et al, 2019 (SMART subsea cable sensors) 2. Apprill et al, 2023
SUPPORTING VARIABLES MEASURED	**Temperature** (sea surface temperature, subsurface temperature), **salinity** (sea surface salinity, subsurface salinity), **turbidity** (ocean colour, dissolved organic carbon, particulate matter), **pH** (oxygen), **total alkalinity** (stable carbon isotopes), **dissolved inorganic carbon (DIC)** (inorganic carbon, transient tracers), **herbivory & reef EOVs** (macroalgal canopy cover & composition, fish abundance & distribution)	**Temperature** (sea surface temperature, subsurface temperature), **salinity** (sea surface salinity, subsurface salinity), **turbidity** (ocean colour, particulate matter), **pH** (oxygen)	**Temperature** (sea surface temperature, subsurface temperature), **salinity** (sea surface salinity, subsurface salinity), **turbidity** (ocean colour, particulate matter dissolved organic carbon), **pH** (oxygen), **dissolved inorganic carbon (DIC)** (inorganic carbon, transient tracers)

APPROACH / PLATFORM SHALLOW & DEEP	**Fixed-point (other): Community-based image monitoring**	**Genetic tools: eDNA & 'omics**	**Taxonomic expertise: museum**
EOV SUB-VARIABLE(S) MEASURED	**Coral condition and health** **Coral diversity**	**Coral condition and health** **Coral diversity** **Live coral cover and areal extent**	**Coral diversity**
TECHNIQUE / SENSOR TYPE	1. **Volunteer surveys/citizen-science** for assessing community biodiversity and/or spatial extent from environmental events - **Reef-Check** (diver-based, fixed transects) - **Basic abiotic sampling** (temperature, salinity, pH, etc.) 2. **Smartphone apps/interactive websites** - **ex. FathomNet** (volunteer training machine-learning models in FathomNet database via a site/app to reduce annotation time for visual data)	1. **Coral-specific markers** for assessing species-level resolution using specific primers/probes or **holobiont** or **universal markers** for assessing external microbial/reef diversity - broad community assessments 2. **Target-capture bait sets/ stress-gene assays** for stressor genes (ex. apoptosis) or reproduction (ex. gamete production) - early warning indicators of stress 3. **3. eDNA** measurements for rapid assessment of coral distribution	1. **Specimen collection** (by divers, ROV, etc.) 2. **Reference library curation** (morphological and genetic) and usage of **biological collections** for documentation of historical biodiversity 3. **Integrative taxonomy** for confirming species ID over livestreams (ex. Okeanos, Nautilus Live) and for **linking physical specimens with genetic and image data**

SUGGESTED METHODS AND BEST PRACTICES	- **Field-based** citizen-science protocols for shallow, **annotation/media-based** protocols for deep - **Photo-quadrat** time series **References:** 1. Forrester et al. 2015 (utility of citizen-science for long-term reef monitoring); Done et al. 2017 (utility of ReefCheck AU monitoring data) 2. Katija et al. 2022 (FathomNet image annotation database for training ML/automatic annotation for underwater imagery)	- **DNA sampling** via divers/AUVs for shallow-water, and AUVs/ROVs or fixed-platforms for deep-water - **High-throughput sequencing** **- Triplicate water sampling** **- qPCR for pathogen detection** **References:** 1. Nishitsuji et al. 2024 (scleractinian-specific eDNA using mini-ROVs); Alexander et al. 2020 (scleractinian-specific multi-assay combined with diver/visual surveys) 2. DeLeo et al. 2018 (gene expression profiling of stress genes in deep-water corals, proposes diagnostic markers for response monitoring) 3. Kutti et al. 2020	- **Collection** of coral samples across survey sites for laboratory analyses or deposition in biological collections **- Collaboration with taxonomists** for confirmation of species identifications and descriptions **References:** 1. Etnoyer et al. 2006 (deep-sea coral collection protocols); Mazzeo et al. 2021 2. Ross et al. 2011 (utility of museum records for documenting coral distributions) 3. Kenitz et al. 2023 (utility of taxonomic knowledge for image annotation efforts)
SUPPORTING VARIABLES MEASURED	**Temperature** (sea surface temperature, subsurface temperature), **salinity** (sea surface salinity, subsurface salinity), **pH** (oxygen), **Herbivory & reef EOVs** (macroalgal canopy cover & composition, fish abundance & distribution)	**Herbivory & reef EOVs** (macroalgal canopy cover & composition, fish abundance & distribution)	**Herbivory & reef EOVs** (macroalgal canopy cover & composition, fish abundance & distribution)

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

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

[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.

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/

Coral Data products:

National Coral Reef Monitoring Program Visualization Tool - reef status and trends for shallow (0-30m) U.S. coral reef ecosystems in the Atlantic, Caribbean, and Pacific.
ReefCloud - open-access platform designed to quickly and efficiently collate and analyse data to improve decision-making and inform conservation across the world.
MERMAID - an open-source application that collects and manages real-time coral reef health data, developed in partnership between the WCS, WWF, and Sparkgeo.
eReefs - reef forecasting and modelling program

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Guides, best practices and methods

NOAA, National Coral Reef Monitoring Program (2024) Benthic Assessment Protocols for the Atlantic Region: U.S. Caribbean, Florida and the Gulf of Mexico: 2024. Silver Spring, MD, NOAA, National Coral Reef Monitoring Program (NCRMP), 29pp. DOI: **https://doi.org/10.25923/e3gf-vk84**
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Integrated EOV products and visualisations

National Coral Reef Monitoring Program Visualization Tool - reef status and trends for shallow (0-30m) U.S. coral reef ecosystems in the Atlantic, Caribbean, and Pacific.

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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

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.

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. (BIP definition)

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 (GUM)1. It includes all contributions to the uncertainty, expressed in units of 2 standard deviations, unless stated otherwise

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.

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 contribution to other essential variable frameworks, multilateral environmental agreements, contribution to indicators and GOOS applications

EOV		
CORRESPONDING ESSENTIAL VARIABLES	ECV	Sea surface temperature, Ocean color
	EBV	Species populations, Ecosystem structure
GLOBAL INDICATORS EOV CAN CONTRIBUTE	**SDG**	SDG 14.2.1 (Proportion of degraded reefs) SDG 14.5 (Marine protected area coverage)
	CBD	Aichi Target 10 (Coral vulnerability reduction)
	CLIMATE	Reef heat stress alerts (NOAA Coral Reef Watch)
	OTHER	Ocean Health: Reef Resilience Index, IUCN Red List assessments
GOOS APPLICATIONS		

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